Results of Monitoring Water Levels in the Wetlands of Fourmile Branch near the F and H Areas of SRS: January to December 2002 (U)

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Executive Summary

Since 1996, a network of piezometers has been used to measure hydraulic head in the water-table aquifer (Upper Aquifer Zone of the Upper Three Runs Aquifer, or UAZ of the UTRA) along the groundwater outcrops (i.e. seeplines) near the F- and H-Areas. The piezometers were installed near the seeplines to assess potential impacts of the F- and H-Area Groundwater Remediation Wastewater Treatment Units (WTUs) on the riparian wetlands located between the former F- and H-Area seepage basins and Fourmile Branch. The piezometers were installed in areas expected to be most impacted by the remediation system. Eight additional piezometers were added to the network in 2002 in two locations near the F-Area seepline and two locations near the H-Area seepline, extending coverage further downstream from the seepage basins.

The goals of the RCRA Part B Permit governing the WTUs are to 1) achieve a 70% reduction in the mass flux of tritium to Fourmile Branch within five years of Corrective Action Plan approval and reduce the discharge of other contaminants (metals and radionuclides other than tritium) to Fourmile Branch to levels less than the Groundwater Protection Standards (GWPS), and 2) reduce the discharge at the seepline of all contaminants to levels that are less than the GWPS by July 31, 2010. Because of the potential for WTU operation to dry portions of the nearby wetland areas, the purpose of the piezometer network was: 1) to establish baseline hydraulic head data for the water-table aquifer (UAZ) at the F- and H-Area seeplines prior to startup of the groundwater extraction/injection remediation system (completed), and 2) to observe the effects of the remediation system on the hydraulic head after system start-up (ongoing).

Hydraulic head was measured monthly in 2002 using an electric water-level meter at each of the piezometers. For the piezometers equipped with data loggers, hydraulic head was recorded hourly in addition to the monthly measurements. Results from 2002 were compared with previous years' results, including results recorded before the WTUs began operating (the baseline period).

Minimum and average measurements at nearly all the F- and H-Area piezometers were lower in 2002 than in 2001 and the baseline period. Two of the three reference piezometers exhibited large drops in average hydraulic head compared to 2001, and all three had average heads lower than the baseline period. The average change in elevation for each area was 0.8 ft, 0.7 ft, and 2.1 ft for F-Area, H-Area, and the reference piezometers, respectively. The magnitude of the decrease at the reference locations reflects the ongoing drought in 2002.

Drought conditions continued for much of 2002. Drought status in counties that comprise SRS was upgraded from severe to extreme in July, then downgraded to incipient drought status in November. F- and H-Area rainfall in 2002 was lower than the long-term (1985-2000) average, but was higher than in 2000 and 2001 due to higher than average rainfall received in November and December. Rainfall averaged 3.6 inches per month at F Area and 3.7 inches per month at H Area in 2002. The average monthly rainfall calculated for the baseline period was 3.9 inches per month for both F Area and H Area.

Decreases in groundwater extraction volumes tempered the effect of drought in the F- and H-Area piezometers. Daily groundwater extraction volumes dropped by an average of 45% in F Area in June, and again from August through December, and by about 50% in H Area in December. Hydraulic head elevations began increasing in August in the F-Area piezometers. This timing coincided more closely to the prolonged reduction in groundwater extraction than to an increase in rainfall, which began in June or July. Hydraulic head in FPZ004A, which is located close to the extraction wells, increased by nearly three feet during the latter half of the year following reduction in extraction rates. The greatest decreases in average hydraulic head in H Area continued to be in the piezometers closest to the extraction wells. However, hydraulic heads in these H-Area piezometers rose in December as a result of reduction in H-Area groundwater extraction volumes.

Wetlands are defined by the presence of hydric soils, saturated soil conditions during a portion of the growing season, and vegetation adapted to live in saturated soils. Lowering groundwater levels for a prolonged period could change the wetland hydrologic conditions and the vegetation growing in these areas. In many locations, the hydraulic head never reached the root zone during 2002. For several years now, the water table has remained below levels required to sustain the herbaceous components of wetland vegetation at some locations. These hydrologic conditions may allow early successional species to germinate in these areas. In other areas, changes already have occurred. Nelson (2001) documented changes in herbaceous species diversity and establishment of early successional non-wetland species due to declines in water levels in recent years in the F- and H-Area tree kill zones (FPZ005A and HPZ001A are located there), areas where tree mortality in seepline-fed wetlands downslope from the seepage basins was first identified in the 1970s. However, these changes would not cause the areas to lose their wetland classification.

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Introduction

Seepage basins in the F and H Areas of the Savannah River Site (SRS) formerly received low-level radioactive wastewater from the nuclear materials separations facilities. This wastewater consisted mostly of sodium hydroxide, nitric acid, low levels of various radionuclides (primarily tritium) and some metals (Killian et al. 1985a,b). Discharges to the seepage basins were discontinued in 1988 and the basins were closed in accordance with an approved Resource Conservation and Recovery Act (RCRA) closure plan by February 1991.

The aquifer beneath and down-gradient of the basins was contaminated as a result of basin operations. The contamination is located primarily in the Upper Aquifer Zone (UAZ) (i.e. the water-table aquifer) of the Upper Three Runs Aquifer (UTRA) and in the Lower Aquifer Zone (LAZ) of the UTRA. Near the seepage basins in both F and H Areas, shallow groundwater flows toward Fourmile Branch. The UAZ discharges to the wetlands and Fourmile Branch, whereas the LAZ discharges primarily to Fourmile Branch. Contaminants originating from the seepage basins have been detected in shallow groundwater outcrops (i.e. the seepline) in the wetlands along Fourmile Branch near both F and H Areas (Haselow et al. 1990, Dixon et al. 1993, Dixon and Rogers 1993, Dixon et al. 1994).

Groundwater remediation wastewater treatment units (WTUs) were installed near F and H Areas in accordance with a RCRA Hazardous Waste Part B Permit to clean up the groundwater. The goals of the RCRA Part B Permit are to 1) achieve a 70% reduction in the mass flux of tritium to Fourmile Branch within five years of Corrective Action Plan approval and reduce the discharge of other contaminants (metals and radionuclides other than tritium) to Fourmile Branch to levels less than the Groundwater Protection Standards (GWPS), and 2) reduce the discharge at the seepline of all contaminants to levels that are less than the GWPS by July 31, 2010.

The WTUs include a network of extraction and injection wells. Figures 1 and 2 show the locations of the wetlands near Fourmile Branch and the extraction wells for the water-table aquifer (the UAZ of the UTRA) in F Area and H Area, respectively. The extraction well numbers have the prefix “FEX” or “HEX.”

Models simulating the operation of the WTUs predicted decreases in the water level of up to six feet at the seepline and in the wetlands nearby (Sadler 1995, Flach 1998). Decreases in water levels could result in drying of a portion of the wetlands, and an overall movement of the seepline towards Fourmile Branch. Chronic depression of the water table at portions of the wetlands affected by the extraction wells could alter the wetland plant and animal communities in this area.

Changes in water levels in and near the wetlands along Fourmile Branch needed to be monitored to assess the impacts of the F- and H-Area WTU remediation systems on the wetlands. The definition of wetlands differs between federal agencies. Under the U.S. Environmental Protection Agency (EPA) and the U.S. Corps of Engineers (USCOE) definition, an area must exhibit three attributes – hydric soil, hydrophytic vegetation and wetland hydrology – to be considered a wetland. An area is considered to have wetland hydrology if it is inundated or saturated to the surface continuously for at least 5% of the growing season in most years. For soil saturation to impact vegetation, it must occur within a major portion of the root zone (usually within 12 inches of the surface) (USCOE 1987).

To accomplish this monitoring, a network of piezometers was established in 1996 in and near the wetlands of Fourmile Branch in both F and H Areas (Dixon 1996). The purpose of the piezometer network was two-fold: 1) to establish baseline hydraulic head data for the water-table aquifer (the UAZ of the UTRA) at the F- and H-Area seeplines prior to startup of the groundwater extraction/injection remediation system (the baseline period), and 2) to observe the effects of the remediation system on the water table levels after system start-up. The first objective, developing a baseline, was completed in 1997. The second objective is ongoing. The purpose of this report is to present the results of the monthly and continuous hydraulic head elevations measured in 2002 at these piezometers.

Piezometer Installation and Instrumentation

In 1996 and 1997, 23 water-table piezometers were installed at 17 locations in and near the wetlands of Fourmile Branch near F and H Areas and in an upstream location. These piezometers were given the prefixes “FPZ”, “HPZ,” and “FHR” respectively. The FPZ (Figure 1) and HPZ (Figure 2) piezometers were installed near the seepline, focusing on those areas expected to be most impacted by the remediation system. The location of the seepline varies with time depending on the elevation of the water table. At locations with heterogeneous stratigraphy, piezometers were installed in clusters so that the hydraulic head could be measured for each layer. The deeper piezometers were given well numbers with the suffix "A" and the shallower piezometers, the suffix "B." The FHR piezometers (Figure 3) were installed in an upstream reference area located in the wetlands of Fourmile Branch, but outside the expected area of influence of the remediation system. Hydraulic head changes observed in these reference piezometers could be compared to changes observed in the FPZ and HPZ piezometers to help distinguish between natural variation in hydraulic head and treatment system impacts.

In 2002, additional piezometers were installed in two locations near the F-Area seepline (given the “FSP” prefix, Figure 1) and two locations near the H-Area seepline (given the “HSP” prefix, Figure 2). The piezometers were installed in clusters so that the hydraulic head could be measured for each layer. The letter following the piezometer number indicates the relative depth, with “A” corresponding to the deeper layer and “B” corresponding to the shallower layer.

With the exception of FPZ003A, all FPZ, HPZ and FHR piezometers were installed using hand augering equipment (3 1/4” bucket auger) in accordance with WSRC-3Q5 (Chapter 7) procedures. Installation methods are summarized in Table 1 and described in Dixon (1996). Piezometer FPZ003A, and the FSP and HSP piezometers were installed using a hollow stem augering method. Additional piezometer construction information can be found in Halverson (2000).

To investigate the natural water level variability and storm event influences in the Fourmile Branch riparian wetland system, nine piezometers were equipped with data logging equipment in 1996 to allow continuous water level monitoring. Five additional piezometers were equipped with data loggers in 1998. The three reference piezometers were equipped with data loggers in 1999.

Methods

Water levels in the piezometers were measured monthly in 2002 using a manual electric water-level meter. From these measurements, the hydraulic head was determined for each location.

Water levels were measured and recorded hourly at the piezometers equipped with data loggers. The data loggers were In-Situ Inc. TROLL Model SP4000 units with 15 psig pressure transducers. An unusually long cold spell during the winter of 2002/2003 shortened the life of the data logger batteries. Battery levels in the data logger at piezometer FHR003 dropped too low to sustain logger operation, and data recorded since the previous downloading were lost.

Some of these piezometers were utilized in other studies during 2002. In cases where water sample collection or other work in the piezometers temporarily disturbed the water levels, the affected data were deleted.

Status of the Wastewater Treatment Units

The monthly volumes of groundwater treated by the F-Area and H-Area WTUs (1997–2002) are shown in Tables 2 and 3, respectively. Daily extraction (i.e. pumping) rates for 2002 are shown in Figure 4.

The F-Area Groundwater Remediation WTU began operating in shakedown mode in April 1997, and continued to operate in this manner during the remainder of 1997 and all of 1998.

Flow rates were limited due to system testing, and full-operation was not initiated. Pumping rates were not consistent due to significant system downtime (WSRC 1997a, 1998a&c, 1999a). In 1999, the F-Area WTU operated 57% of the time. By 2000, the F-Area WTU was operating essentially full time.

In 2002, the F-Area WTU operated at essentially full capacity from January through May, and again in July. In June and from August to December, however, pumping rates averaged just 55% of the rates from the beginning of the year (Long 2002b, 2003a) (Table 2).

The H-Area WTU began operating in a shakedown mode in July 1997 and continued in this mode in 1998. Flow rates were limited due to system testing and limited injection well capacity, and there was significant system downtime (WSRC 1997b, 1998b&d, 1999b). In 1999, the H-Area WTU operated 82% of the time. By 2000, the H-Area WTU was operating essentially full time.

In 2002, the H-Area WTU operated at essentially full capacity from January through November. In December, however, the pumping volume dropped to about 50% of the average monthly volume (Long 2002b, 2003a) (Table 3).

Results and Discussion

Drought conditions continued for much of 2002. In July, drought status in counties that comprise SRS was upgraded from severe to extreme, the most serious drought category (SCDNR 2002a). However, in November these counties were downgraded to incipient drought status, the least severe classification (SCDNR 2002b).

F- and H-Area rainfall in 2002 was lower than the long-term (1985-2000) average, but was higher than in 2000 and 2001 due to higher than average rainfall received in November and December. For the most of the year, cumulative rainfall was lower in 2002 than in other years of this study (1996-2001). However, more than four inches of rainfall per month in November and December for F Area and October through December in H-Area brought 2002 rainfall totals above 2000 and 2001 totals. In contrast, less than one inch of rain per month fell during the last quarter of 2001. Rainfall totals for 2002 were 42.9 inches (averaging 3.6 inches per month) measured at F Area and 44.9 inches (averaging 3.7 inches per month) measured at H Area. The average monthly rainfall calculated for the baseline period was 3.9 inches per month for both F Area and H Area. The long-term (1985 – 2000) average annual rainfall is 49 inches in F Area and 51 inches in H Area. Monthly and cumulative rainfall amounts for 1996 through 2002 and the long-term average are shown in Figures 5and 6 for F Area and H Area, respectively. The 2002 total rainfall in F Area was 8% higher than the 2001 total rainfall and 13% lower than the long-term average. H-Area rainfall was 21% higher than the 2001 total rainfall and 13% lower than the long-term average.

Rainfall measured in H Area was used for comparison with reference piezometer hydraulic head because it is the closest meteorological station. Actual rainfall near the reference piezometers might have been significantly different than the rainfall measured at the H-Area meteorological station, which recorded the most rainfall at SRS in 2002. Rainfall measured in 2002 at twelve different locations at SRS varied from about 34 inches near P Area to about 45 inches measured near H-Area.

Results from the monthly hydraulic head measurements for 2002 are presented in Table 4. Summary statistics for each location are presented in Table 5. Table 5 also presents summary statistics based on data logger measurements for 2002.

Table 6 compares the hydraulic head measurements from 2002 with 2001 measurements for the "A" series (deeper wells) and reference piezometers. Minimum and average measurements at nearly all F-Area piezometers were lower in 2002 than in 2001. The only exception was FPZ008A, where average hydraulic head was unchanged. The average change in elevation across the piezometer network was a 0.8 ft decrease from 2001 levels. The largest differences in average elevation for F-Area piezometers occurred in FPZ001A, FPZ002A and FPZ003A, with decreases of one or more feet from 2001. Hydraulic head at FPZ004A, which has exhibited large decreases in previous years, rebounded during the last half of the year when groundwater extraction rates were reduced to about 55% of normal, resulting in an overall decrease in average head elevation of only 0.3 ft.

For the H-Area piezometers, minimum and average hydraulic head measurements were lower in 2002 than in 2001 for all but one piezometer, HPZ006A, where the average head was unchanged (Table 6). HPZ002A had the largest decrease in average hydraulic head for the third consecutive year (1.5 ft). Water level elevation in the H-Area piezometer network decreased an average of 0.7 ft from 2001 levels.

Two of the three reference piezometers exhibited large drops in hydraulic head while the third increased slightly (Table 6). The average hydraulic head decreased at FHR001 and FHR002 by 2.7 ft and 3.6 ft, respectively, while the level at FHR003 was unchanged. From 2001 to 2002, the average change in average hydraulic head elevations over all three reference piezometers was a 2.1 ft decrease.

Table 7 compares the 2002 groundwater elevations with baseline elevations. For F- and H-Area piezometers, the pre-operational period was used for the baseline (January 1996 through March 1997 for F Area and January 1996 through June 1997 for H Area) (WSRC 1997a, 1998c). For the reference piezometers, the first 6 months of data (July – December 1997) were used as a baseline. These baseline periods spanned less than two years. Thus, while the baseline data may be useful for comparison with current water levels, that data may not truly represent the long-term average water levels at these locations.

The 2002 minimum and average hydraulic head elevations were all lower than in the baseline period for the F-Area piezometers, though the average FPZ008A elevation was only 0.1 ft lower (Table 7). The largest change in average elevation for F-Area piezometers occurred in FPZ002A and FPZ004A, with decreases of 6.2 feet and 7.0 ft, respectively, compared to baseline levels. The average change in elevation across the piezometer network was a 3.3 ft decrease from baseline levels. All F-Area piezometers except FPZ008A exhibited an increase in standard deviation in 2002 compared to the baseline period. On the average, the standard deviation for F-Area piezometers in 2002 was six times the baseline level.

In 2002, minimum and average hydraulic head elevations were lower for most H-Area locations compared to the baseline period (Table 7). HPZ003A and HPZ006A were exceptions. However, these piezometers are located within the wetlands bordering Fourmile Branch and could have been influenced by seasonal stream flows and periodic beaver-dam building activity. On the average, hydraulic head elevations in 2002 were 2.2 ft lower than the baseline. If HPZ003A and HPZ006A are not included, average change in hydraulic head elevation was a 3.4 ft decrease compared to the baseline. The largest changes in average elevation occurred in HPZ002A and HPZ005A, with decreases of 6.3 ft and 5.1 ft, respectively, compared with baseline levels. The standard deviation was higher in 2002 than in the baseline period for most H-Area piezometers, averaging about three times the baseline level.

Elevations at all the reference piezometers in 2002 were lower than the baseline, with declines ranging from 0.3 ft to 6.5 ft. (Table 7). FHR003 levels showed less variation from baseline levels than either FHR001 or FHR002. The greatest decrease from baseline occurred at FHR002. The average decrease in average hydraulic head elevations over all three reference piezometers was 3.8 ft compared to baseline.

Hydrographs for each F- and H-Area piezometer location were created from the monthly measurements and are presented in Figures 7 through 24. Hydrographs for the reference locations are shown in Figures 25 through 27. Each hydrograph covers the entire monitoring period.

Hydrographs of the hydraulic head elevations, based on the data logger measurements, are shown in Figures 28 through 41 for the F- and H-Area piezometers. Figures 42 through 44 show the hydrographs from the data loggers at the reference piezometers. Elevations for the years 1996 to 2002 are plotted together. For periods in 2002 when the data loggers were not operating or head elevations dropped below the data logger, monthly data are shown. Rainfall in 2002 is also plotted on each of these hydrographs for comparison with the 2002 elevation data.

Hydraulic head elevations began increasing in August in the F-Area piezometers (Figures 28 through 35). This timing coincides more closely to the prolonged reduction in groundwater extraction, which also began in August, than to the increase in rainfall, which began in June or July. F-Area A-series piezometers ended the year with higher hydraulic heads than at the beginning of the year. The greatest increase over the year occurred at FPZ003A (Figure 30), the piezometer with the greatest variability in elevation. FPZ004A (Figure 31), which is located close to the extraction wells, also increased by nearly three feet due to a dramatic rise in hydraulic head following reduction in extraction rates during the latter half of the year. Prior to this rise in head, however, water levels sank below the bottom of the piezometer. FPZ003A and FPZ008A had the highest year-end hydraulic head elevations recorded since the beginning of the study.

H-Area A-series piezometers (Figures 36 through 41) generally ended the year with similar or higher hydraulic head than at the beginning of the year, except for HPZ004A which was slightly lower at the end of the year. HPZ005A (Figure 40) hydraulic head elevation was more than 4 ft higher at the end of the year, and HPZ002A (Figure 37) was nearly two feet higher. These are the H-Area piezometers closest to the extraction wells. Both exhibited sudden increases in head corresponding to mid-November rainfall and further increases in December, which coincide with reduction in extraction rates.

In contrast, two of the reference piezometers, FHR001 (Figure 42) and FHR002 (Figure 43), ended the year with hydraulic heads two to three feet lower than at the beginning of the year, in spite of the fact that total rainfall in 2002 (in H Area) was actually higher than in 2001. Without the influence of extraction wells, the reference locations did not experience the same rise in hydraulic head caused by the reduction in groundwater extraction. A small rise in hydraulic head occurred at the end of the year in conjunction with late-year rainfall increases (Figures 42 and 43), but it was not enough to overcome the effects of the drought conditions that predominated in 2002. The third reference piezometer, which has exhibited little variation in head over the years, ended the year with a hydraulic head less than one inch higher than at the beginning of the year.

Hydraulic head at FPZ002A (Figure 29), HPZ002A (Figure 37), and HPZ005A/B (Figures 23 and 40) has remained below the plant root zone since 1999. The water table has remained below the root zone for four years at FPZ004A (Figure 31) and FHR002 (Figure 26), but since this study began in 1996, hydraulic head at these locations reached the root zone only during 1998, an exceptionally wet year, and the frequency of saturated soil conditions prior to 1996 is not known.

Figure 45 shows the difference between the annual average hydraulic head and the baseline for the years 2001 and 2002 for the piezometers closest to the extraction wells and the two most variable reference piezometers. The annual volumes of groundwater extracted at the F-Area and H-Area WTUs are also shown. The effects of drought during 2002 are revealed by the large decreases in reference piezometer hydraulic head compared to 2001 (approximately 2.5 ft to 3 ft). Decreases in H-Area groundwater extraction volume in December and the resulting rebound in hydraulic head tempered the effect of drought, as seen in HPZ002A and HPZ005A, which decreased by about 2 ft compared to 2001. The more prolonged reduction in F-Area groundwater extraction volumes is reflected in smaller decreases in hydraulic head, 1 ft to 1.5 ft, from 2001 levels.

To further investigate the effect of the WTU operation on the hydraulic head at the seepline piezometers, the daily volume of groundwater extracted was plotted along with the hydrographs of piezometers that exhibited declining head levels. Effects were discernable at some piezometers, but because the increase in rainfall during the latter part of the year overlaps the periods with reduced extraction, the effect of WTU operation on the hydraulic head was not clear for other piezometers. The effect was most pronounced at FPZ004A, HPZ002A and HPZ005A. These are the three piezometers closest to extraction wells. In addition, the extraction wells closest to FPZ004A (FEX 1, FEX2, FEX3 and FEX4, see Figure 1 and Table 2) and HPZ002A (HEX1 and HEX17, see Figure 2 and Table 3) extracted more groundwater than the other extraction wells. The reduction in groundwater extraction during the last part of the year was more pronounced in these extraction wells, as well.

