**Monitoring of the Water Levels in the Wetlands of Fourmile
Branch near the F and H Areas of SRS: September 1997 to
December 1998**

by

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(U)**

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Monitoring of the Water Levels in the Wetlands of Fourmile Branch near the F and H Areas of SRS: September 1997 to December 1998

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Executive Summary

A network of twenty-three piezometers was used to measure hydraulic head in the water-table aquifer along the groundwater outcrop (i.e. seepage line) at the F- and H-Area seepages. The piezometers were installed to assess potential impacts of the F- and H-Area Groundwater Remediation Waste Treatment Units (WTUs) on the riparian wetland system located between the former F- and H-Area seepage basins and Fourmile Branch. Operation of the WTUs has the potential to lower the water table near the WTUs' extraction wells, potentially drying a portion of the nearby wetland areas. The piezometers were positioned specifically to target areas closest to the extraction wells. The purpose of the piezometer network is two-fold: 1) to establish baseline hydraulic head data for the water-table aquifer at the F- and H-Area seepages prior to startup of the groundwater extraction/injection remediation system, and 2) to observe the effects of the remediation system on the water table levels after system start-up.

During the period September 1997 through December 1998, water levels were measured by hand monthly at each piezometer. For the fourteen piezometers equipped with data loggers, water levels were recorded every hour or half hour in addition to the monthly hand measurements. Results from 1998 were compared to results recorded before the WTUs began operating (the pre-operational period). In addition, all results recorded since the WTUs began operating (the operational period) were compared to the pre-operational period. For F Area, January 1996 through March 1997 was used as the pre-operational period. For H Area, January 1996 through June 1997 was used as the pre-operational period. These pre-operational periods span less than two years. Thus, whereas the pre-operational period data is useful for comparing with current water levels, it is not representative of the long-term average water levels at these locations.

The changes in the piezometer water elevations in 1998 were generally small and are expected to have had insignificant effects on the wetland system between the former F- and H-Area seepage basins and Fourmile Branch. During the operational period, most piezometers measured greater fluctuations in groundwater elevations than in the pre-operational period. Overall, the average change in the 1998 water elevations, compared to the pre-operational period elevations, was a 0.28 ft increase for F-Area piezometers and a 0.32 foot decrease for H-Area piezometers. When water elevation measurements were averaged for the entire operational period, the average change was a 0.10 ft increase for F-Area piezometers and a 0.22 ft decrease for H-Area piezometers, compared to the pre-operational period elevations.

Looking at individual "A" series piezometers, some exhibited increases in the average water elevation and some exhibited decreases. For nine of the piezometers, average groundwater levels in 1998 and for the entire operational period actually increased compared to levels measured in the pre-operational period. The piezometers showing increased average water elevations were FPZ001A, FPZ002A, FPZ004A, FPZ006A, FPZ007A, FPZ008A, HPZ002A, HPZ003A and HPZ006A. These increases may be a result of increased rainfall in the operational period (an average of 4.8 inches per month for F Area and 5.0 inches per month for H Area) compared to the pre-operational period (an average of 3.9 inches per month for both areas). Only five of the piezometers recorded 1998 and operational period average water levels that were lower than pre-operational levels. These piezometers were FPZ003A, FPZ005A, HPZ001A, HPZ002A and HPZ004A.

In twelve of the fourteen "A" series piezometer locations, average 1998 water levels changed by less than one foot from the pre-operational levels. The two piezometers with a greater than one foot change were FPZ002A (1.04 ft increase) and HPZ004A (3.12 ft decrease). When water elevation measurements were averaged for the whole operational period, only HPZ004A exhibited a change of greater than six inches compared to the average pre-operational period elevation. The average water elevation at HPZ004A appears lower in 1998 than in previous years due to the wide elevation swings recorded during the period January through June 1998. The magnitude of the elevation swings and the fact that hand measurements during that period do not correlate with the data logger measurements are indicative of instrument error rather than actual changes in the piezometric head. Water elevation measurements at HPZ004A stabilized and returned to the pre-operational period level after June 1998.