Figure 46 compares F-Area WTU groundwater extraction and hydraulic head at piezometer FPZ004A. The effect of the extraction on the hydraulic head could be seen clearly during three periods when the extraction decreased. During these times, the hydrographs showed steady increases in hydraulic head that look different from the shorter-lived, nearly instantaneous increases brought about by rainfall events. Hydraulic head rose from August through October, even during a 12-day rainless period in September. Individual rainfall events were not distinguishable from August through October, indicating the reduction in extraction levels had a greater effect than the increased rainfall. A similar rise in head could be seen to a lesser degree other F-Area piezometers, but individual rainfall events were still distinguishable.

Figure 47 shows the comparison between H-Area WTU groundwater extraction and hydraulic head at piezometer HPZ002A and HPZ005A. The hydraulic head response shows up clearly during December, when extraction volumes were greatly reduced. Onset of the increase in hydraulic head correlates precisely with the drop in extraction, not rainfall.

Linear correlation was used to identify the strength of relationships between hydraulic head trends and operational and rainfall trends. Monthly average hydraulic heads were calculated and compared with monthly values for groundwater extraction, total rainfall, and the rainfall deficit or surplus (calculated using monthly rainfall averaged from 1985-2000 data, and assumed to be zero at the beginning of the program in 1996). The population correlation calculation returns a coefficient (r) equal to the covariance of the two data sets divided by the product of their standard deviations.

The population correlation calculation can determine whether two ranges of data move together. If the two sets of data tend to increase together, r is positive. If one set tends to increase as the other tends to decrease, r is negative. The value of correlation coefficient lies between -1 and +1, inclusive. The sign of the correlation coefficient determines whether the correlation is positive or negative. The magnitude of the correlation coefficient determines the strength of the correlation. A value of +1 indicates perfect positive correlation, a value of –1 indicates perfect negative correlation and a value of zero indicates the two data sets are unrelated.

Results of the correlation calculations are shown in Table 8. Strong (defined for the purposes of this report as $0.7 \le |r| \le 1.0$) negative correlation existed between groundwater extraction volumes and hydraulic head for several F Area locations: FPZ001A, FPZ002A, FPZ003A, FPZ004A, and FPZ007A. Strong negative correlation also existed for H Area locations HPZ002A and HPZ005A. The negative value indicated the expected result that higher volumes of groundwater extraction corresponded to lower hydraulic head elevations.

Correlation coefficients calculated for the reference piezometers and the remaining F- and H-Area piezometers, except HPZ003A, were moderate (defined for the purposes of this report as $0.5 \le |r| < 0.6$) or moderately strong ($0.6 \le |r| < 0.7$) and negative. Correlation was the weakest at HPZ003A, with a correlation coefficient of -0.46. Results for HPZ006A differed from all other locations in that the correlation coefficient was positive, indicating that higher volumes of groundwater extraction correlated to higher hydraulic head elevations at that location. However, the beaver dams in Fourmile Branch influenced hydraulic head at HPZ003A and HPZ006A.

Hydraulic heads at most F-Area locations and two H-Area locations also were strongly positively correlated to cumulative rainfall deficit/surplus (Table 8). HPZ006A results were notable due to a negative, though very low, correlation between hydraulic head elevation and rainfall deficit. Correlation to monthly rainfall was positive and fairly low at all locations.

While the correlation coefficient is useful as an estimation of the strength of linear relationship between two data sets, the presence of a strong correlation does not necessarily indicate a cause and effect relationship between the two parameters.

Conclusions

The average decrease in hydraulic head elevation for the reference piezometers (2.1 ft) exceeded both the F-Area (0.8 ft) and H-Area (0.7 ft) piezometers, a phenomenon that has not been seen since the WTUs began full time operation. The magnitude of the decrease at the reference locations reflects the ongoing drought in 2002. The more moderate decreases in hydraulic head in F and H Areas reflect the opposing influences of drought and reductions in groundwater extraction.

The continued operation of the WTUs in 2002 affected hydraulic head most notably in the piezometers located closest to the extraction wells. The greatest decreases in average hydraulic head in H Area continued to be in the piezometers closest to the extraction wells. However, decreasing groundwater extraction in the second half of the year moderated hydraulic head declines in F Area near the extraction wells. In both areas, piezometers near the extraction wells also showed the most dramatic rises in groundwater following reduction in groundwater extraction. As in previous years, outage periods were visible on the hydrographs for piezometers FPZ004A, HPZ002A and HPZ005A as steady increases in hydraulic head not attributable to rainfall. Strong negative correlation coefficients calculated for groundwater extraction volumes and hydraulic head at many locations supported the observations.

However, WTU groundwater extraction was not the only cause of the decline in hydraulic head levels during 2002. Four consecutive years of below average rainfall was a major contributor. A correlation analysis indicated that hydraulic head was strongly correlated to cumulative rainfall deficit/surplus at many locations.

Wetlands are defined by the presence of hydric soils, saturated soil conditions during a portion of the growing season, and vegetation adapted to live in saturated soils. Lowering groundwater levels for a prolonged period could change the wetland hydrologic conditions and the vegetation growing in these areas. In many locations, the hydraulic head never reached the root zone during 2002. For several years, the water table has remained below levels required to sustain the herbaceous components of wetland vegetation at some locations. Such hydrologic conditions may allow early successional species to germinate in these areas. In other areas, changes already have occurred. Nelson (2001) documented changes in herbaceous species diversity and establishment of early successional non-wetland species due to declines in water levels in recent years in the F- and H-Area tree kill zones (FPZ005A and HPZ001A are located here), areas where tree mortality in seepline-fed wetlands downslope from the seepage basins was first identified in the 1970s. However, these changes would not cause the areas to lose their wetland classification.

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Table 1 Piezometer Construction Information

Piezometer	Instru-mented	UTM East	UTM North	Ground Elev. (ft)	Depth of Well (ft)	Screened Length (ft)	Depth to top of Screen (ft)	Surface Casing	Well Casing	Well Screen	Date Installed	Installation Technique
FPZ001A	✓	436536.9	3681043.5	197.90	16.27	2.5	13.39	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/4/96	hand auger
FPZ002A	✓	436546.2	3681074.7	201.20	12.33	2.5	9.35	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/4/96	hand auger
FPZ003A	✓	436694.1	3680989.0	194.00	21.5	15	6.11	None	2" PVC	2" PVC Circumslot 0.010"	2/12/96	hollow stem auger
FPZ004A	✓	436782.4	3681237.6	203.10	11.8	2.5	8.64	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/3/96	hand auger
FPZ005A	✓	436825.1	3681133.2	190.90	14.5	2.5	11.80	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/3/96	hand auger
FPZ005B		436825.1	3681133.2	190.90	6.95	5	1.95	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/28/96	hand auger
FPZ006A	✓	436872.7	3681120.6	189.40	14.29	2.5	11.38	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/9/96	hand auger
FPZ006B		436872.7	3681120.6	189.40	7.7	5	2.7	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/28/96	hand auger
FPZ007A	✓	436967.8	3681207.4	194.50	10.67	2.5	7.75	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/8/96	hand auger
FPZ007B		436967.8	3681207.4	194.50	5.4	5	0.4	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/28/96	hand auger
FPZ008A	✓	437053.4	3681282.2	187.40	16.96	2.5	14.04	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/8/96	hand auger
FPZ008B		437053.4	3681282.2	187.40	10.5	7.5	3.0	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/29/96	hand auger
FSP-249A		436419.0	3680751.6	185.5	15.0	2.5	12.5	None	2" PVC	2" PVC Circumslot 0.010"	1/23/02	hollow stem auger
FSP-249B		436418.5	3680752.7	185.7	8.0	5.0	0.5	None	2" PVC	2" PVC Circumslot 0.010"	1/23/02	hollow stem auger
FSP-002A		436774.0	3680895.1	183.5	22.5	2.5	20.0	None	2" PVC	2" PVC Circumslot 0.010"	1/22/02	hollow stem auger
FSP-002B		436773.4	3680895.3	183.8	8.0	5.0	0.5	None	2" PVC	2" PVC Circumslot 0.010"	1/22/02	hollow stem auger
HPZ001A	✓	438656.8	3681699.3	202.40	15.4	5	7.45	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/15/96	hand auger
HPZ002A	✓	438703.5	3681880.8	218.80	11.85	5	6.65	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/15/96	hand auger
HPZ003A	✓	438874.2	3681720.7	200.40	17.5	2.5	14.70	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/10/96	hand auger
HPZ003B		438874.2	3681720.7	200.40	7.43	5	2.43	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/29/96	hand auger
HPZ004A	✓	438903.8	3681824.0	210.70	14	2.5	11.17	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/11/96	hand auger
HPZ005A	✓	439010.6	3681841.5	213.80	9.8	2.5	6.97	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/12/96	hand auger
HPZ005B		439010.6	3681841.5	213.80	6.21	5	1.21	4" PVC	2" PVC	2" PVC Circumslot 0.010"	5/29/96	hand auger
HPZ006A	✓	439071.9	3681730.9	201.70	9.5	5	3.99	4" PVC	2" PVC	2" PVC Circumslot 0.010"	1/12/96	hand auger
HSP-060A		438479.7	3681676.0	202	20.0	2.5	17.5	None	2" PVC	2" PVC Circumslot 0.010"	1/28/02	hollow stem auger
HSP-060B		438479.8	3681677.0	202.1	9.0	5.0	2.0	None	2" PVC	2" PVC Circumslot 0.010"	1/28/02	hollow stem auger
HSP-076A		438350.9	3681552.0	196.9	22.0	5.0	17.0	None	2" PVC	2" PVC Circumslot 0.010"	1/29/02	hollow stem auger
HSP-076B		438350.6	3681552.6	196.9	11.0	5.0	3.5	None	2" PVC	2" PVC Circumslot 0.010"	1/29/02	hollow stem auger
FHR001	✓	442214.1	3681099.6	269.90	12.7	7.5	5.2	4" PVC	2" PVC	2" PVC Circumslot 0.010"	6/30/97	hand auger
FHR002	✓	442224.6	3680988.7	275.40	17.62	10	7.62	4" PVC	2" PVC	2" PVC Circumslot 0.010"	6/30/97	hand auger
FHR003	✓	440289.2	3681299.7	220.50	8.45	2.5	5.95	4" PVC	2" PVC	2" PVC Circumslot 0.010"	6/30/97	hand auger

Table 2 Groundwater extraction (thousands of gallons) by the F-Area Groundwater Remediation Wastewater Treatment Unit, 1997 to 2002

Well ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1997													
TOTAL	*0*	*0*	*0*	*10*	*29*	*29*	*40*	*411*	*189*	*235*	*173*	*560*	*1,676*
1998													
TOTAL	*570*	*547*	*390*	*0*	*0*	*0*	*1,214*	*3,468*	*2,448*	*3,137*	*1,680*	*1,173*	*14,627*
1999													
TOTAL	*842*	*573*	*913*	*4,621*	*4,626*	*1,106*	*1,397*	*3,883*	*6,739*	*7,615*	*6,565*	*7,683*	*46,562*
2000													
TOTAL	*7,586*	*6,093*	*7,593*	*7,363*	*6,404*	*7,302*	*7,529*	*6,624*	*6,381*	*7,530*	*7,231*	*7,098*	*84,739*
2001													
TOTAL	*7,413*	*5,750*	*7,510*	*7,318*	*7,611*	*6,892*	*7,504*	*7,521*	*6,846*	*6,563*	*7,434*	*7,220*	*85,576*
2002													
FEX-1	1,293	1,221	1,378	1,213	1,238	1,308	1,584	925	145	242	555	738	11,838
FEX-2	1,301	1,319	1,241	1,087	1,390	778	1,125	813	132	117	229	243	9,773
FEX-3	1,123	1,015	1,152	995	1,060	949	1,173	696	122	57	304	356	9,000
FEX-4	1,127	1,068	1,211	1,047	1,179	114	633	784	203	152	610	610	8,739
FEX-5	231	220	239	210	236	27	152	135	237	286	214	267	2,455
FEX-6	733	563	706	661	715	78	399	524	701	516	510	680	6,786
FEX-7	894	834	912	781	885	95	450	656	830	629	562	829	8,355
FEX-8	341	293	348	305	346	34	192	195	311	330	108	0	2,802
FEX-9	341	375	353	300	412	36	197	203	303	429	103	0	3,052
FEX-10	0	0	0	0	0	0	2	0	353	537	12	2	905
FEX-11	0	0	0	0	0	0	0	0	370	505	10	69	955
TOTAL	*7,383*	*6,907*	*7,540*	*6,599*	*7,460*	*3,420*	*5,906*	*4,931*	*3,706*	*3,798*	*3,218*	*3,794*	*64,660*

Sources: Long (2001, 2002a&b, 2003a), Wells (2001), WSRC (1997a, 1998a&c, 1999a&c, 2000a&c, 2001a)

Table 3 Groundwater extraction (thousands of gallons) by the H-Area Groundwater Remediation Wastewater Treatment Unit, 1997 to 2002

Well ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1997													
TOTAL	*0*	*0*	*0*	*0*	*0*	*0*	*20*	*0*	*792*	*192*	*23*	*206*	*1,234*
1998													
TOTAL	*133*	*598*	*1,930*	*312*	*0*	*1,227*	*2,142*	*1,805*	*2,494*	*2,298*	*90*	*2,078*	*15,107*
1999													
TOTAL	*1,062*	*3,401*	*4,458*	*4,013*	*2,582*	*6,072*	*6,291*	*6,119*	*5,665*	*6,340*	*5,762*	*6,262*	*58,027*
2000													
TOTAL	*6,285*	*5,581*	*6,285*	*6,006*	*5,724*	*5,990*	*6,231*	*6,049*	*5,899*	*6,229*	*6,061*	*6,181*	*72,525*
2001													
TOTAL	*6,033*	*5,695*	*6,196*	*6,013*	*6,123*	*6,052*	*6,263*	*2,696*	*5,788*	*6,312*	*6,108*	*6,299*	*69,577*
2002													
HEX-1	1,025	853	1,012	932	988	940	1,000	937	833	894	800	305	10,519
HEX-2	0	44	0	0	0	0	125	235	231	220	210	168	1,233
HEX-3	833	669	864	777	849	820	862	802	801	773	731	293	9,071
HEX-4	604	481	613	571	583	520	507	486	476	507	492	240	6,079
HEX-9	355	313	356	341	349	333	329	400	418	445	452	351	4,442
HEX-12	206	181	212	193	209	198	158	614	633	666	629	281	4,178
HEX-16	0	0	0	0	0	0	0	0	0	0	0	217	217
HEX-17	1,797	1,622	1,892	1,717	1,898	1,810	1,852	1,544	1,558	1,604	1,551	633	19,477
HEX-18	1,193	1,056	1,247	1,119	1,198	1,286	1,220	1,160	1,009	1,075	1,070	378	13,011
HEX-19	111	106	123	106	127	102	99	87	111	111	120	97	1,298
TOTAL	*6,123*	*5,326*	*6,318*	*5,755*	*6,199*	*6,008*	*6,152*	*6,263*	*6,071*	*6,294*	*6,054*	*2,964*	*69,526*

Sources: Long (2001, 2002a&b, 2003a), Wells (2001), WSRC (1997b, 1998b&d, 1999b&d, 2000b&d, 2001b)

Table 4 Monthly water levels (feet, msl) at individual piezometers, January to December 2002

Piezometer	Water Level Elevations												Ground
ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Elevation
FSP249A	NA	NA	184.71	184.70	182.83	182.17	181.95	181.92	182.54	183.37	183.66	184.04	185.5
FSP249B	NA	NA	184.70	184.66	182.71	182.13	181.94	181.91	182.56	183.36	183.66	184.02	185.7
FPZ001A	193.2	194.9	195.2	195.1	193.6	193.5	193.7	193.2	193.6	194.0	194.2	194.6	197.9
FPZ002A	195.5	195.3	195.4	195.6	194.4	194.5	194.9	194.2	193.5	193.7	195.0	194.6	201.2
FPZ003A	186.0	187.0	187.4	188.2	184.9	184.4	184.3	184.2	185.0	185.5	185.8	187.3	194.0
FSP002A	NA	NA	180.7	181.7	180.4	180.3	180.5	180.4	177.3	180.6	180.7	180.6	183.5
FSP002B	NA	NA	180.8	180.6	179.9	179.8	179.9	179.8	179.7	179.9	180.0	180.2	183.8
FPZ004A	193.8	193.5	193.5	193.7	191.7	193.3	193.2	192.8	194.1	195.4	195.5	195.6	203.1
FPZ005A	189.8	189.5	190.0	189.8	188.2	188.0	188.2	188.2	188.9	189.5	189.7	189.7	190.9
FPZ005B	189.9	189.6	190.0	189.8	188.3	188.2	188.3	188.3	188.9	189.6	189.7	189.8	190.9
FPZ006A	188.1	187.8	189.4	188.2	186.2	186.2	186.2	186.2	186.9	187.7	187.8	188.1	189.4
FPZ006B	188.2	187.9	188.7	188.5	185.9	185.7	185.6	185.6	186.1	187.2	187.8	188.1	189.4
FPZ007A	190.9	190.3	190.9	190.7	188.9	189.0	188.8	188.8	186.8	190.8	191.0	191.1	194.5
FPZ007B	192.2	191.1	192.3	191.9	188.9	189.0	188.8	188.8	190.4	192.1	192.3	192.3	194.5
FPZ008A	187.5	187.5	187.5	187.5	187.2	187.2	187.3	187.3	187.4	187.5	187.6	187.6	187.4
FPZ008B	187.6	187.5	187.5	187.6	187.4	187.5	187.5	187.4	187.5	187.6	187.6	187.6	187.4
HSP076A	NA	NA	198.6	198.5	198.0	197.9	197.9	197.8	197.9	198.0	198.1	198.2	196.9
HSP076B	NA	NA	196.6	196.4	195.8	195.7	195.8	195.8	195.9	196.1	196.3	196.4	196.9
HSP060A	NA	NA	201.5	201.4	200.3	200.0	199.9	199.7	200.2	200.6	200.7	201.1	202.0
HSP060B	NA	NA	200.7	200.5	199.4	199.3	199.3	199.0	199.4	198.6	199.7	199.8	202.1
HPZ001A	201.9	202.0	202.0	202.0	201.3	200.8	201.3	201.1	201.6	201.8	201.9	201.8	202.4
HPZ002A	212.3	212.4	212.7	212.3	211.5	211.2	210.9	210.7	210.8	210.7	210.6	211.4	218.8
HPZ003A	201.3	201.3	201.3	201.3	200.7	200.6	200.9	200.9	201.1	201.0	201.2	201.3	200.4
HPZ003B	200.8	200.8	200.8	200.8	200.2	200.4	200.7	200.9	200.8	201.0	201.0	201.0	200.4
HPZ004A	209.1	209.0	209.2	209.1	208.3	208.2	208.0	207.9	208.1	208.0	208.3	208.5	210.7
HPZ005A	207.5	208.8	209.1	209.2	207.0	205.8	206.8	205.1	205.5	205.6	206.5	208.5	213.8
HPZ005B	207.8	208.7	209.1	209.4	208.3	208.2	208.2	208.2	208.2	207.6	207.7	208.9	213.8
HPZ006A	202.5	202.4	202.4	202.4	202.4	202.4	202.8	202.9	202.9	202.8	202.9	202.9	201.7
FHR001	265.6	265.4	265.5	265.4	264.2	263.9	263.3	262.9	262.8	262.5	262.4	262.6	269.9
FHR002	266.6	266.4	266.3	266.4	265.5	265.1	264.6	264.2	264.0	263.6	263.5	263.3	275.4
FHR003	219.8	219.7	219.8	219.8	219.6	219.7	219.4	219.4	219.3	219.5	219.6	219.4	220.5

NA – Not available

Table 5 Maximum, minimum and average water level measurements, January to December 2002

Piez. ID	Monthly Measurements						Continuous Measurements					
	Max. Water Level (ft, msl)	Min. Water Level (ft, msl)	Avg. Water Level (ft, msl)	Change from 2001 Avg. (ft)[a]	Range (ft)	Std. Dev. (ft)	Max. Water Level (ft, msl)	Min. Water Level (ft, msl)	Avg. Water Level (ft, msl)	Change from 2001 Avg. (ft)[a]	Range (ft)	Std. Dev. (ft)
FSP249A	184.7	181.9	183.2	NA	2.8	1.1	NA	NA	NA	NA	NA	NA
FSP249B	184.7	181.9	183.2	NA	2.8	1.1	NA	NA	NA	NA	NA	NA
FPZ001A	195.2	193.2	194.1	-1.4	2.0	0.7	195.6	193.0	194.2	-2.0	2.6	0.6
FPZ002A	195.6	193.5	194.7	-1.5	2.1	0.7	196.3	194.1	195.0	-1.0	2.2	0.5
FPZ003A	188.2	184.2	185.8	-1.0	4.1	1.4	189.2	183.9	185.9	-1.4	5.4	1.3
FSP002A	181.7	177.3	180.3	NA	4.4	1.1	NA	NA	NA	NA	NA	NA
FSP002B	180.8	179.7	180.1	NA	1.1	0.4	NA	NA	NA	NA	NA	NA
FPZ004A	195.6	191.7	193.9	-0.8	3.8	1.2	196.5	193.0	194.2	-0.3	3.5	1.1
FPZ005A	190.0	188.0	189.1	-0.6	1.9	0.8	190.4	187.3	189.2	-0.6	3.2	0.7
FPZ005B	190.0	188.2	189.2	-0.5	1.8	0.7	NA	NA	NA	NA	NA	NA
FPZ006A	189.4	186.2	187.4	-0.4	3.2	1.0	189.1	185.5	187.5	-0.4	3.6	0.9
FPZ006B	188.7	185.6	187.1	-0.5	3.0	1.2	NA	NA	NA	NA	NA	NA
FPZ007A	191.1	186.8	189.8	-0.9	4.3	1.4	192.1	188.2	190.2	-0.5	3.9	0.9
FPZ007B	192.3	188.8	190.8	-0.6	3.6	1.6	NA	NA	NA	NA	NA	NA
FPZ008A	187.6	187.2	187.4	0.0	0.4	0.1	187.9	187.0	187.5	0.0	0.9	0.2
FPZ008B	187.6	187.4	187.5	0.1	0.1	0.1	NA	NA	NA	NA	NA	NA
HSP076A	198.6	197.8	198.1	NA	0.8	0.3	NA	NA	NA	NA	NA	NA
HSP076B	196.6	195.7	196.1	NA	0.8	0.3	NA	NA	NA	NA	NA	NA
HSP060A	201.5	199.7	200.5	NA	1.8	0.6	NA	NA	NA	NA	NA	NA
HSP060B	200.7	198.6	199.6	NA	2.1	0.6	NA	NA	NA	NA	NA	NA
HPZ001A	202.0	200.8	201.6	-0.3	1.2	0.4	202.2	200.6	201.7	-0.2	1.5	0.4
HPZ002A	212.7	210.6	211.4	-1.9	2.1	0.8	214.4	210.6	211.7	-1.5	3.8	0.8
HPZ003A	201.3	200.6	201.1	-0.1	0.7	0.3	201.7	200.6	201.2	-0.1	1.1	0.3
HPZ003B	201.0	200.2	200.8	-0.1	0.8	0.2	NA	NA	NA	NA	NA	NA
HPZ004A	209.2	207.9	208.5	-0.7	1.3	0.5	209.4	207.3	208.5	-0.7	2.1	0.5
HPZ005A	209.2	205.1	207.1	-1.7	4.1	1.5	212.1	205.6	207.6	-1.4	6.5	1.4
HPZ005B	209.4	207.6	208.3	-0.8	1.8	0.5	NA	NA	NA	NA	NA	NA
HPZ006A	202.9	202.4	202.6	0.1	0.6	0.2	203.8	202.3	202.7	0.0	1.6	0.2
FHR001	265.6	262.4	263.9	-2.7	3.1	1.3	266.1	262.5	264.0	-2.7	3.6	1.1
FHR002	266.6	263.3	265.0	-3.3	3.3	1.3	266.8	263.4	265.0	-3.6	3.4	1.2
FHR003	219.8	219.3	219.6	-0.1	0.5	0.2	220.1[b]	219.7[b]	219.8[b]	0.2[b]	0.4[b]	0.0[b]

[a] 2001 data were reported in Halverson (2002).
[b] Based on only approximately two months of data due to a battery failure in the data logger.
NA = Not Applicable

Table 6 Comparison of piezometer water-level statistics in 2001 and 2002

Piezometer	Maximum			Minimum			Average			Standard Deviation		
	2001 (ft, msl)	2002 (ft, msl)	Difference[b] (ft)	2001 (ft, msl)	2002 (ft, msl)	Difference[b] (ft)	2001 (ft, msl)	2002 (ft, msl)	Difference[b] (ft)	2001 (ft, msl)	2002 (ft, msl)	Difference[b] (ft)
FPZ001A	197.4	195.6	-1.8	194.6	193.0	-1.9	195.7	194.2	-2.0	0.5	0.6	0.1
FPZ002A	196.9	196.3	-0.7	195.1	194.1	-1.1	196.3	195.0	-1.0	0.5	0.5	-0.1
FPZ003A	190.8	189.2	-1.5	185.0	183.9	-1.1	187.1	185.9	-1.4	1.9	1.3	-0.6
FPZ004A	195.6	196.5	1.1	193.7	193.0	-0.7	194.8	194.2	-0.3	0.5	1.1	0.7
FPZ005A	191.0	190.4	-0.6	188.6	187.3	-1.3	189.9	189.2	-0.6	0.7	0.7	0.0
FPZ006A	189.2	189.1	-0.1	186.3	185.5	-0.8	187.8	187.5	-0.4	0.8	0.9	0.0
FPZ007A	192.1	192.1	0.0	189.4	188.2	-1.3	190.7	190.2	-0.5	0.7	0.9	0.2
FPZ008A	187.7	187.9	0.2	187.3	187.0	-0.3	187.5	187.5	0.0	0.1	0.2	0.1
HPZ001A	202.2	202.2	0.0	201.4	200.6	-0.7	201.9	201.7	-0.2	0.2	0.4	0.2
HPZ002A	215.2	214.4	-0.8	212.2	210.6	-1.6	213.3	211.7	-1.5	0.7	0.8	0.1
HPZ003A	202.0	201.7	-0.3	201.0	200.6	-0.6	201.2	201.2	-0.1	0.1	0.3	0.2
HPZ004A	209.9	209.4	-0.5	208.6	207.3	-1.3	209.2	208.5	-0.7	0.2	0.5	0.3
HPZ005A	212.7	212.1	-0.6	206.7	205.6	-1.1	209.1	207.6	-1.4	1.5	1.4	-0.1
HPZ006A	203.5	203.8	0.4	202.4	202.3	-0.2	202.7	202.7	0.0	0.1	0.2	0.1
FHR001	268.7	266.1	-2.6	265.0	262.5	-2.6	266.7	264.0	-2.7	1.0	1.1	0.1
FHR002	272.2	266.8	-5.4	266.0	263.4	-2.6	268.6	265.0	-3.6	1.6	1.2	-0.4
FHR003[a]	220.0	220.1	0.1	219.3	219.34	0.0	219.6	219.613	0.0	0.1	0.2	0.1

[a] Electric water-level meter measurements were substituted for months where no data logger data was available. 2001 data reported in Halverson (2002).
[b] Positive number indicates that the 2002 value was greater than the 2001 value. Negative number indicates the 2002 value was less than the 2001 value.

Table 7 Comparison of the 2002 piezometer water-level statistics with baseline values

	Maximum			**Minimum**			**Average**			**Standard Deviation**		
Piezometer	Baseline[b] (ft, msl)	2002 (ft, msl)	Difference[c] (ft)	Baseline[b] (ft, msl)	2002 (ft, msl)	Difference[c] (ft)	Baseline[b] (ft, msl)	2002 (ft, msl)	Difference[c] (ft)	Baseline[b] (ft, msl)	2002 (ft, msl)	Difference[c] (ft)
FPZ001A	198.1	195.6	-2.5	197.8	193.0	-4.8	197.9	194.2	-3.7	0.1	0.6	0.5
FPZ002A	201.9	196.3	-5.6	201.0	194.1	-6.9	201.2	195.0	-6.2	0.2	0.5	0.2
FPZ003A[d]	191.2	189.2	-2.0	187.1	183.9	-3.2	188.9	185.9	-3.0	1.2	1.3	0.1
FPZ004A	202.5	196.5	-6.0	200.9	193.0	-7.9	201.2	194.2	-7.0	0.2	1.1	1.0
FPZ005A	191.3	190.4	-0.9	191.0	187.3	-3.7	191.1	189.2	-1.8	0.1	0.7	0.6
FPZ006A	189.8	189.1	-0.7	188.5	185.5	-3.0	189.2	187.5	-1.7	0.3	0.9	0.6
FPZ007A[d]	193.3	192.1	-1.2	192.7	188.2	-4.5	193.0	190.2	-2.9	0.2	0.9	0.7
FPZ008A[d]	187.7	187.9	0.2	187.6	187.0	-0.5	187.6	187.5	-0.1	0.1	0.2	0.1
HPZ001A[d]	202.4	202.2	-0.2	202.1	200.6	-1.4	202.3	201.7	-0.6	0.1	0.4	0.3
HPZ002A	218.8	214.4	-4.4	217.4	210.6	-6.9	218.0	211.7	-6.3	0.3	0.8	0.5
HPZ003A	201.6	201.7	0.1	200.4	200.6	0.2	201.2	201.2	0.0	0.3	0.3	0.0
HPZ004A	210.5	209.4	-1.1	209.9	207.3	-2.6	210.1	208.5	-1.7	0.1	0.5	0.4
HPZ005A	213.7	212.1	-1.6	211.5	205.6	-5.9	212.7	207.6	-5.1	0.4	1.4	1.0
HPZ006A[d]	202.1	203.8	1.7	201.5	202.3	0.8	201.9	202.7	0.8	0.2	0.2	0.1
FHR001[d]	269.5	266.1	-3.4	267.7	262.5	-5.2	268.6	264.0	-4.6	0.6	1.1	0.5
FHR002[d]	273.6	266.8	-6.8	269.9	263.4	-6.5	271.5	265.0	-6.5	1.3	1.2	-0.1
FHR003[a,d]	220.0	220.1	0.1	219.8	219.3	-0.5	219.9	219.6	-0.3	0.1	0.2	0.1

[a] Electric water-level meter measurements were substituted for months where no data logger data was available.
[b] Baseline data was reported in Halverson and Dixon (1999). Baseline for FPZ and HPZ piezometers was the pre-operational period: 1/96 – 3/97 for F-Area piezometers and 1/96 – 6/97 for H-Area piezometers. Baseline for the reference piezometers (FHR) was the first six months of data, 7/97 – 12/97.
[c] Positive number indicates that the 2002 value was greater than the baseline period value. Negative number indicates the 2002 value was less than the baseline period value.
[d] Baseline values were based on monthly electric water-level meter measurements because data loggers were not installed at that time.

Table 8 Population Correlation Coefficients for Monthly Hydraulic Head vs. Groundwater Extraction, Temperature, Rainfall, and Cumulative Rainfall Surplus/Deficit
Strong correlation coefficients are shown in bold.

	Correlation Coefficient		
Location	**Extraction**	**Cumulative Rainfall Surplus/Deficit[a]**	**Rainfall**
FPZ001A	**-0.75**	**0.87**	0.24
FPZ002A	**-0.75**	**0.87**	0.24
FPZ003A	**-0.83**	**0.80**	0.26
FPZ004A	**-0.83**	**0.80**	0.26
FPZ005A	-0.53	**0.72**	0.23
FPZ006A	-0.64	**0.72**	0.23
FPZ007A	**-0.75**	**0.77**	0.28
FPZ008A	-0.68	0.50	0.25
HPZ001A	-0.69	0.43	0.13
HPZ002A	**-0.88**	**0.75**	0.28
HPZ003A	-0.46	0.28	0.17
HPZ004A	-0.66	**0.73**	0.13
HPZ005A	**-0.82**	0.66	0.33
HPZ006A	0.59	-0.16	0.04
FHR001 [b]	-0.62	**0.83**	0.23
FHR002 [b]	-0.65	**0.78**	0.29
FHR003 [b]	-0.59	0.57	0.27

[a] Assumed to be zero at the beginning of the program in 1996.
[b] Correlation with H-Area data.

Table 9 Population Correlation Coefficients between Groundwater Extraction, Rainfall, and Cumulative Rainfall Surplus/Deficit

		Cumulative Rainfall Surplus/Deficit[a]	**Extraction**
F Area	Extraction	-0.42	
F Area	Rainfall	0.19	-0.35
H Area	Extraction	-0.42	
H Area	Rainfall	0.20	-0.22

[a] Assumed to be zero at the beginning of the program in 1996.

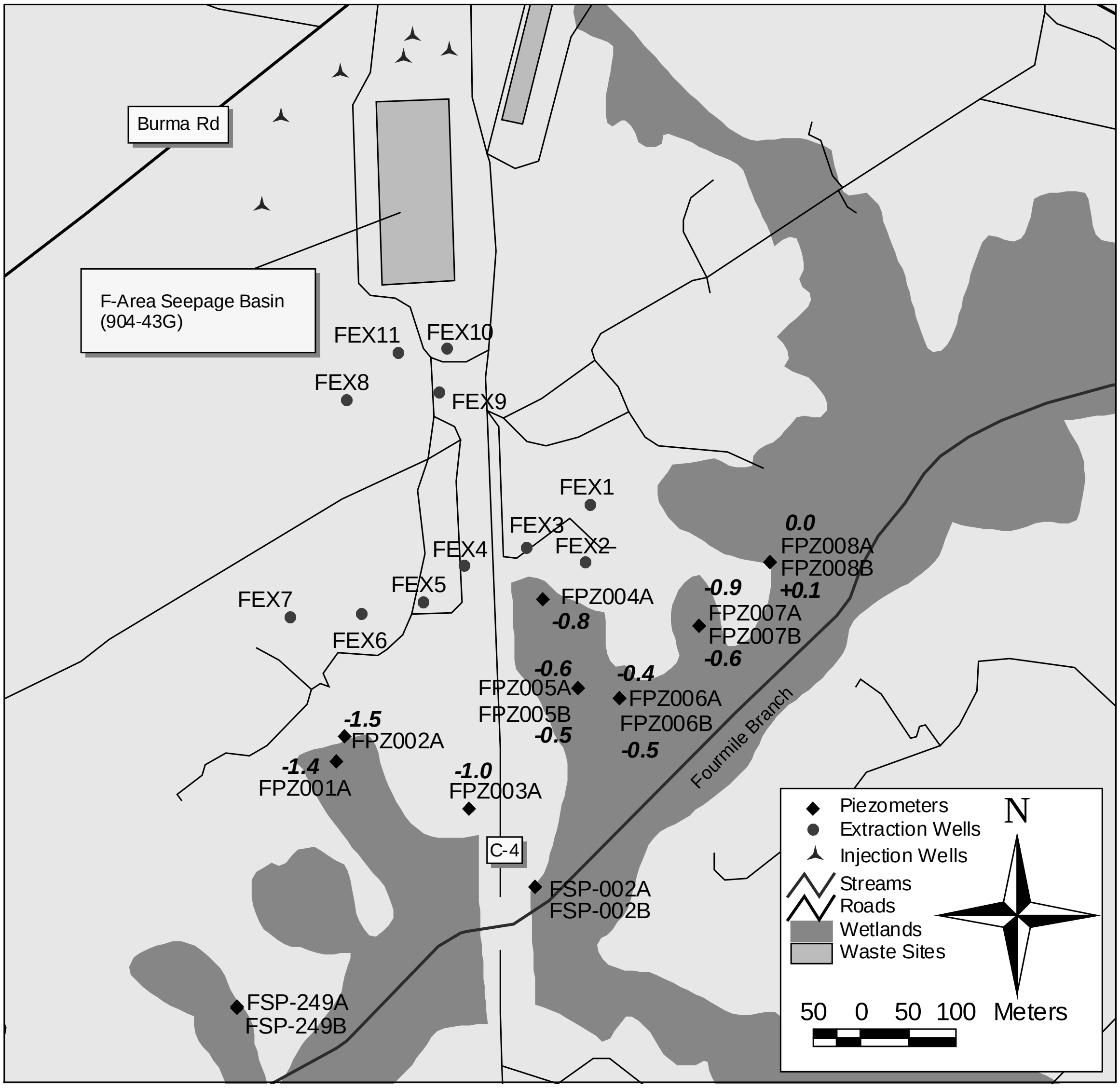


Figure 1 Extraction / injection well and piezometer locations for the water table aquifer (UAZ) in F Area Only operating extraction wells are labeled. Change in average hydraulic head elevation from 2001 to 2002 is shown in italics.

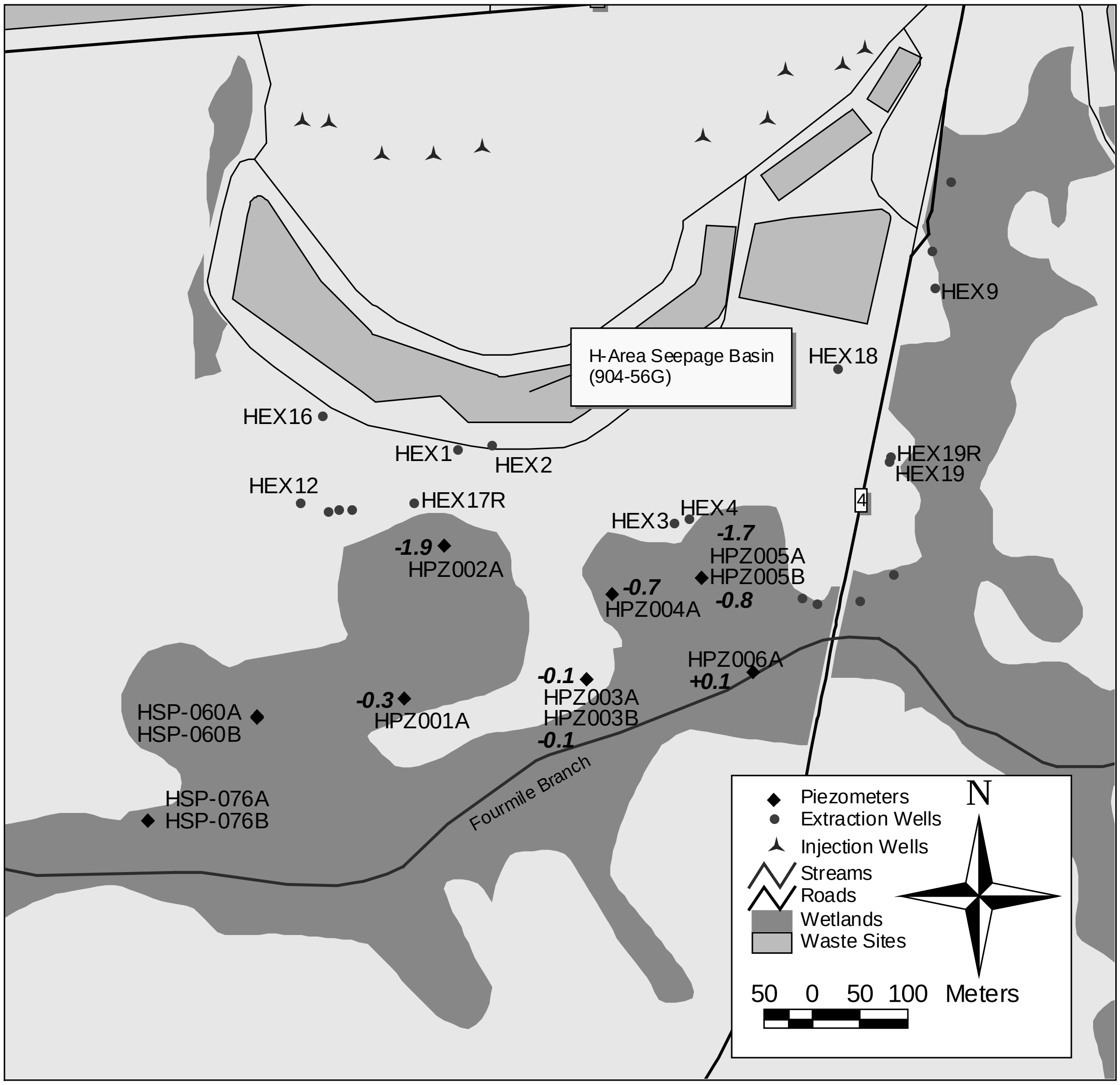


Figure 2 Extraction / injection well and piezometer locations for the water table aquifer (UAZ) in H Area Only operating extraction wells are labeled. Change in average hydraulic head elevation from 2001 to 2002 is shown in italics.

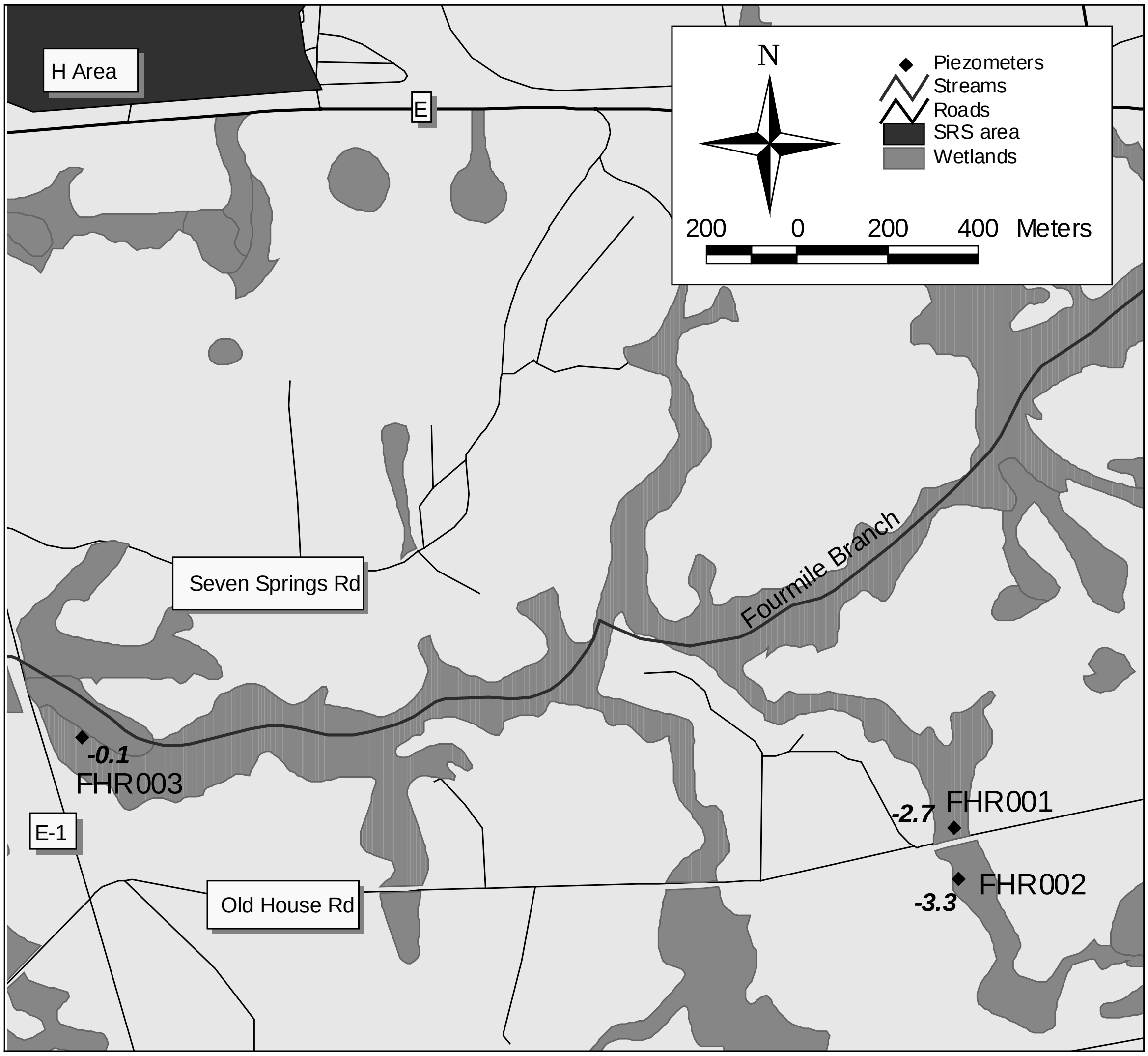
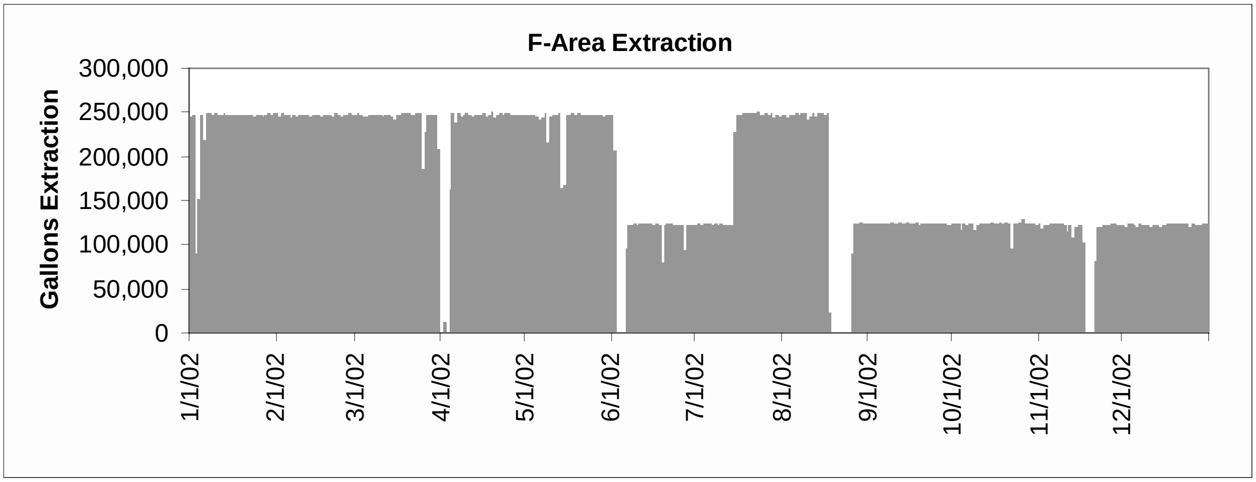
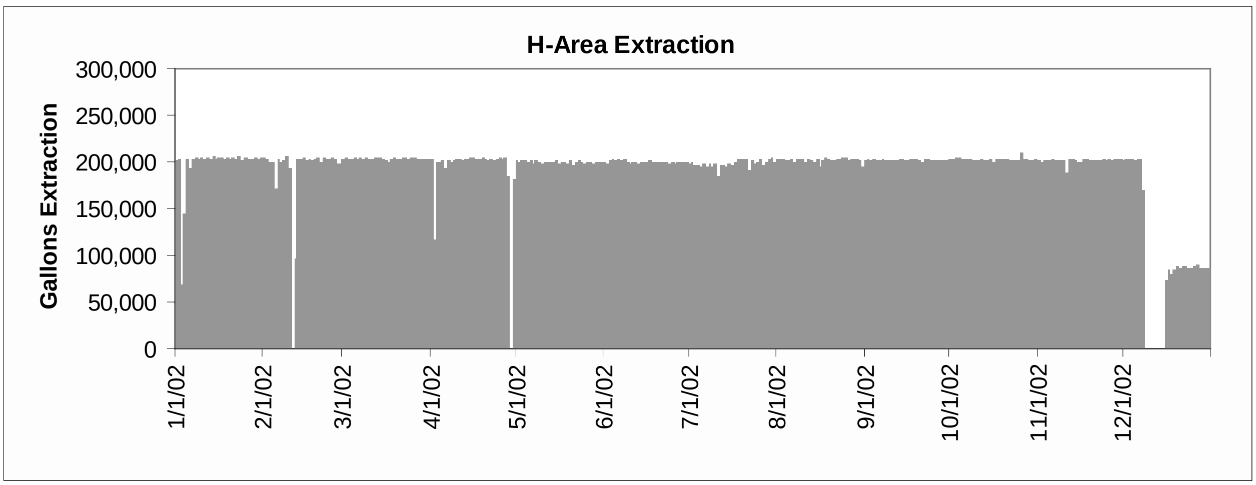