Groundwater elevations have been measured monthly at three reference locations, FHR001, FHR002 and FHR003, since July 1997. Groundwater elevations at these locations during the pre-operational period are not available. The standard deviation of groundwater elevation measurements calculated at FHR002 was the highest of all the piezometer locations except HPZ004A (when calculated from the data logger measurements). At all three reference locations, groundwater elevations peaked between January and June 1998. Similar groundwater elevation peaks in the first half of 1998 were evident in most of the other piezometers. As would be expected, rainfall during this period was greater than during the latter half of 1998. The fact that most F- and H-Area piezometers recorded piezometric changes similar to those in the reference locations might indicate that the rise in groundwater levels during this period could be simply the result of natural causes.

The only information available on the pumping schedule for the WTU extraction wells at the time of this report was the total monthly volume pumped from each extraction well. From these data, it can be inferred that the WTUs were not operating steadily or at full capacity in 1998. However, the relationship between the WTU operations and the wetland ecosystem cannot be determined at this time. To determine the relative influence of rainfall and the WTUs on groundwater elevations along the seep lines, more detailed information on WTU operations, including system start-up and shut-down times and dates, and extraction rates and volumes, would be required.

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Introduction

Seepage basins in the F and H Areas of the Savannah River Site (SRS) 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 capped and sealed in 1990.

As a result of basin operations, groundwater beneath and down-gradient of the basins was contaminated. The contamination is located primarily in the water-table aquifer and in the Barnwell/McBean Aquifer. Near the seepage basins in both F and H Area, groundwater flows toward Fourmile Branch. The water-table aquifer discharges to the wetlands and Fourmile Branch whereas the Barnwell/McBean Aquifer discharges primarily to Fourmile Branch. Contaminants originating from the seepage basins have been detected in shallow groundwater outcrops (i.e. the seepage) in the wetlands along Fourmile Branch in both F and H Areas (Haselow et al., 1990; Dixon et al., 1993; Dixon and Rogers, 1993; Dixon et al., 1994).

Groundwater Remediation Waste Treatment Units (WTU) have been installed in F and H Areas in accordance with a Resource Conservation and Recovery Act (RCRA) Hazardous Waste Part B Permit. The WTUs include a network of extraction and injection wells to maintain hydraulic control of the 10,000 pCi/ml tritium plume. Figures 1 and 2 show the locations of the extraction/injection wells for the water-table aquifer (Aquifer Zone IIB₂) in F Area and H Area, respectively. The extraction well numbers have the prefix "FEX" or "HEX" and the injection well numbers have the prefix "FIN" or "HIN."

Models simulating the operation of the WTUs predicted decreases in the water level of up to five feet at the seepage and in the wetlands nearby (Dixon 1995). Decreases in water levels associated with drawdown near the extraction

wells could result in drying of a portion of the wetlands, and an overall movement of the seepage towards Fourmile Branch. Chronic depression of the water table at the wetlands, and the associated reversal in direction of groundwater flow, could alter the wetland plant and animal communities in this area. Further, changes in the hydrology of the wetlands would impact contaminant transport and contaminant concentrations at the new seepages.

Changes in water levels in and near the wetlands must be monitored to assess the impacts of the remediation system on the wetlands. To establish a baseline, hydraulic head data for the water-table aquifer at both the F- and H-Area seepages needed to be collected for a period before the groundwater extraction system began operating. Hydraulic head data collected after the extraction system began operating could be compared to the baseline data to determine whether any wetland impacts that may be observed following startup of the extraction/injection system are due to system operation or natural causes.

To accomplish this, a network of piezometers was established in 1996 in the wetlands of Fourmile Branch in both F and H Areas (Dixon, 1996). Currently, this network consists of twenty-three piezometers at seventeen different locations. The purpose of this report is to present the results of the monthly and continuous water level measurements.