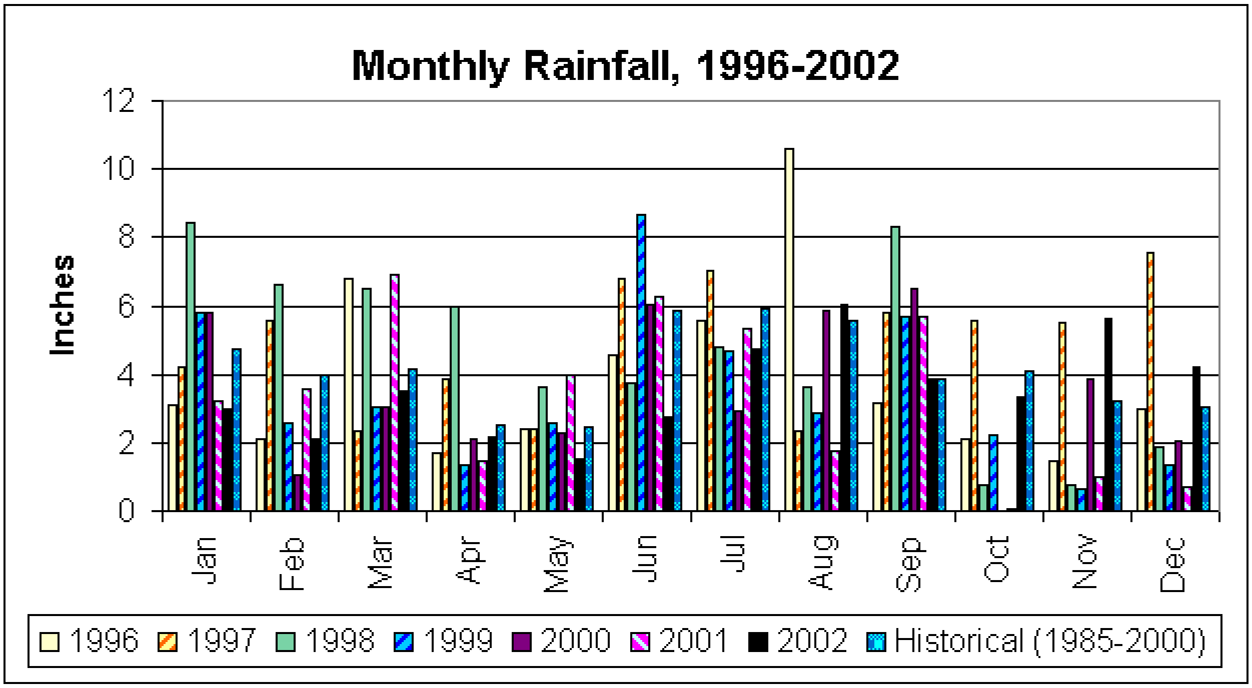
Figure 3 Reference piezometer locations
Change in average hydraulic head elevation from 2001 to 2002 is shown in italics.





Source: Long (2003b&c)

Figure 4 Groundwater extraction rates (gal/day) in F Area and H Area, 2002



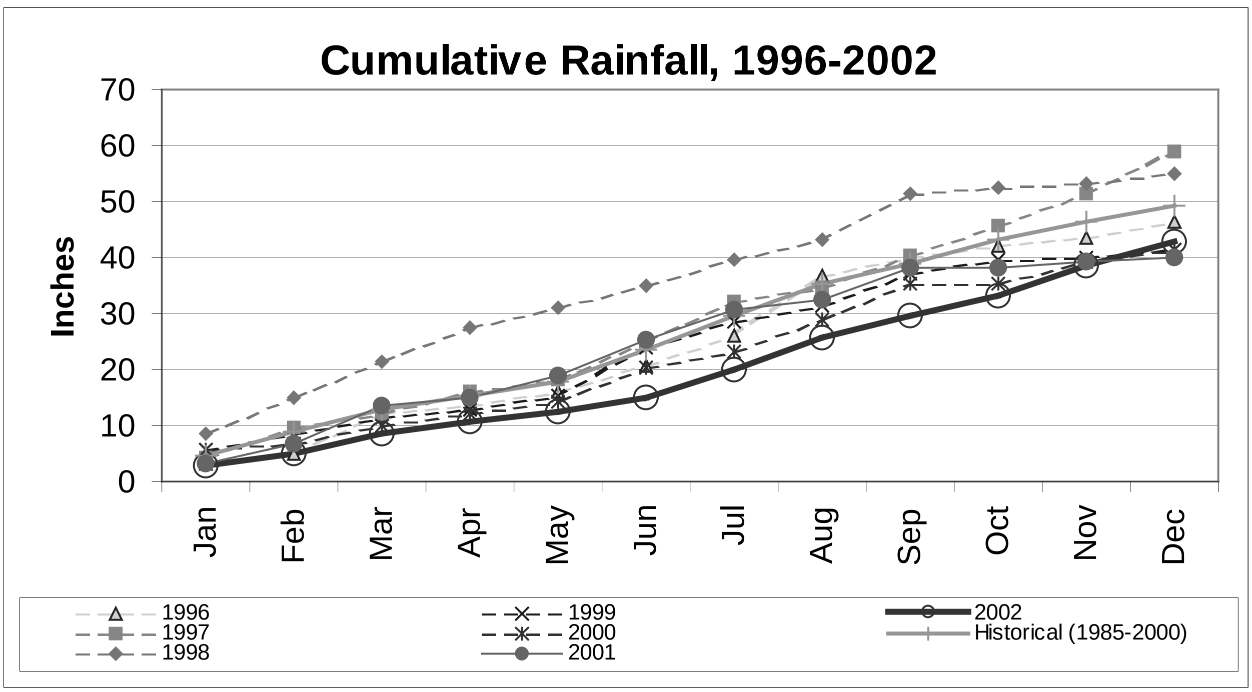
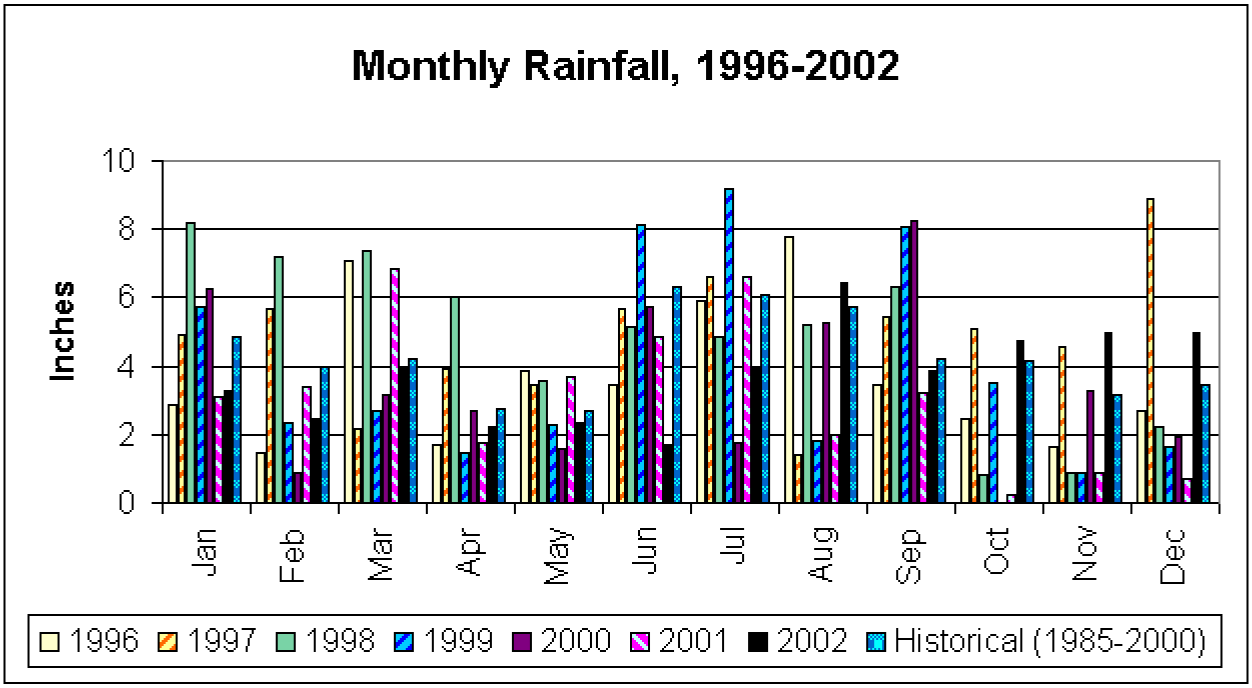


Figure 5 Monthly and cumulative rainfall (inches) in F Area, 1996 to 2002



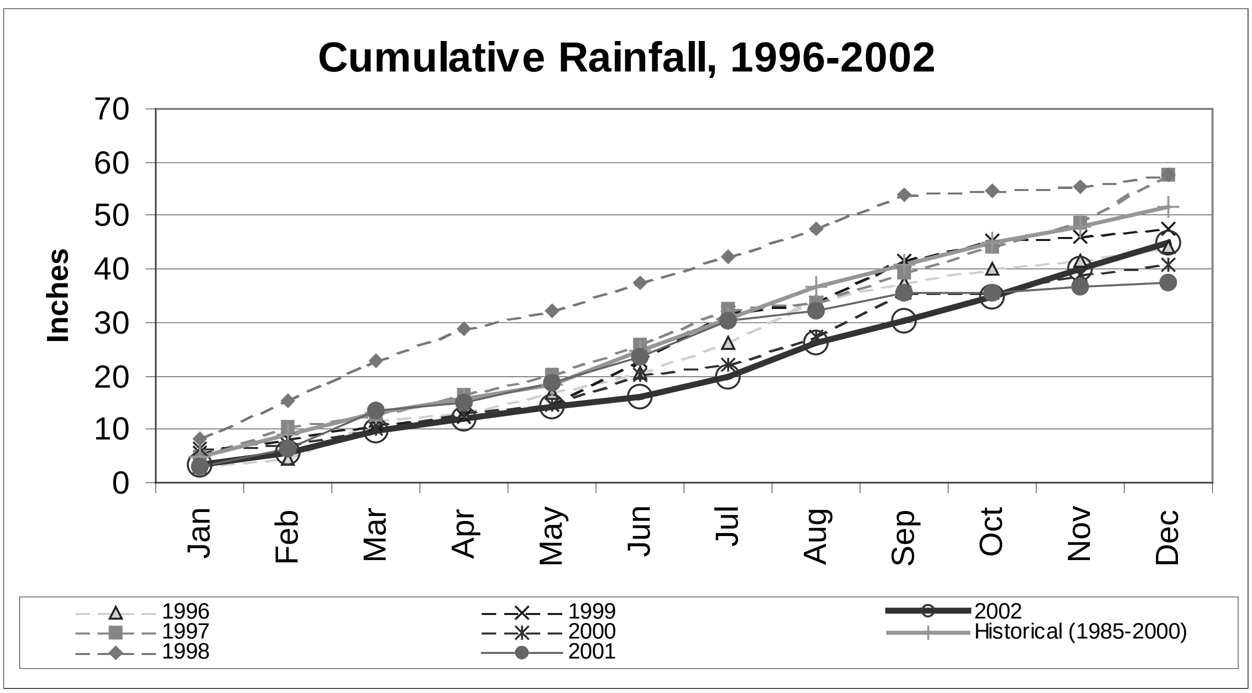


Figure 6   Monthly and cumulative rainfall (inches) in H Area, 1996 to 2002

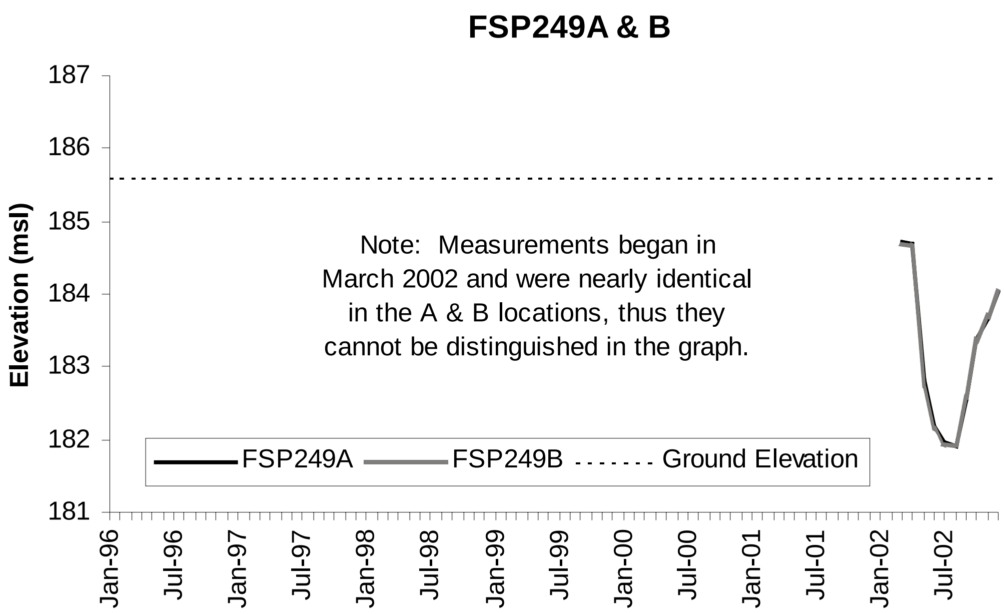


Figure 7 Monthly hydraulic head elevations (ft, msl) at FSP249A and FSP249B, through December 2002

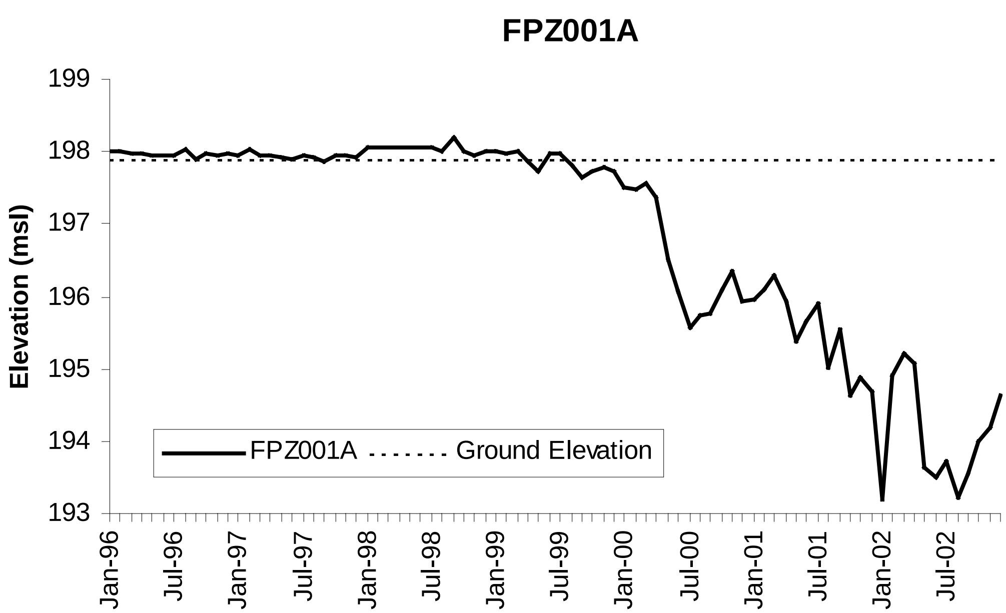


Figure 8 Monthly hydraulic head elevations (ft, msl) at FPZ001A, January 1996 to December 2002

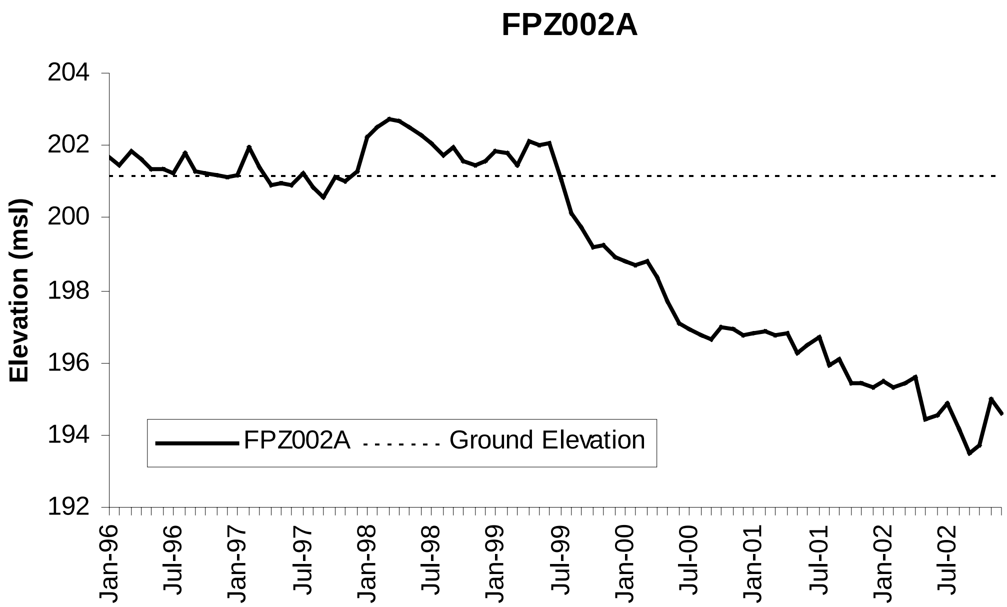


Figure 9 Monthly hydraulic head elevations (ft, msl) at FPZ002A, January 1996 to December 2002

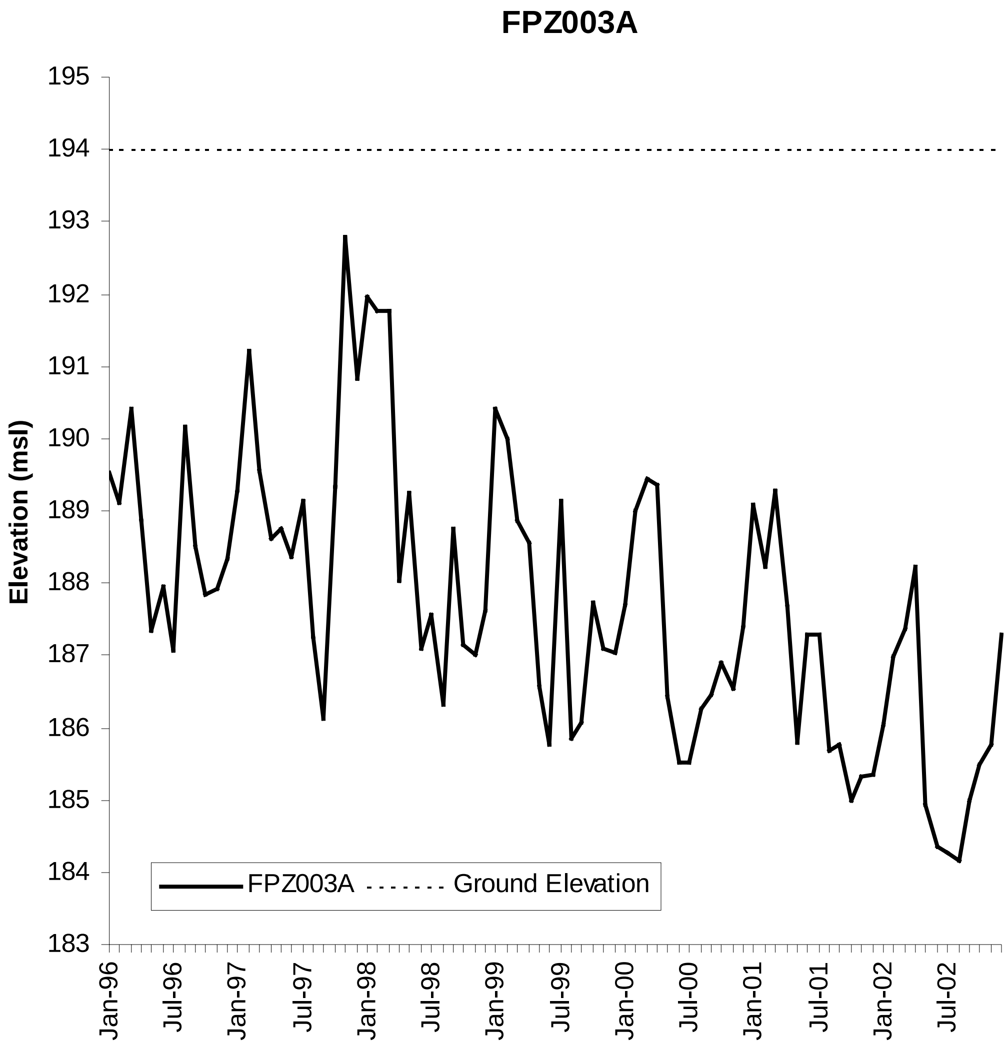


Figure 10 Monthly hydraulic head elevations (ft, msl) at FPZ003A, January 1996 to December 2002

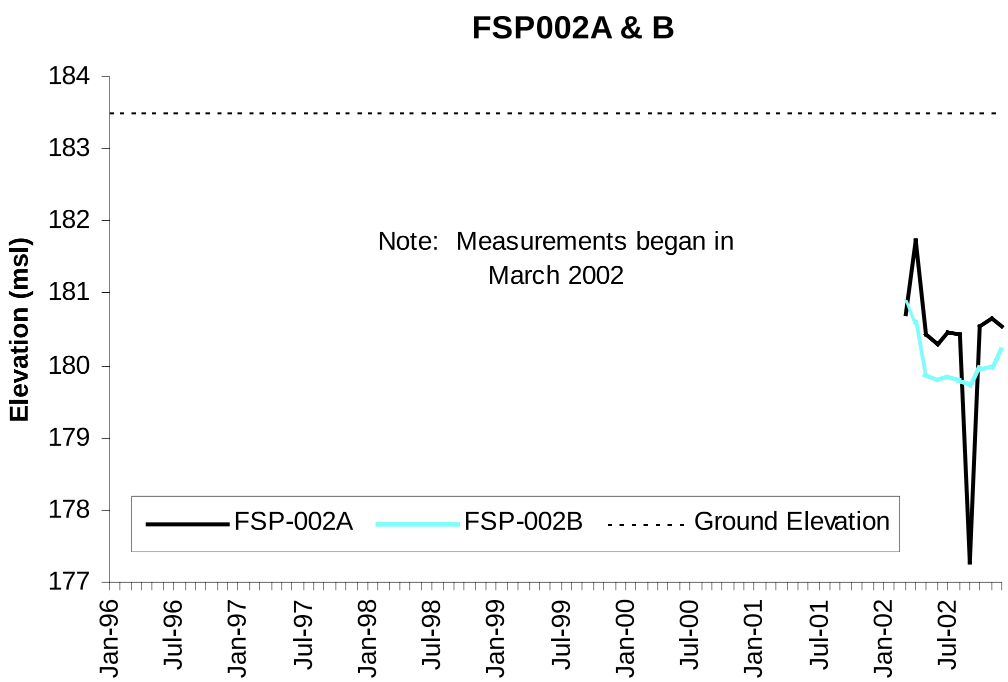


Figure 11   Monthly hydraulic head elevations (ft, msl) at FSP002A and FSP002B through December 2002

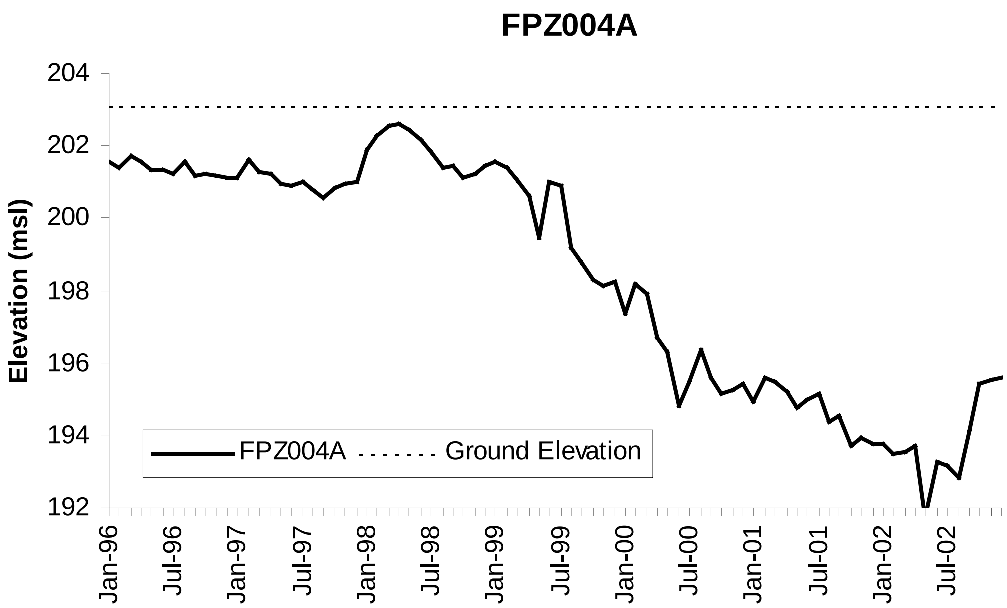


Figure 12   Monthly hydraulic head elevations (ft, msl) at FPZ004A, January 1996 to December 2002

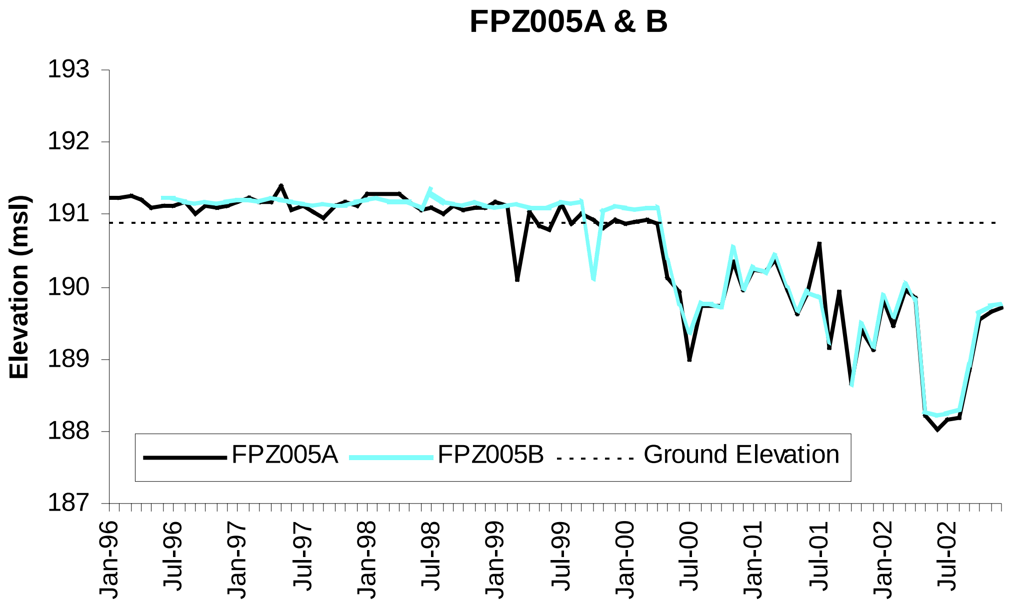


Figure 13 Monthly hydraulic head elevations (ft, msl) at FPZ005A and FPZ005B, January 1996 to December 2002

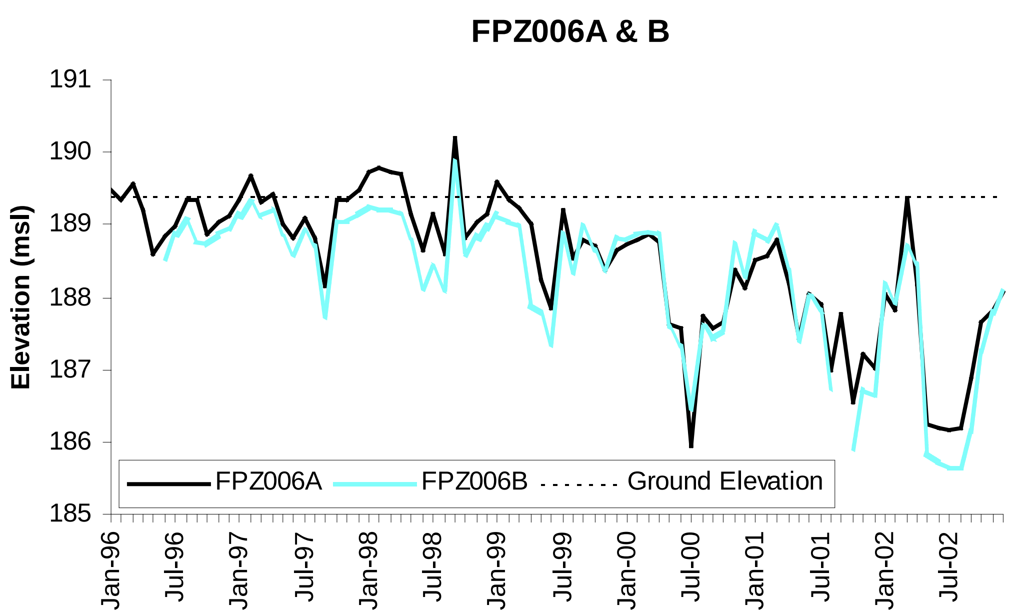


Figure 14 Monthly hydraulic head elevations (ft, msl) at FPZ006A and FPZ006B, January 1996 to December 2002

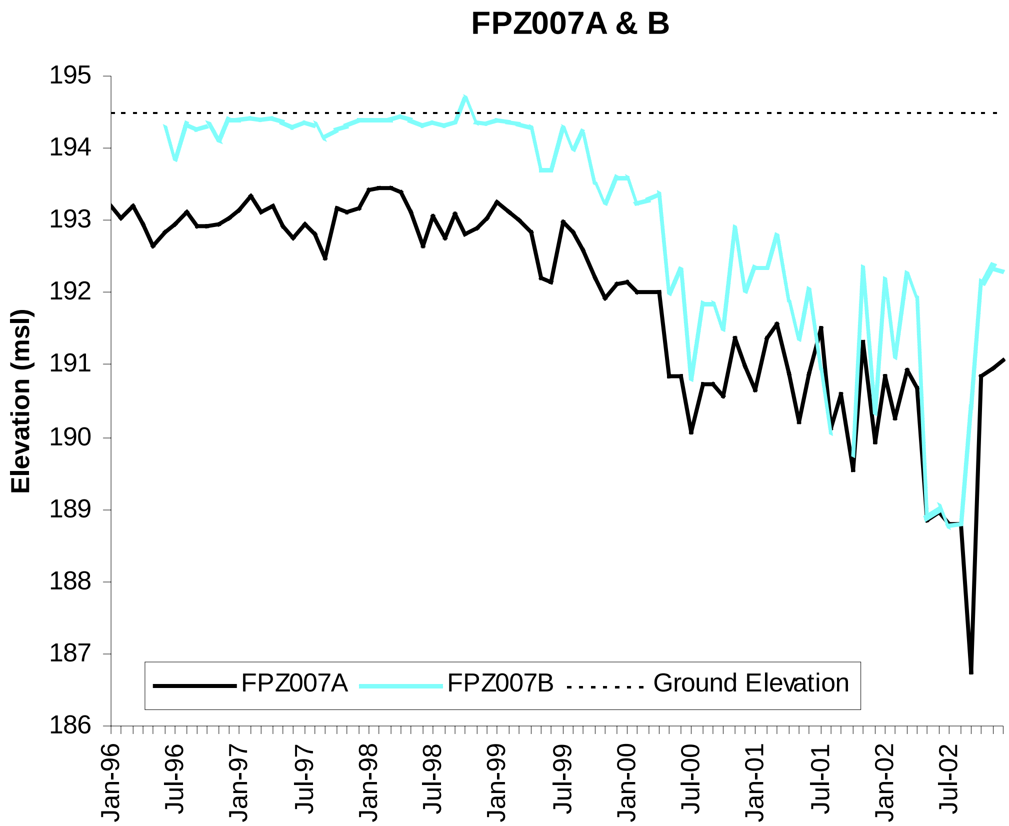


Figure 15 Monthly hydraulic head elevations (ft, msl) at FPZ007A and FPZ007B, January 1996 to December 2002

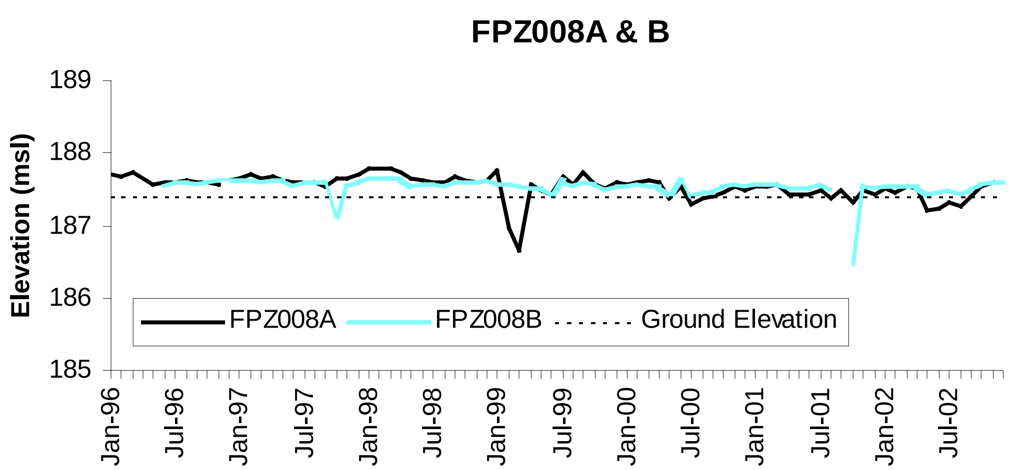


Figure 16 Monthly hydraulic head elevations (ft, msl) at FPZ008A and FPZ008B, January 1996 to December 2002

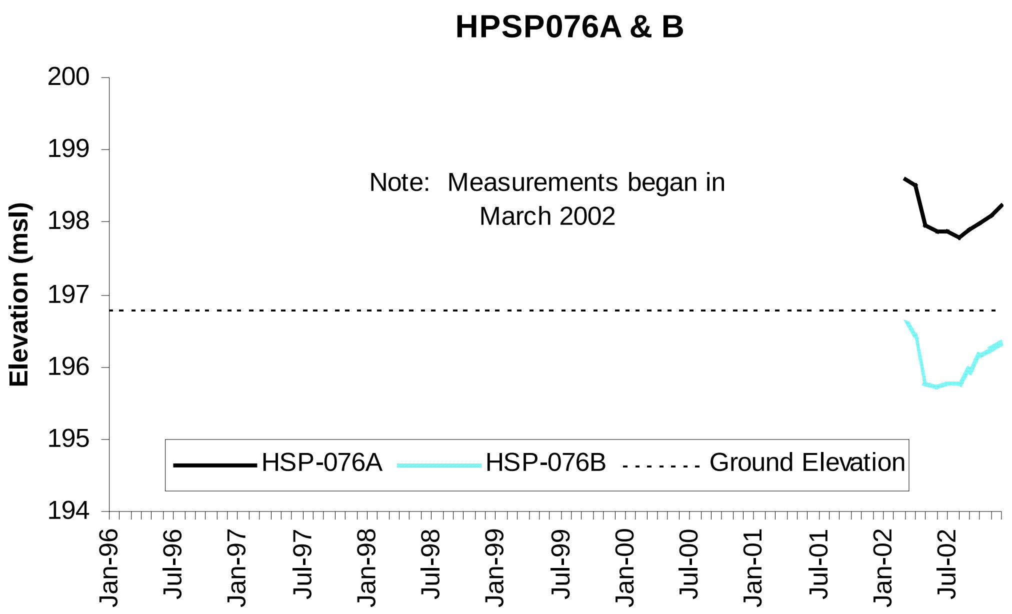


Figure 17 Monthly hydraulic head elevations (ft, msl) at HSP076A & HSP076B, through December 2002

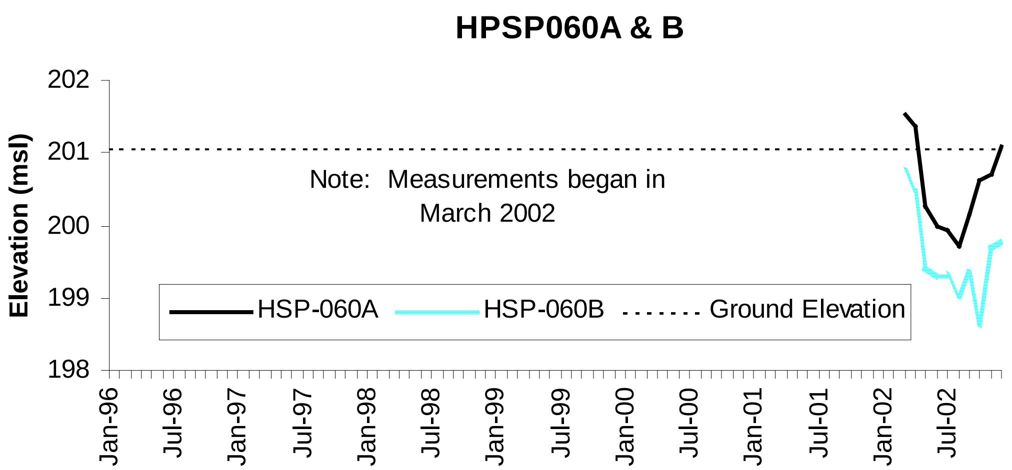


Figure 18 Monthly hydraulic head elevations (ft, msl) at HSP060A and HSP060B, through December 2002

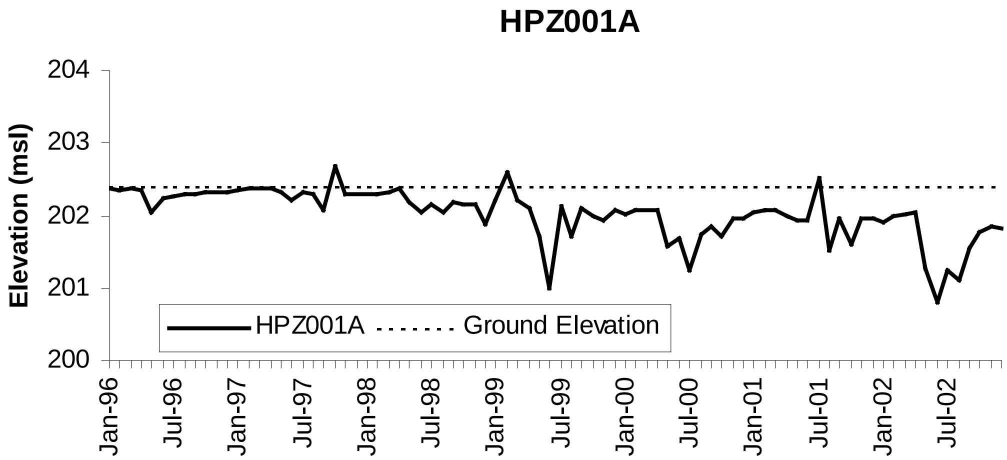


Figure 19 Monthly hydraulic head elevations (ft, msl) at HPZ001A, January 1996 to December 2002

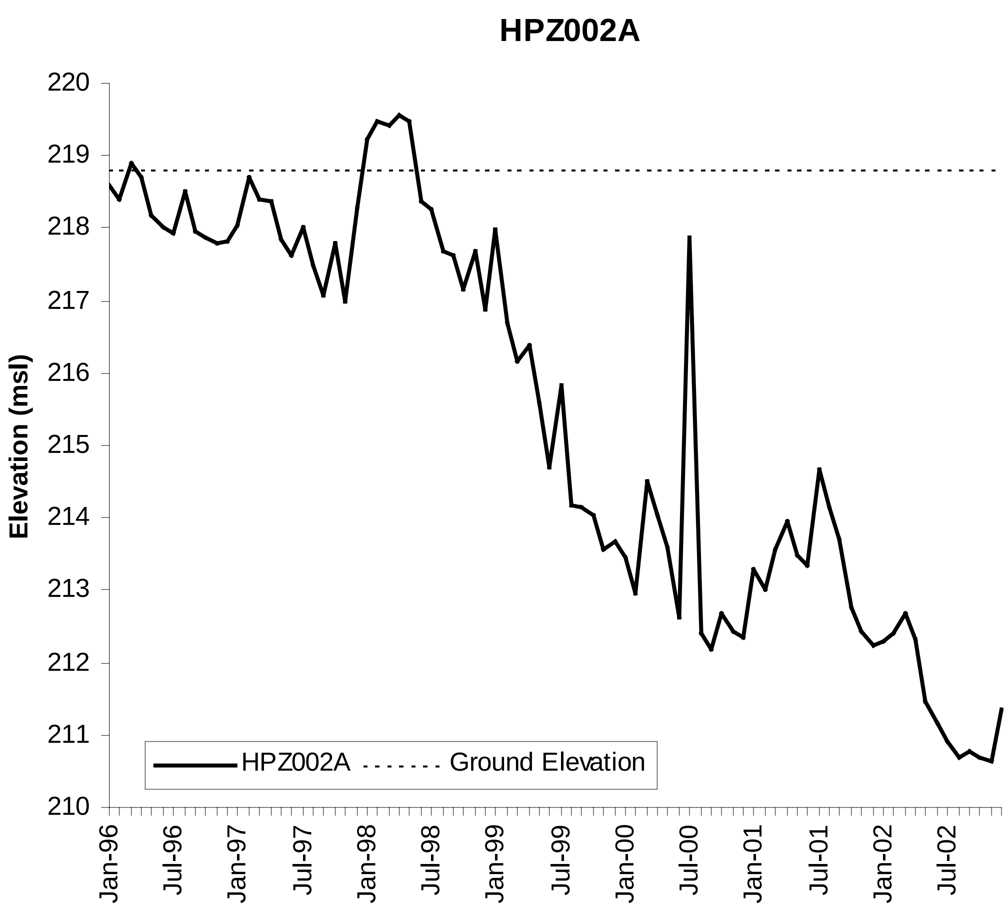


Figure 20 Monthly hydraulic head elevations (ft, msl) at HPZ002A, January 1996 to December 2002