Piezometer Installation and Instrumentation

A total of twenty-three water-table piezometers has been installed at seventeen locations in the wetlands of Fourmile Branch near F and H Areas since January 1996. During January and May of 1996, twenty of the piezometers were installed at fourteen locations in a network in both F (Figure 1) and H Areas (Figure 2). These piezometers have the prefixes FPZ and HPZ, respectively. The network was designed to outline the current seepage, focusing on those areas expected to be most impacted by the remediation system. At locations with

installed in clusters so that the piezometric surface could be measured for each layer. The deeper piezometers have well numbers with the suffix "A", and the shallow piezometers have the suffix "B".

During June 1997, three additional piezometers were installed in a reference area located in the wetlands of Fourmile Branch, but outside the area of influence of the remediation system. These piezometers have the prefixes FHR (Figure 3). Water level changes observed in these reference piezometers could be compared to changes observed in the FPZ and HPZ piezometers to help distinguish between natural variation and treatment system impacts.

With the exception of FPZ003A, all piezometers were installed using hand augering equipment (3 1/4" bucket auger) in accordance with WSRC-3Q5 (Chapter 7) procedures. Installation methods are detailed in Dixon (1996). Piezometer FPZ003A, which is located in an upland area, was installed using a hollow stem augering method due to the depth to the water table at this location. Table 1 gives the piezometer construction information for all the piezometers (FPZ, HPZ, and FHR series).

To investigate the natural water level variability 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. Because the frequency, magnitude, and duration of these natural variations are unknown, more frequent monitoring is required to determine these characteristics. Variation in the hydrologic system in and around the wetlands is expected to increase following startup of the extraction/injection system. Variations are expected to be more pronounced at those locations closest to the extraction wells. Thus, the piezometers closest to the extraction wells were chosen for initial instrumentation.

The piezometers selected for instrumentation are listed in Table 2 and shown in Figures 1 and 2. Table 2 also lists the date the data logger was installed for each piezometer. Each of the nine

piezometers originally selected for instrumentation was equipped with a pressure transducer (5 psig range) controlled by a Campbell Scientific, Inc. CR10X data logger. In-Situ Inc. Troll Model SP4000 data loggers were installed in the five additional piezometers selected in 1998.

Several of the Campbell data loggers malfunctioned for various periods of time. Known causes for the malfunctions included a lightning strike, animal damage to the exterior transducer cabling, battery problems stemming from animal damage to the solar panel cable, a tree falling on the equipment and other interferences. The equipment was repaired and restored to functioning each time a malfunction occurred. Additional measures, such as enclosing exterior cabling in conduit, were taken to prevent further interruptions in data collection. Other situations could cause the sensors to temporarily exceed their range, resulting in sudden very low elevation readings. Data recorded during periods when the data loggers were not functioning properly were deleted.

In early 1999, the Campbell data loggers were all replaced with Troll data loggers. The new data loggers are completely enclosed in the piezometer casing, thus increasing the probability of uninterrupted data collection.

Methods

Water levels in the piezometers were measured monthly using an electric water-level tape. From these measurements, the elevation of the water table was determined for each location. Additionally, the water level of Fourmile Branch was measured at two locations. These two stream sites were located where Road C4 and Road E1 cross Fourmile Branch.

For the piezometers equipped with data loggers, water level measurements were monitored continuously at each location and averaged every thirty minutes for the CR10X data loggers and every hour for the Troll data loggers.

Status of the Waste Treatment Units

The F-Area Groundwater Remediation WTU was in a start-up mode during the first and second quarters of 1997, operating a total of 100 hours. The facility operated in a shake-down mode during the third and fourth quarters of 1997, extracting, treating and reinjecting approximately 1.6 million gallons of water. The WTU operated only 6.8 percent of the time during that period. Flow rates were limited due to system testing, and full-operation was not initiated (WSRC 1998a). The WTU continued in the shake-down mode during first and second quarters 1998, extracting, treating and reinjecting approximately 1.5 million gallons of water. The WTU operated only 8.4 percent of the time during that period (WSRC 1998b). The F-Area Groundwater Remediation WTU did not operate during these quarters.