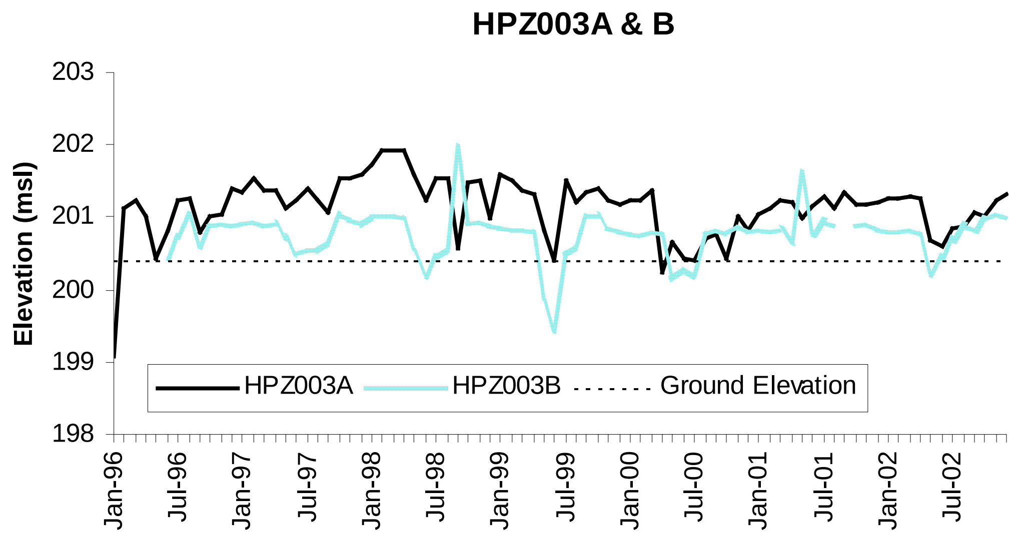


Figure 21 Monthly hydraulic head elevations (ft, msl) at HPZ003A and HPZ003B, January 1996 to December 2002

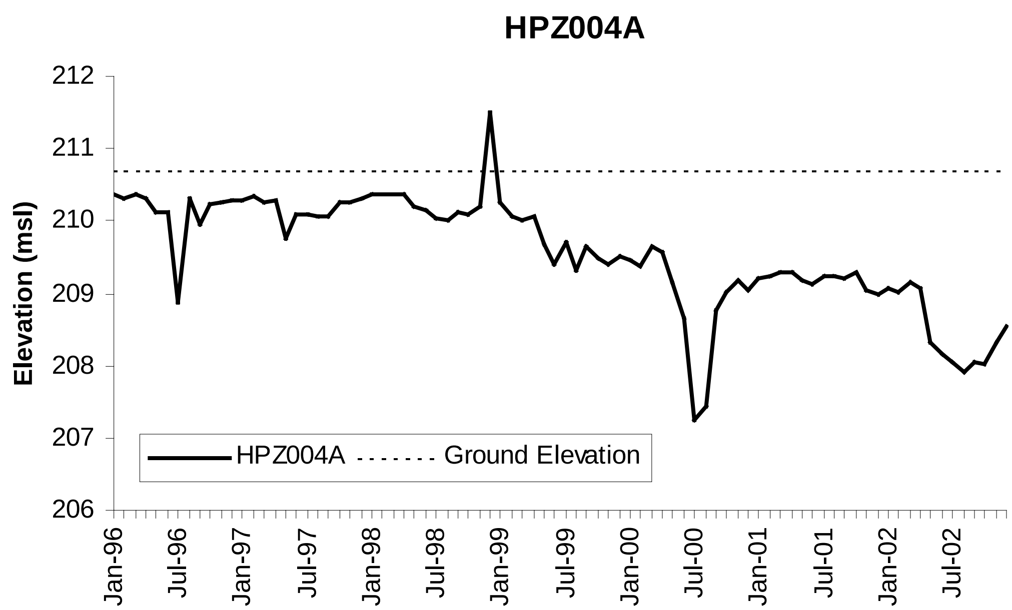


Figure 22 Monthly hydraulic head elevations (ft, msl) at HPZ004A, January 1996 to December 2002

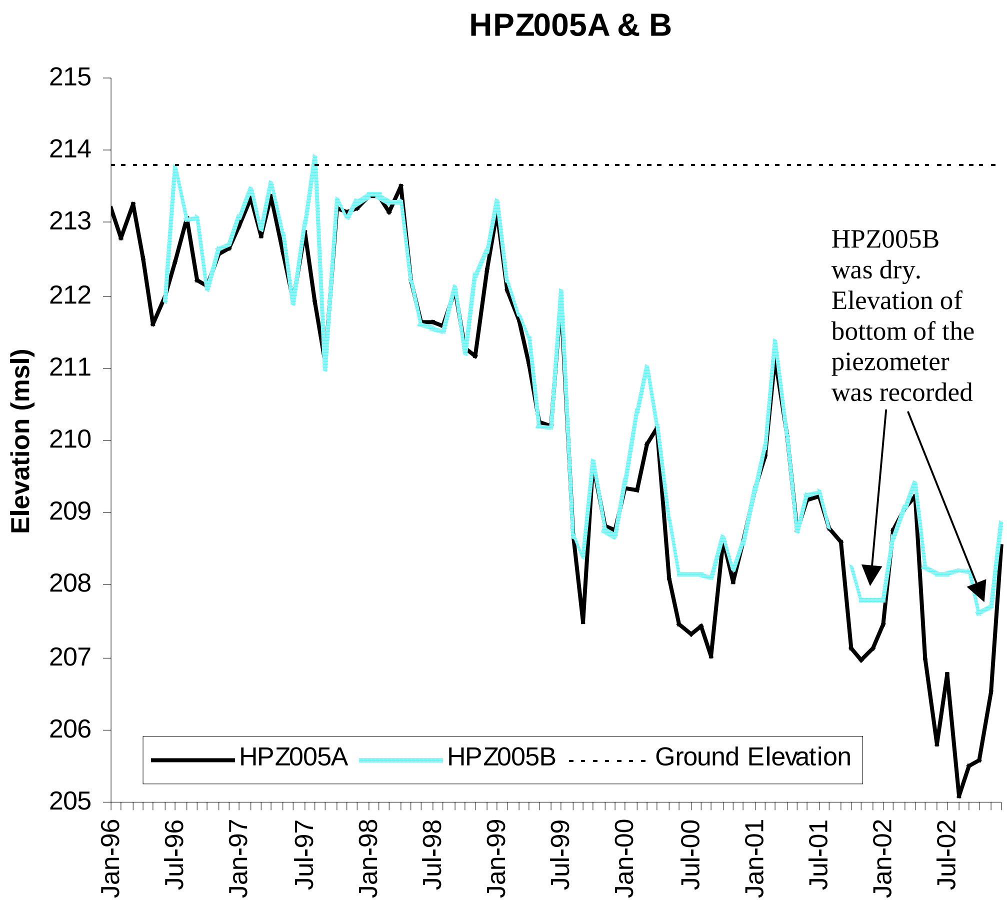


Figure 23 Monthly hydraulic head elevations at HPZ005A and HPZ005B (ft, msl), January 1996 to December 2002

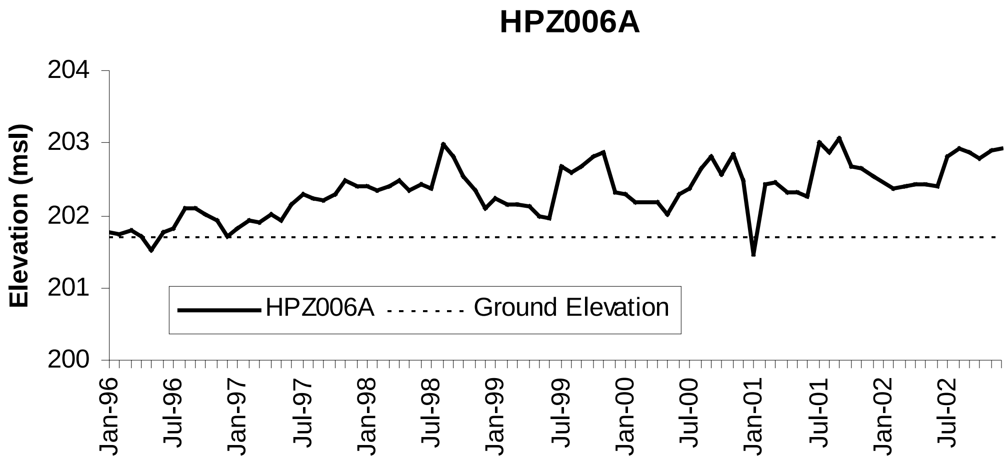


Figure 24 Monthly hydraulic head elevations (ft, msl) at HPZ006A, January 1996 to December 2002

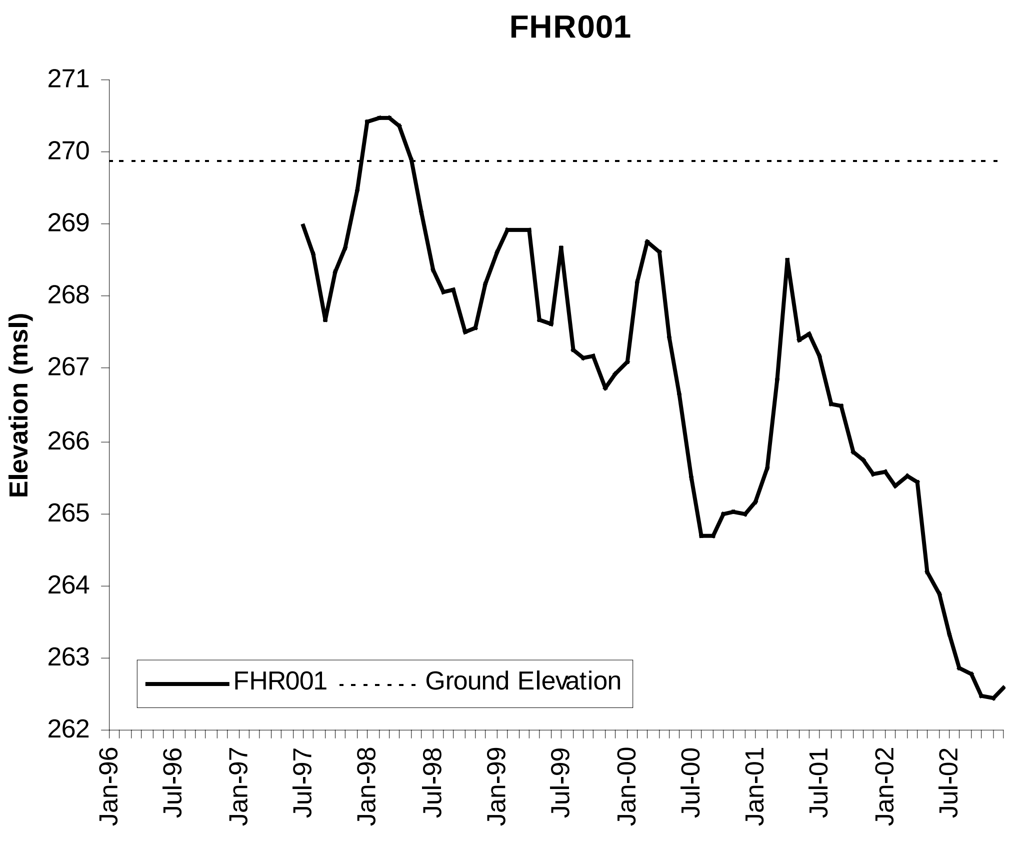


Figure 25 Monthly hydraulic head elevations (ft, msl) at FHR001, July 1997 to December 2002

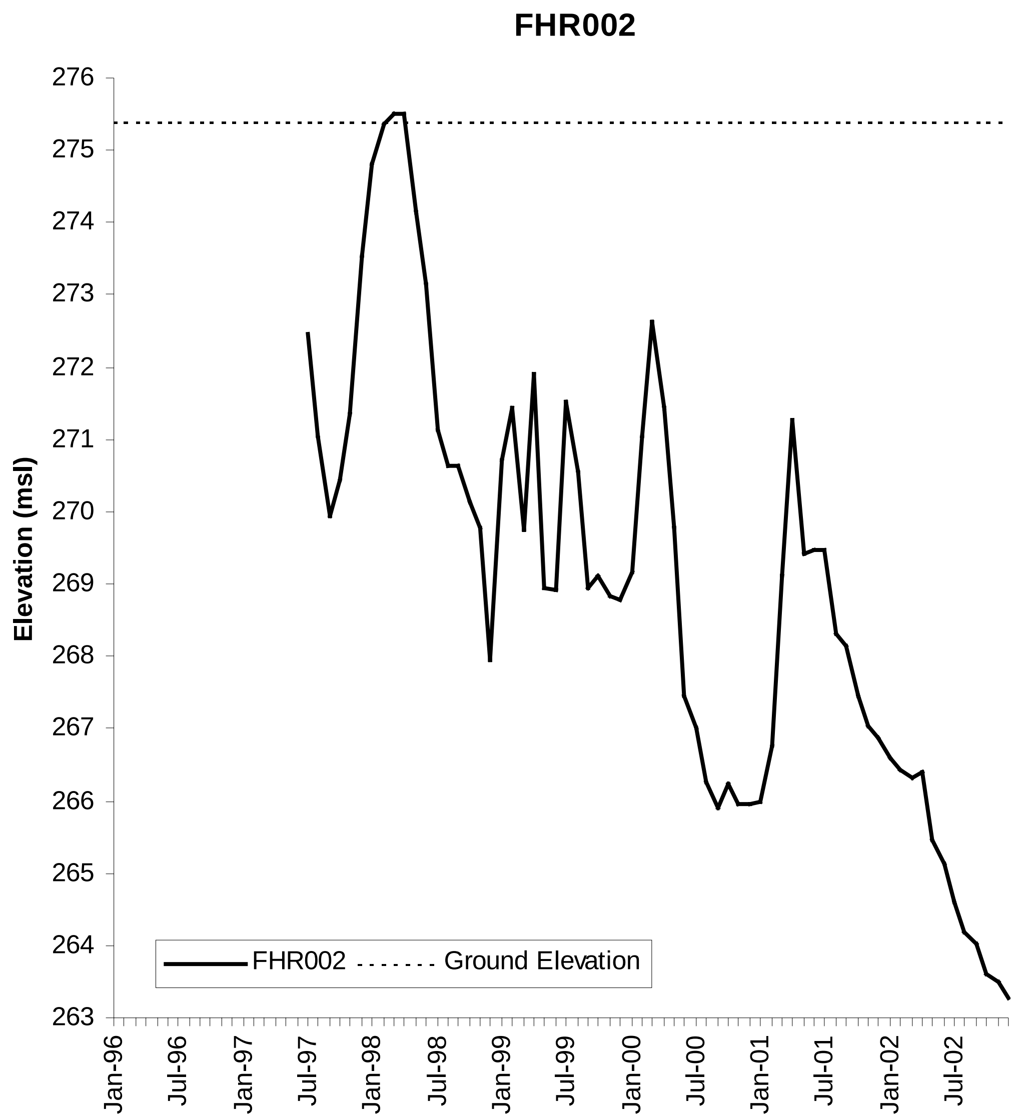


Figure 26 Monthly hydraulic head elevations (ft, msl) at FHR002, July 1997 to December 2002

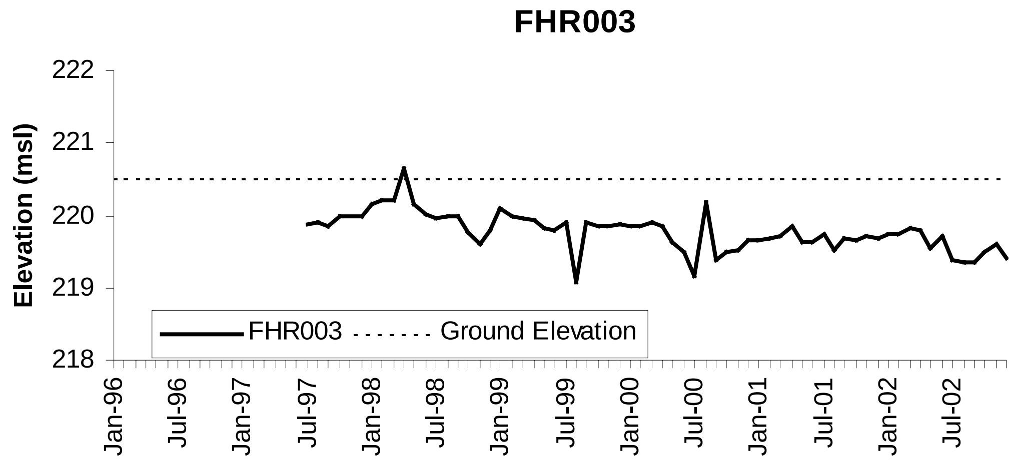


Figure 27 Monthly hydraulic head elevations (ft, msl) at FHR003, July 1997 to December 2002

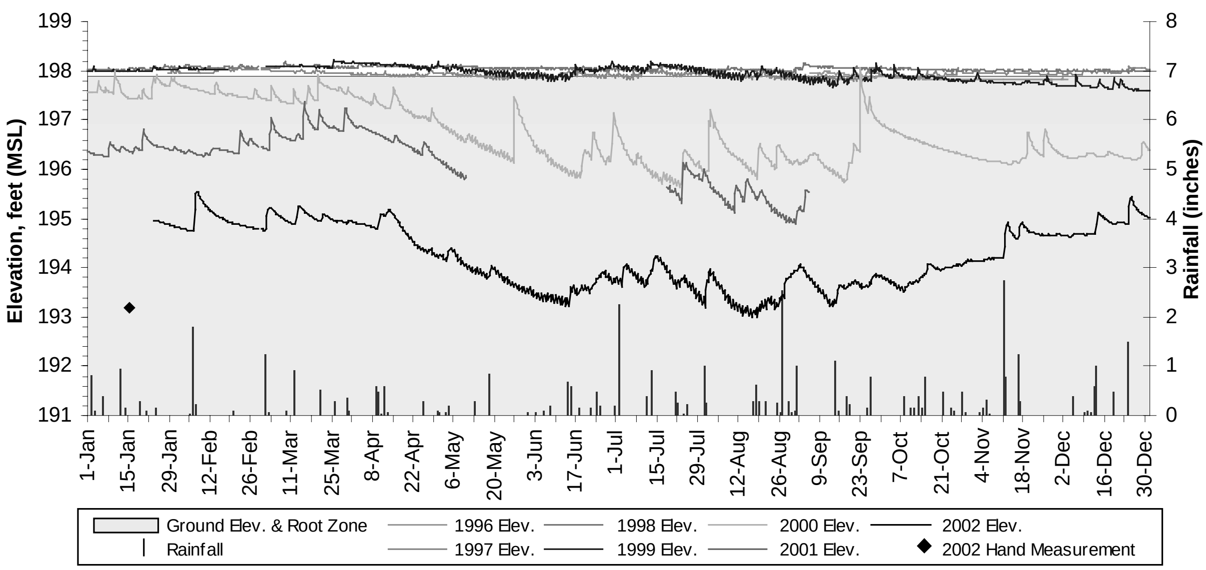


Figure 28 Comparison of hydraulic head elevation and rainfall at FPZ001A (F Area) in 2002

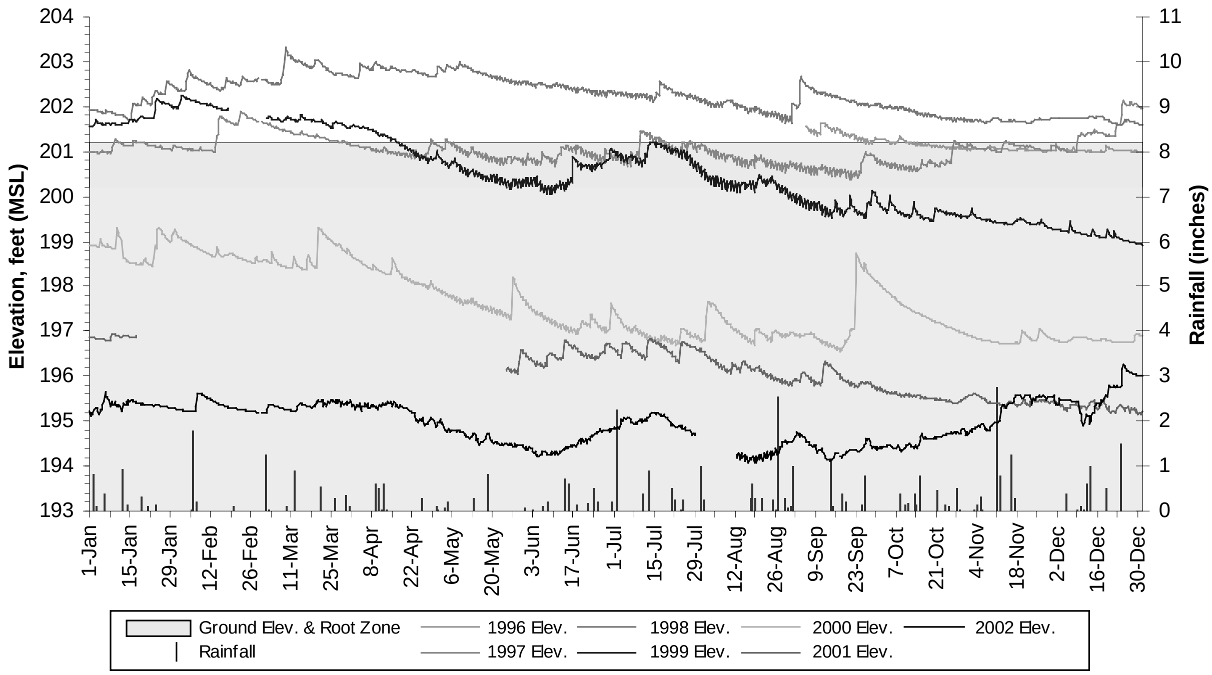


Figure 29 Comparison of hydraulic head elevation and rainfall at FPZ002A (F Area) in 2002

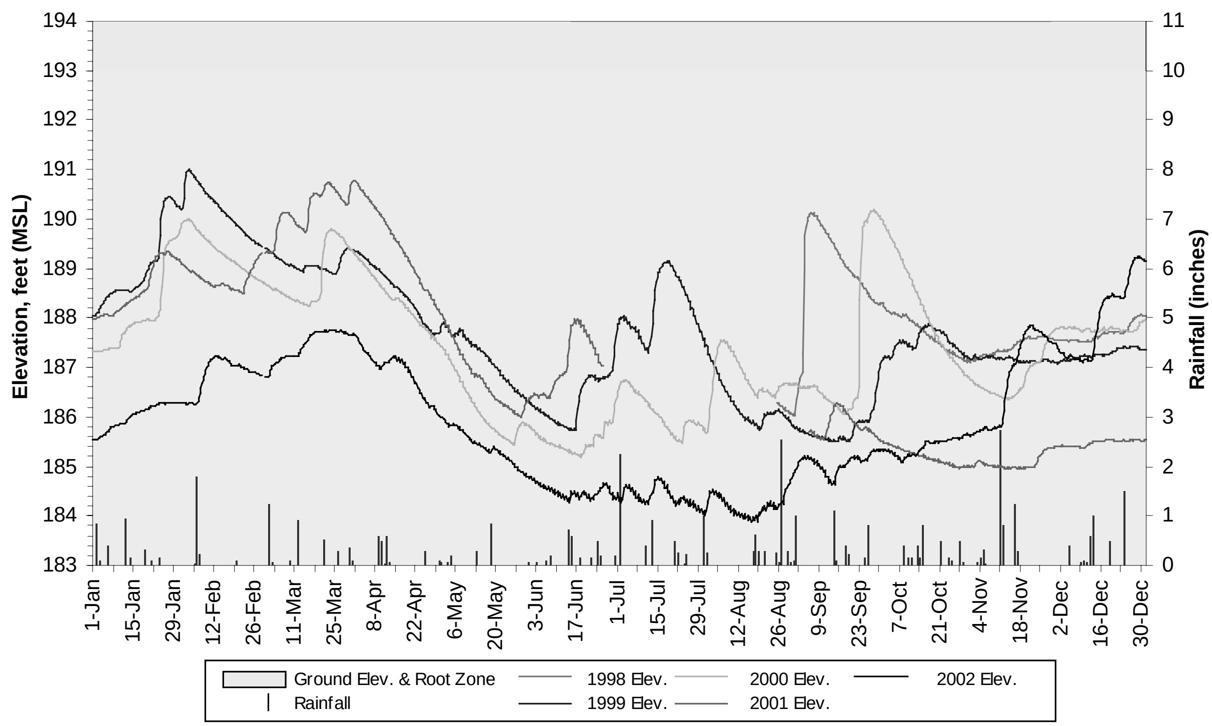


Figure 30 Comparison of hydraulic head elevation and rainfall at FPZ003A (F Area) in 2002

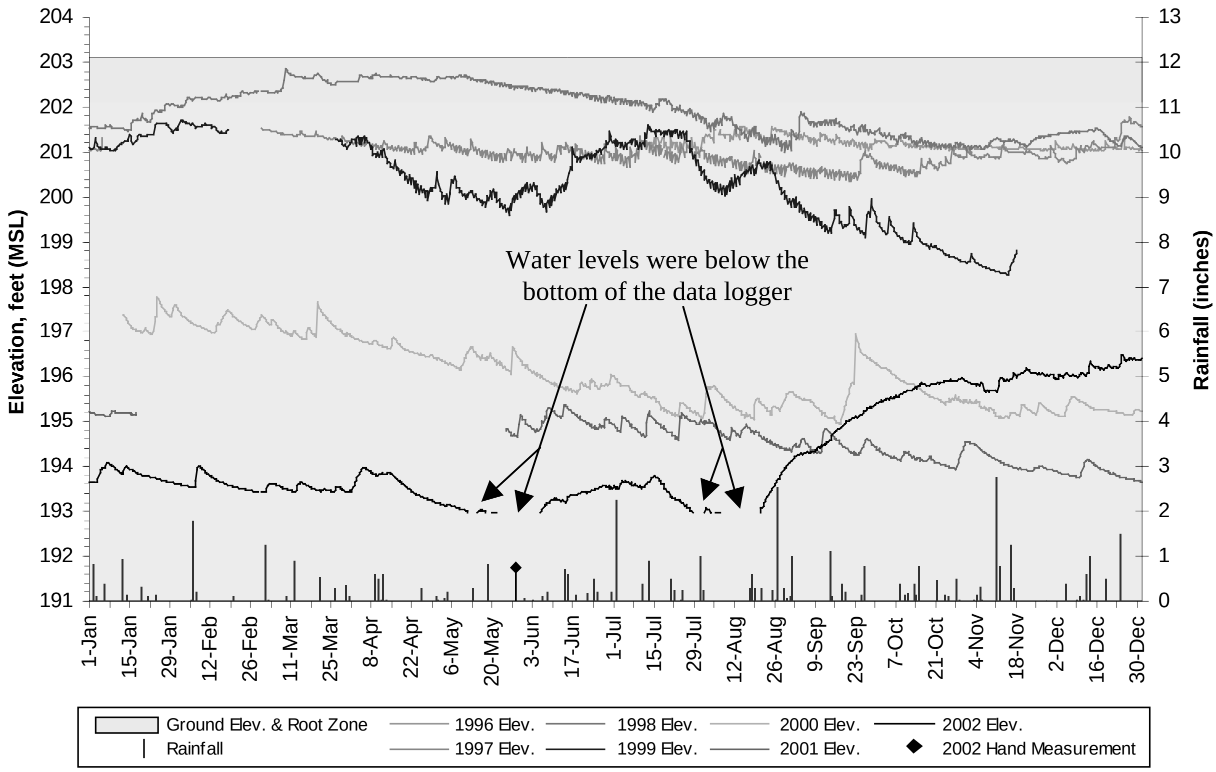


Figure 31 Comparison of hydraulic head elevation and rainfall at FPZ004A (F Area) in 2002

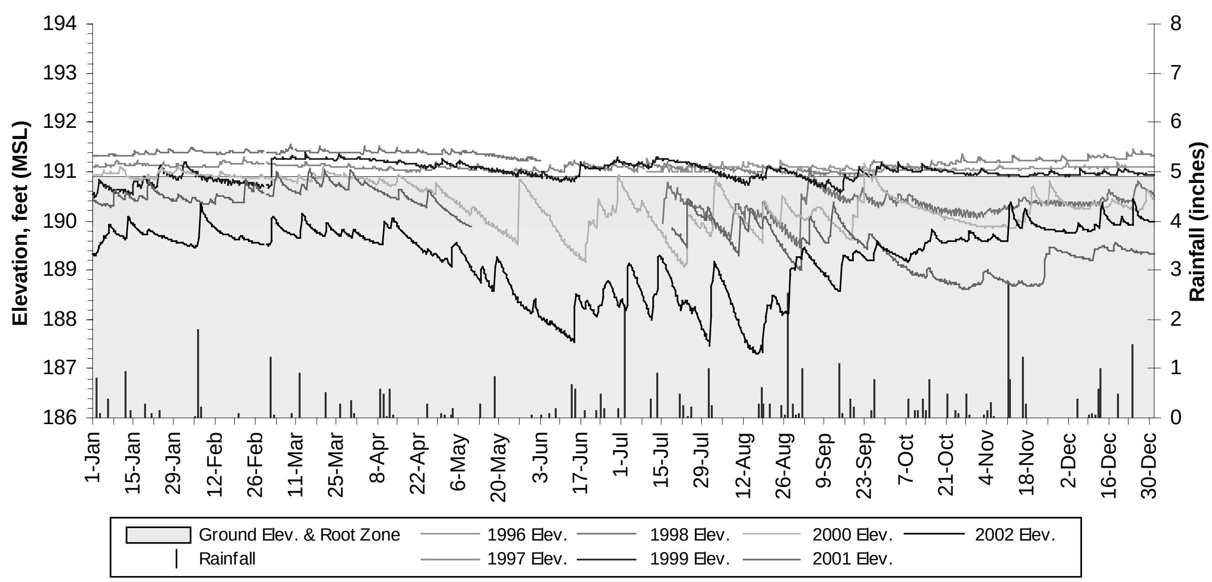


Figure 32 Comparison of hydraulic head elevation and rainfall at FPZ005A (F Area) in 2002

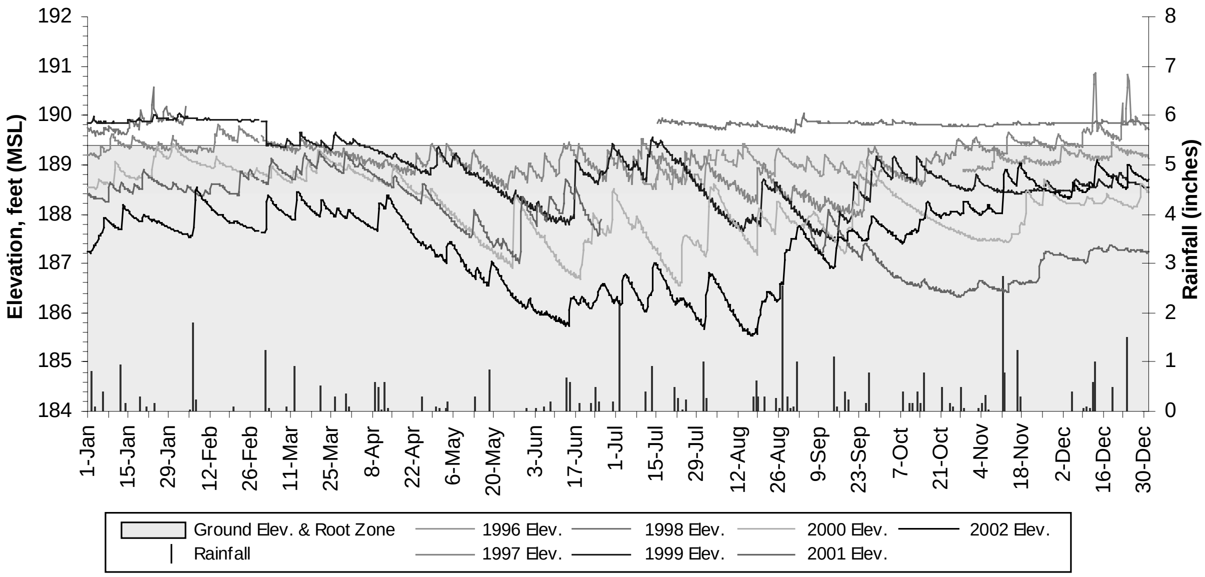


Figure 33 Comparison of hydraulic head elevation and rainfall at FPZ006A (F Area) in 2002

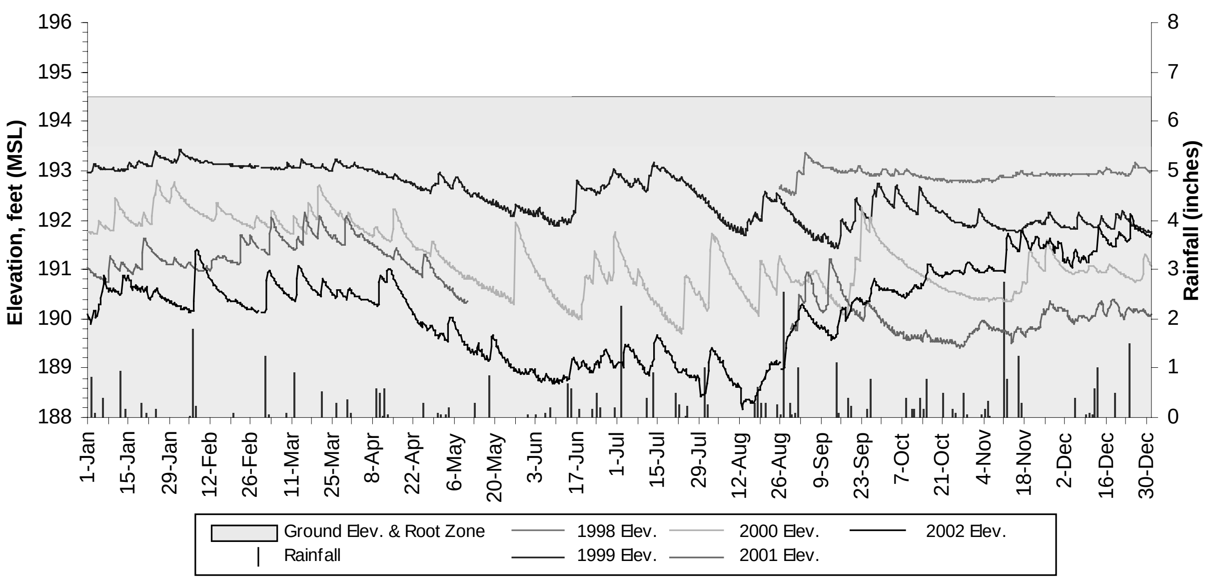


Figure 34 Comparison of hydraulic head elevation and rainfall at FPZ007A (F Area) in 2002

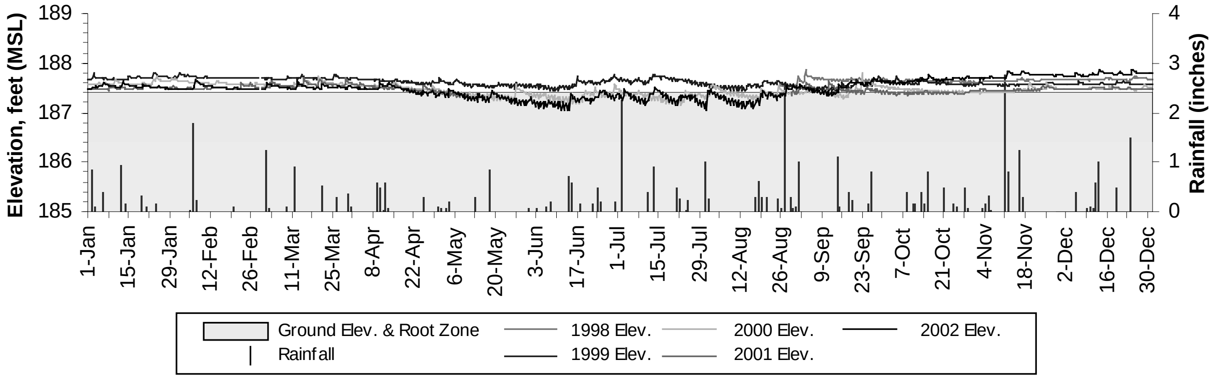


Figure 35 Comparison of hydraulic head elevation and rainfall at FPZ008A (F Area) in 2002

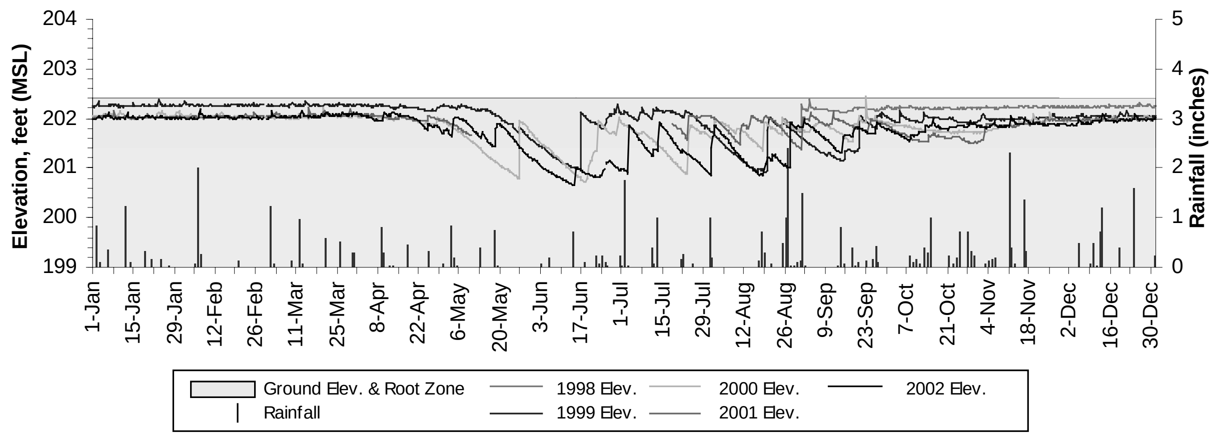


Figure 36 Comparison of hydraulic head elevation and rainfall at HPZ001A (H Area) in 2002

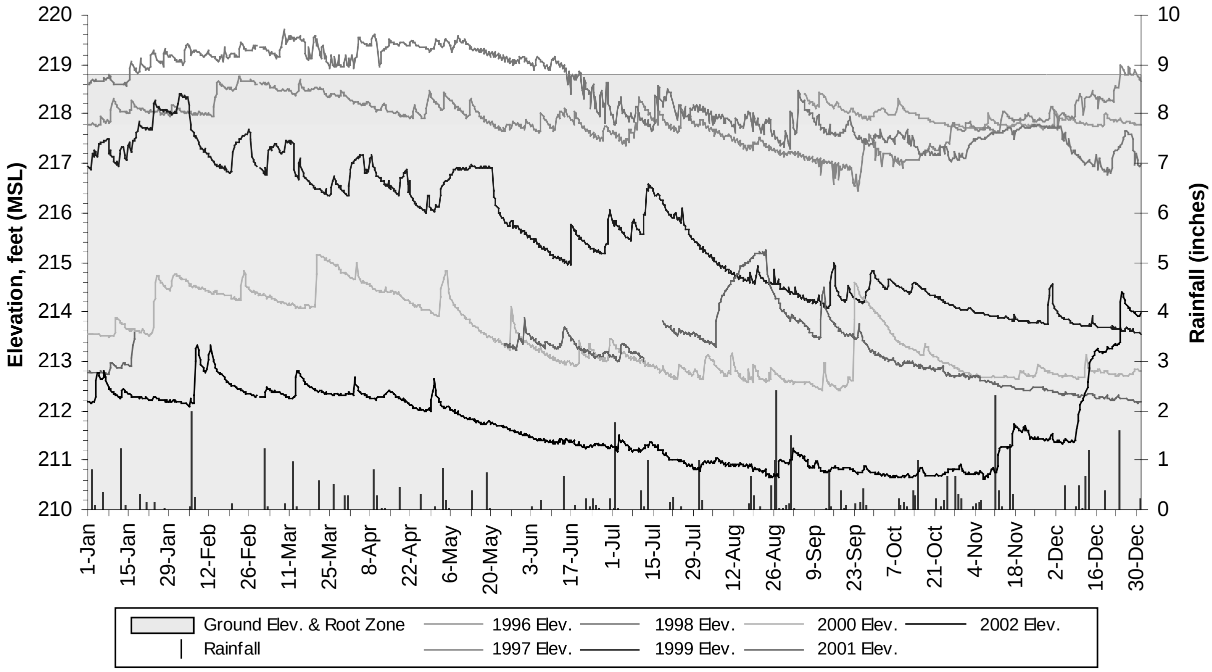


Figure 37 Comparison of hydraulic head elevation and rainfall at HPZ002A (H Area) in 2002

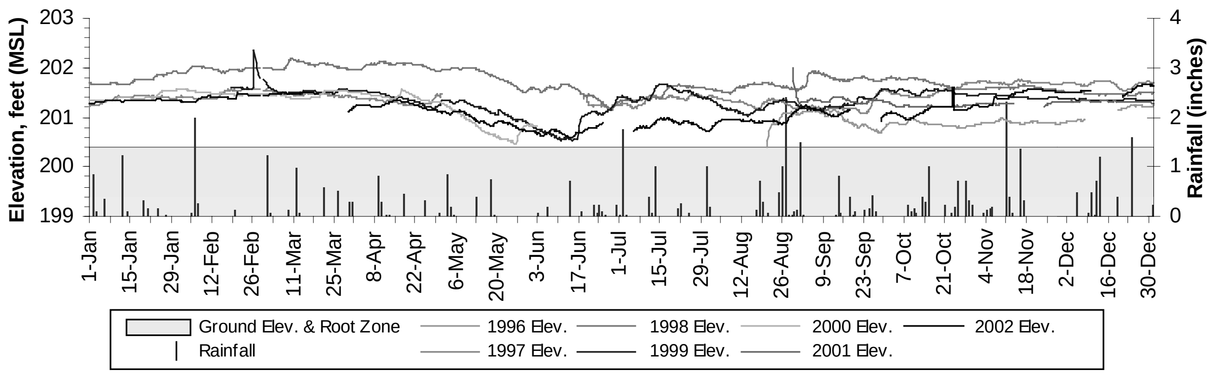


Figure 38 Comparison of hydraulic head elevation and rainfall at HPZ003A (H Area) in 2002

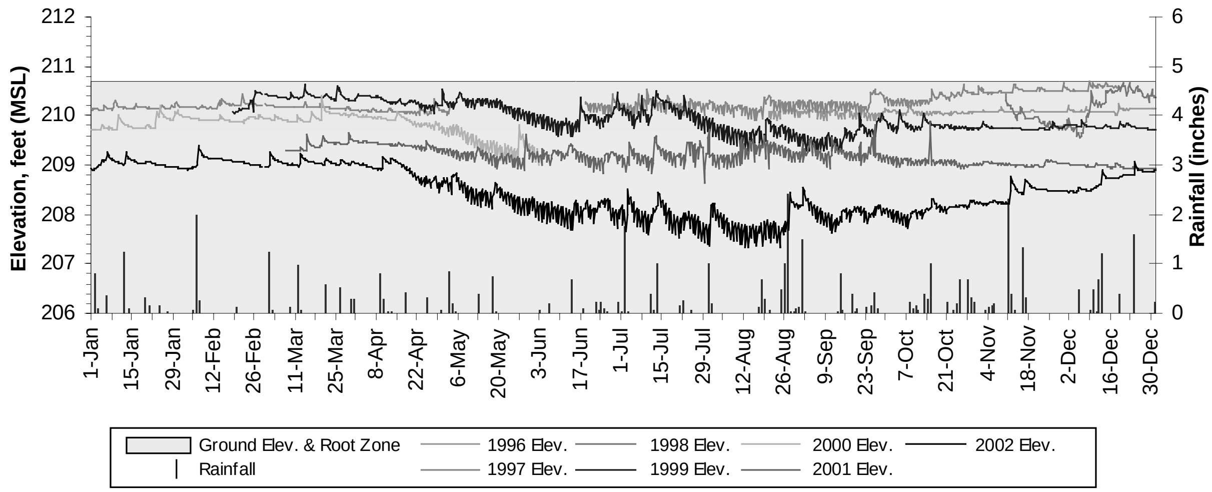


Figure 39 Comparison of hydraulic head elevation and rainfall at HPZ004A (H Area) in 2002