The shakedown mode continued for the F-Area Groundwater Remediation WTU throughout the third and fourth quarters of 1998. Approximately 12.8 million gallons of groundwater were extracted, treated and reinjected. Pumping rates still were not consistent due to significant system downtime (WSRC 1999a). The monthly volumes of groundwater treated are shown in Table 3.

The H-Area WTU also operated in a shake-down mode during the third and fourth quarters of 1997, extracting and treating and reinjecting approximately 1.2 million gallons of groundwater. Flow rates were limited due to system testing and limited injection well capacity. The WTU operated only 5.2 percent of the time during these quarters (WSRC 1998c). The WTU continued in the shake-down mode during first and second quarters 1998, extracting and treating approximately 4.2 million gallons and reinjecting about 4.1 million gallons of groundwater. The WTU operated only 16.6 percent of the time during that period (WSRC 1998d). The shakedown mode continued throughout the third and fourth quarters of 1998 as well. Approximately 10.7 million gallons of groundwater were extracted, treated and reinjected. However, pumping rates still were

not consistent due to significant system downtime (WSRC 1999b). The monthly volumes of groundwater treated are shown in Table 4.

Results and Discussion

Rainfall totals for 1996, 1997 and 1998 were 46.4, 58.9 and 55.0 inches for F Area and 44.3, 57.7 and 57.8 for H Area, respectively (Hunter 1999). Monthly rainfall calculated for the pre-operational period was 3.9 inches per month for both F and H Areas. Monthly rainfall calculated for the operational period was 4.8 inches per month for F Area and 5.0 inches per month for H Area.

Results from the monthly water level measurements for the period of September 1996 through December 1998 are presented in Table 5. Summary statistics for each location are presented in Table 6. Table 6 also presents summary statistics based on the data logger measurements for the period from September 1997 to December 1998.

These two sets of statistics were not expected to be the same because they were based on data measured two different ways. The elevation measured monthly by electric tape represents a single point in time, which may or may not be representative of the whole range of water levels for the entire month. For locations where the water elevation swings over a large range, a single monthly measurement might be taken at an extreme point of the swing, thus giving the false impression that the water level is much higher or lower than the previous month. In contrast, water elevations measured at a location where the water level does not experience much change are likely to be representative of the whole range of elevations at that location. In contrast, an individual data point from the data loggers was the calculated average water level recorded for a half-hour period. Therefore, even the measurements by the data loggers may not represent the true maximum and minimum water elevations, though they would provide a good estimate of the true average water elevation.

The greatest difference in results between the two types of measurements (i.e. manual vs. data logger) was in piezometer HPZ004A, in which the average elevation calculated from the continuous measurements was 2.6 feet lower than the elevation calculated from the monthly measurements. For the other piezometers, the average elevations calculated by the two methods differed by less than 4 inches, except for those piezometers instrumented in August 1998: FPZ003A, FPZ007A, FPZ008A, HPZ001A and HPZ006A. The piezometers instrumented in August 1998 have not recorded a full year of data, so the calculated average water elevations would not be expected to be representative of the entire year.

Table 7 compares the 1998 groundwater elevations with the elevations recorded before the WTUs began operating. All available piezometer data that preceded the startup of the WTUs was used for this comparison. For F Area, January 1996 through March 1997 was used as the pre-operational period. For H Area, January 1996 through June 1997 was used as the pre-operational period (WSRC 1997a, WSRC 1998b). These pre-operational periods span less than two years. Thus, while the pre-operational period data may be useful for comparison with current water levels, it cannot truly represent the long-term average water levels at these locations.

In general, maximum, minimum and average water levels were higher in 1998 for the F-Area "A" series piezometers than in the pre-operational period. The largest change in average elevation occurred in FPZ002A, with a rise of slightly more than one foot compared to pre-operational levels. The average change in the water elevation was a 0.28 ft increase. Only FPZ003A and FPZ005A exhibited a decrease in average water elevation. The standard deviation, which is an indicator of the variability of the elevation, was considerably higher in 1998 than in the pre-operational period for most F-Area piezometers. The maximum increase was observed in FPZ005A, where the standard deviation was eleven times the pre-operational level. On the average, the standard deviation for

F-Area piezometers in 1998 was 2.85 times the pre-operational level. Only FPZ001A and FPZ006A exhibited a decrease in standard deviation.