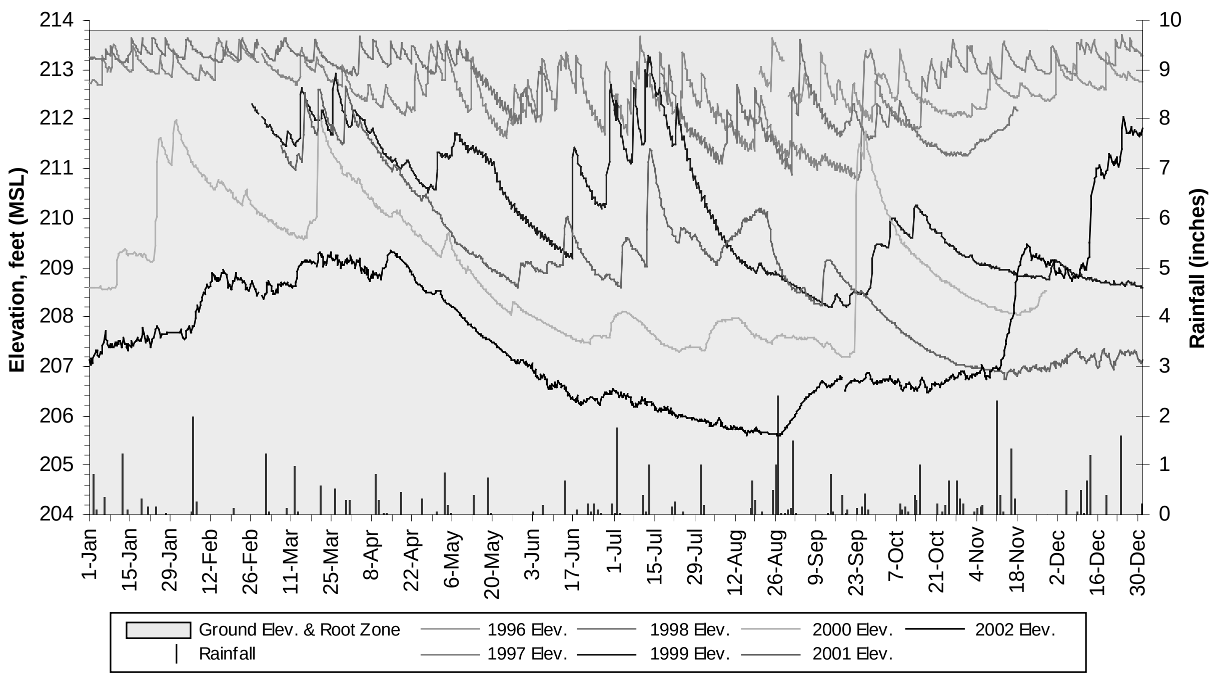


Figure 40 Comparison of hydraulic head elevation and rainfall at HPZ005A (H Area) in 2002

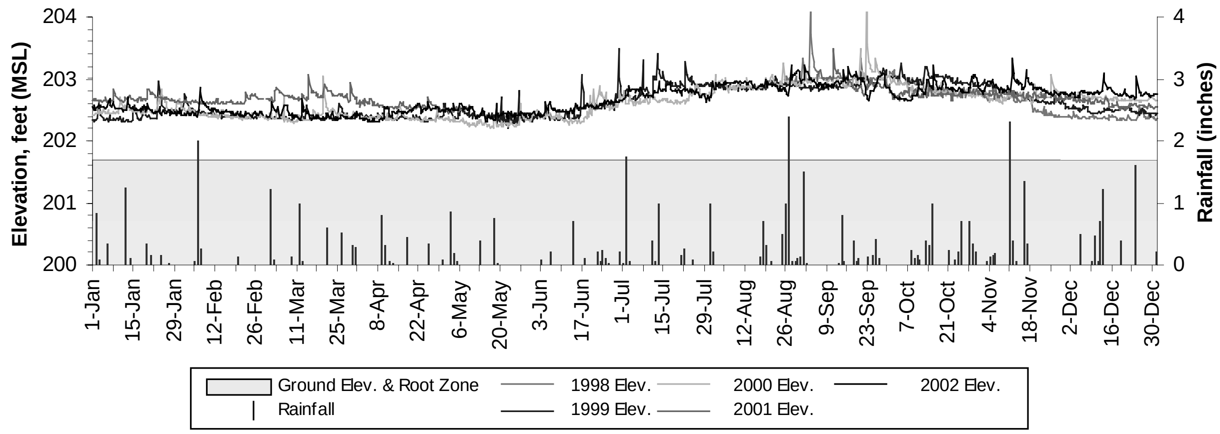


Figure 41 Comparison of hydraulic head elevation and rainfall at HPZ006A (H Area) in 2002

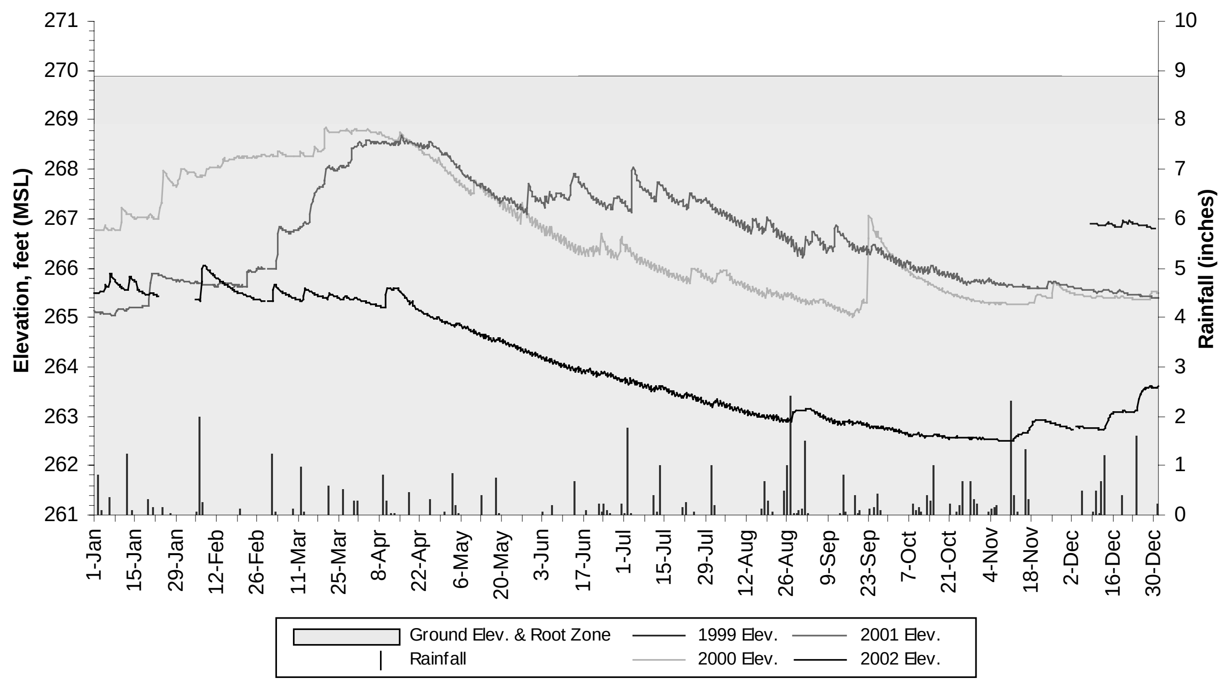


Figure 42 Comparison of hydraulic head elevation and rainfall (H Area) at FHR001 in 2002

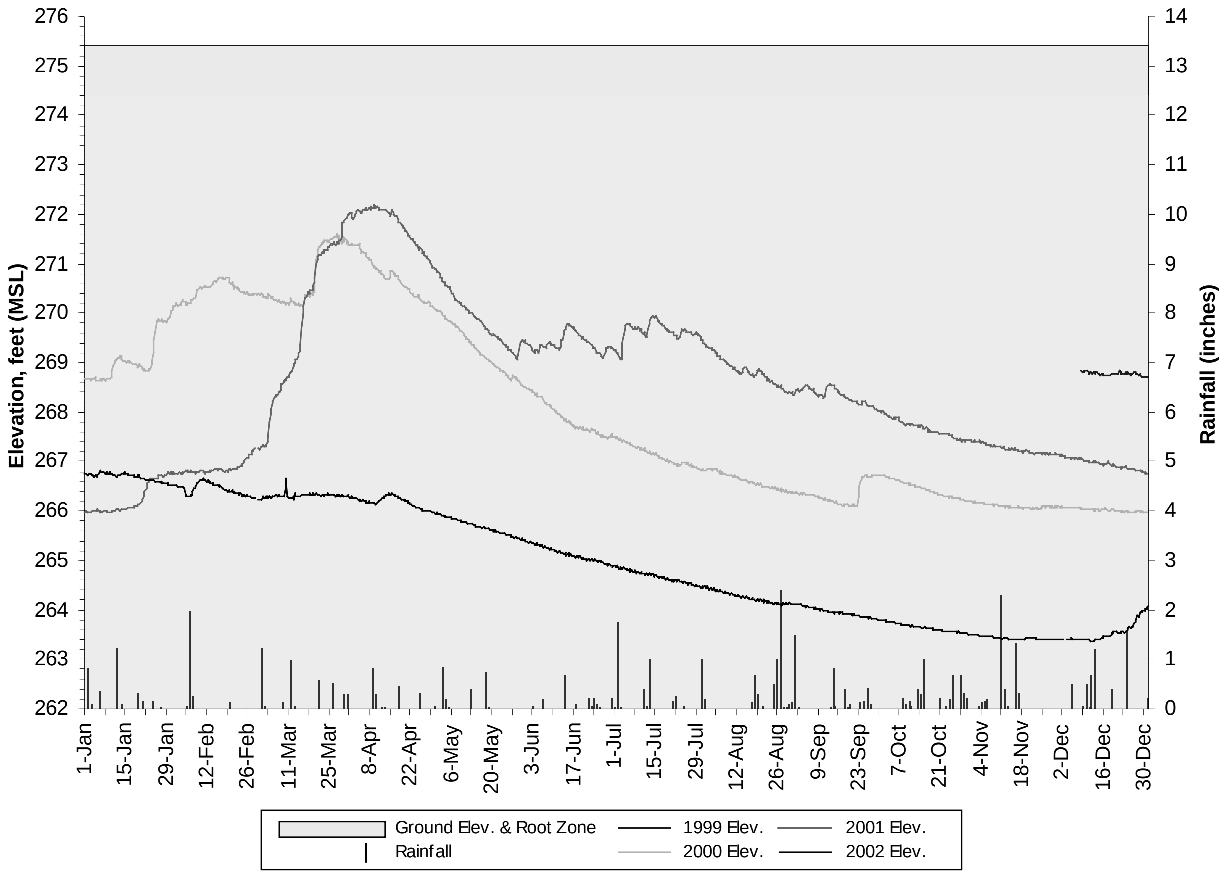


Figure 43 Comparison of hydraulic head elevation and rainfall (H Area) at FHR002 in 2002

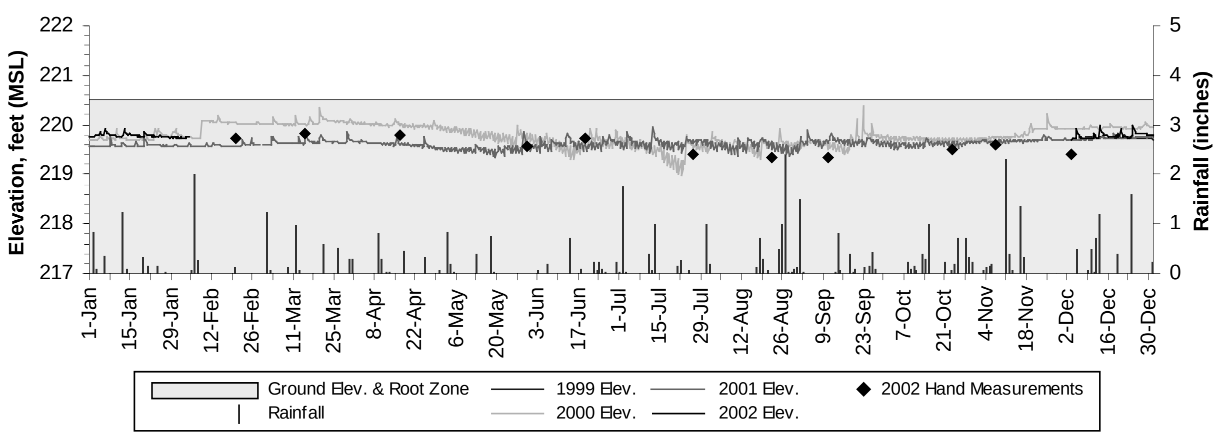


Figure 44 Comparison of hydraulic head elevation and rainfall (H Area) at FHR003 in 2002

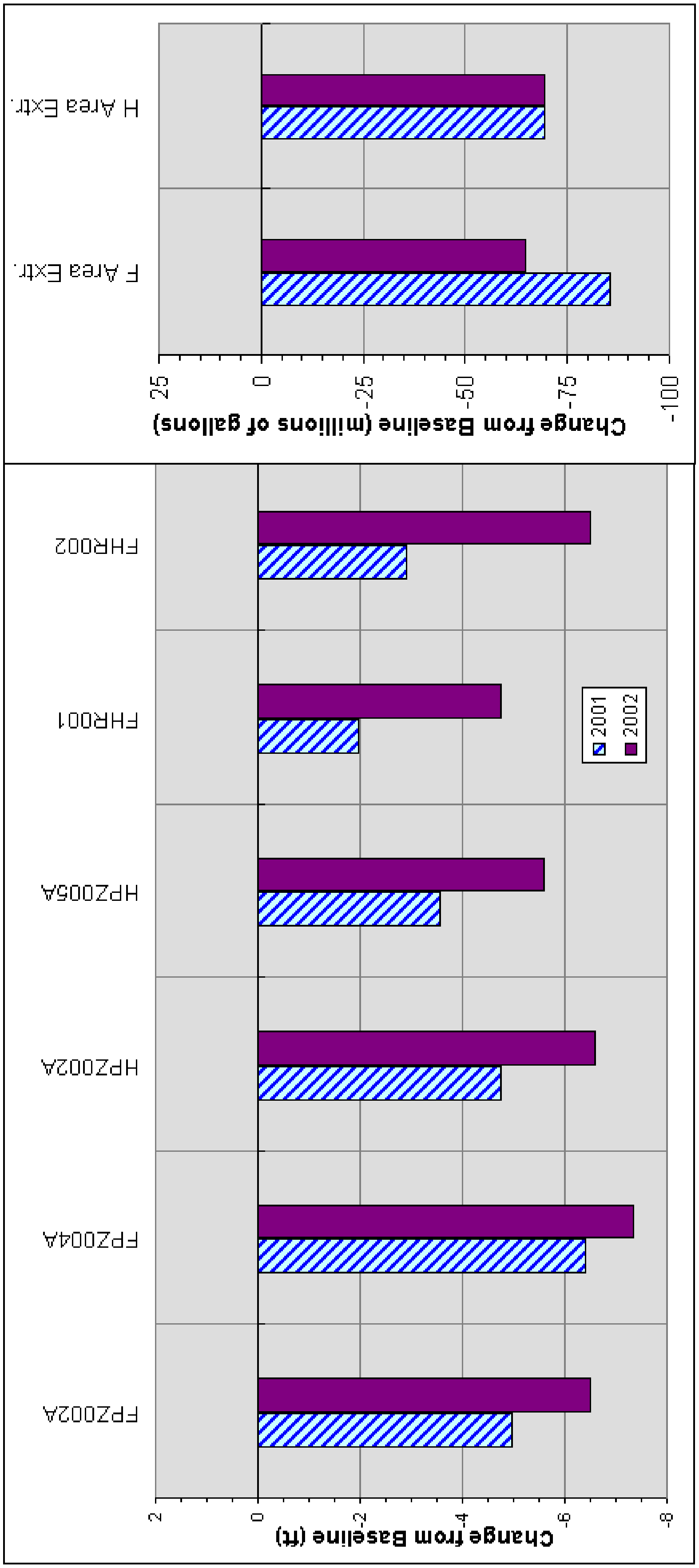


Figure 45 Changes from the baseline period for annual average hydraulic head elevations compared with groundwater extraction
Extraction is shown as negative volumes for comparison purposes.

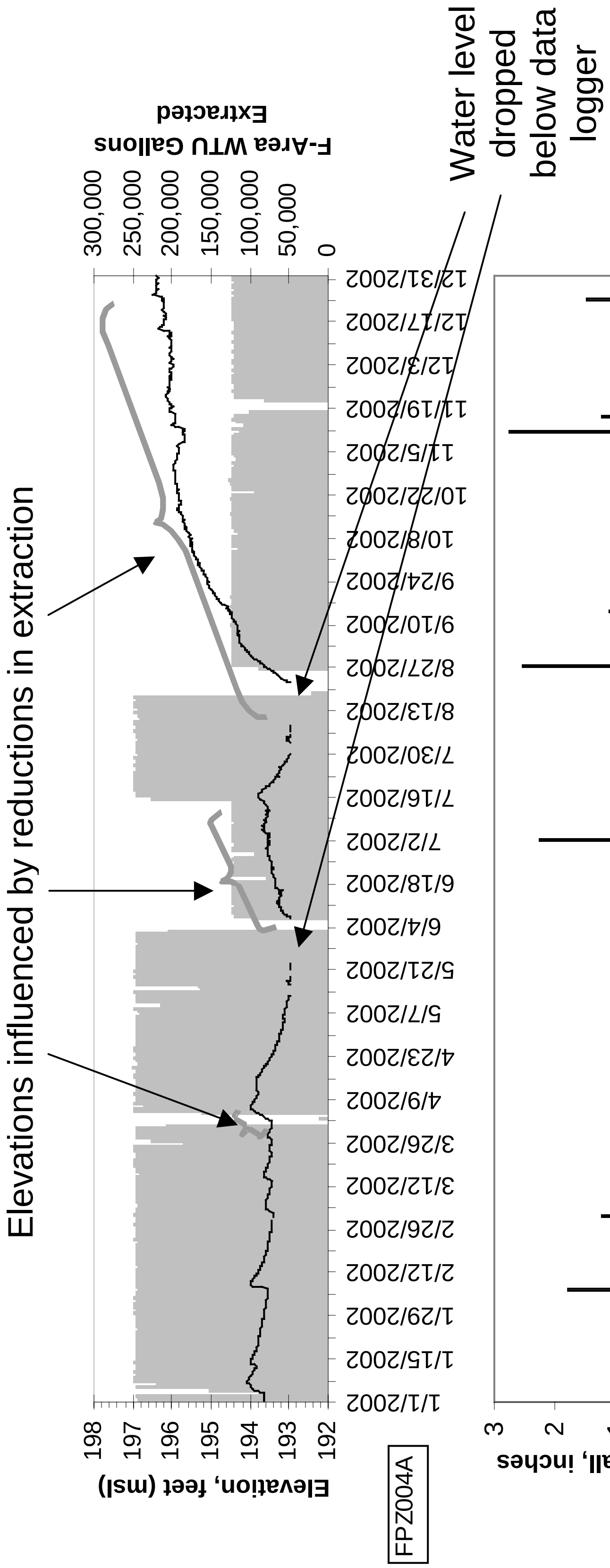


Figure 46 F-Area WTU extraction volume compared to FPZ004A hydraulic head elevations and rainfall

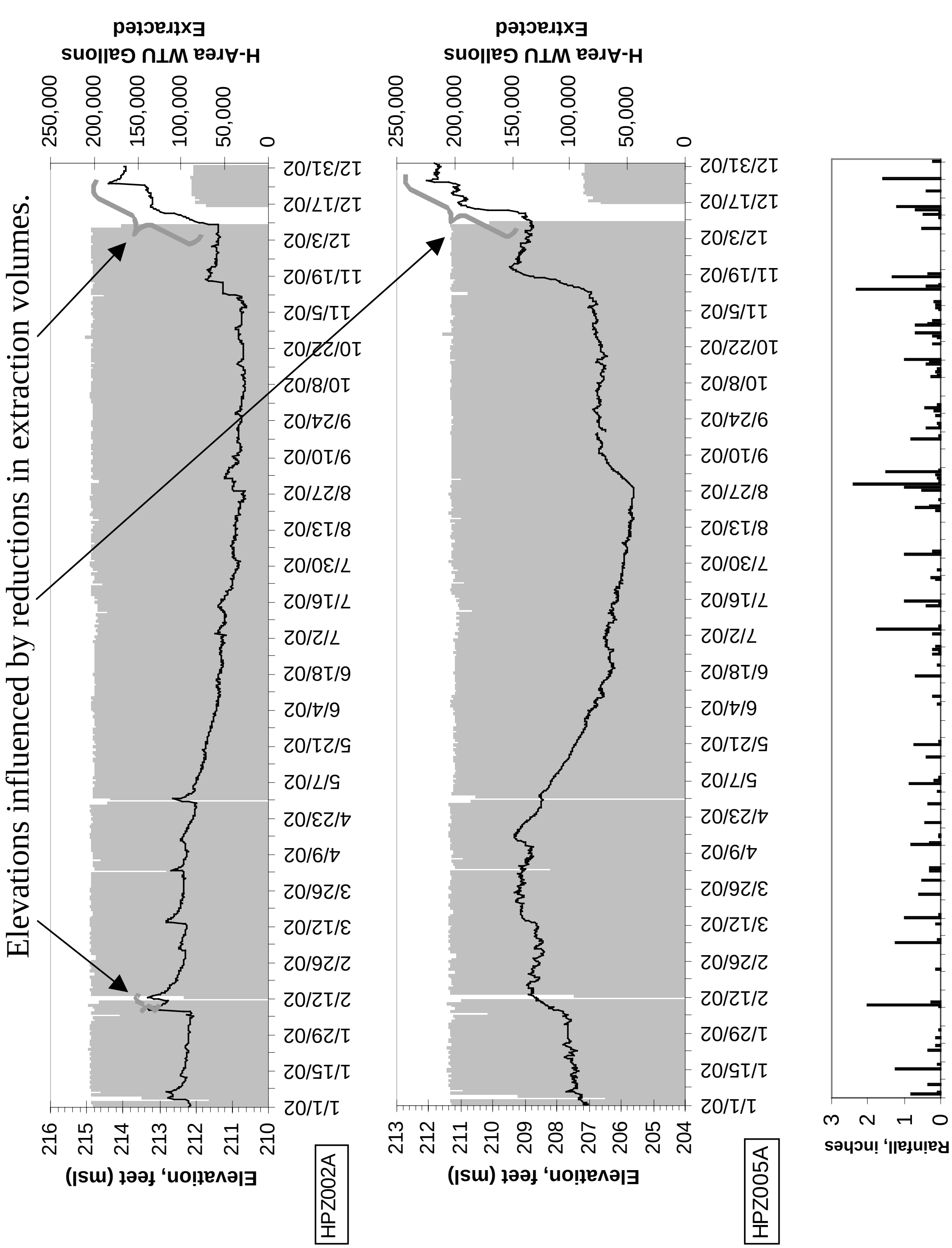


Figure 47 H-Area WTU extraction volume compared to HPZ002A and HPZ005A hydraulic head elevations and rainfall