For the H-Area "A" series piezometers, maximum water levels were higher in 1998 than in the pre-operational period. Minimum levels decreased in most of the piezometers, but increased in HPZ003A and HPZ006A. The average water level decreased in piezometers HPZ001A, HPZ004A, and HPZ005A, and increased in HPZ002A, HPZ003A and HPZ006A. The largest change in average elevation occurred in HPZ004A, with a drop of more than three feet compared with pre-operational levels. The average change in the average water elevation was a 0.32 foot decrease. The standard deviation was considerably higher in 1998 than in the pre-operational period for most H-Area piezometers. The maximum increase was observed in HPZ004A, where the standard deviation was fifty times the pre-operational level. On the average, the standard deviation for H-Area piezometers in 1998 was ten times the pre-operational level. Only HPZ003A exhibited a decrease in standard deviation.

Table 8 compares statistics from the entire operational period with the pre-operational values. All piezometer data recorded since the WTUs started to operate was used for this comparison. For F Area, the operational period began in April 1997. For H Area, the operational period began in July 1997 (WSRC 1997a, WSRC 1998b).

Maximum and minimum water elevations were higher in F-Area "A" series piezometers after the WTUs began operations than in the pre-operational period. The average water elevation at the piezometers also increased slightly, in general, though FPZ003A and FPZ005A exhibited lower average elevations in the operational period. The largest change in average elevation occurred in FPZ002A, with a rise of 0.49 ft compared with pre-operational elevations. The average change in the average water elevation was a 0.10 ft increase. The standard deviation was considerably higher in

operational period than in the pre-operational period for most F-Area piezometers. An increase in standard deviation would be expected because of the variations introduced by sporadic operation of the WTUs. The maximum increase was observed in FPZ005A, where the operational standard deviation was nine times the pre-operational level. On the average, the standard deviation has approximately tripled for F-Area piezometers since the WTUs began operating. Only FPZ001A exhibited a decrease in standard deviation.

Maximum water elevations in H-Area "A" series piezometers were higher after the WTUs began operations than in the pre-operational period. Minimum water elevations decreased except at HPZ003A and HPZ006A. The average water elevation at the piezometers decreased in HPZ001A, HPZ004A and HPZ005A, and increased in HPZ002A, HPZ003A and HPZ006A. The largest change in average elevation occurred in HPZ004A, with a drop of more than two feet compared with pre-operational elevations. The average change in average water elevation was a 0.22 ft decrease. The standard deviation was considerably higher in operational period than in the pre-operational period for most H-Area piezometers. The maximum increase was observed again in HPZ004A, where the operational standard deviation was approximately 47 times the pre-operational level. On the average, the standard deviation rose to nine times the pre-operational level. Only HPZ003A exhibited a decrease in standard deviation.

Hydrographs for each F- and H-Area piezometer location were created from the monthly measurements and are presented in Figures 4 through 17. Hydrographs for the reference locations are shown in Figures 18 through 20. Hydrographs of the groundwater elevations based on the data logger measurements are shown in Figures 21 through 34. The latter set of figures shows groundwater elevation responses to rainfall and evapotranspiration. Each piezometer is discussed individually below.

Groundwater elevation at piezometer FPZ001A (Figure 21) varied by less than 0.5 ft over the entire monitoring period. The location was alternately wet and dry throughout 1996 and 1997. However, FPZ001A was wet throughout 1998, with the groundwater elevation near 198 ft compared to the ground elevation of 197.90 ft. The monthly measurements recorded during the period when the data logger was not functioning were consistent with the data logger measurements from the rest of the monitoring period. The average water elevation in 1998 was 0.13 ft higher than during the pre-operational period (Table 7). Diurnal variations were slightly bigger during the summer months than during the cooler months.

Groundwater elevation at location FPZ002A (Figure 22) exhibited greater variation than at FPZ001A (Figure 21). Diurnal variations were larger during the summer months, approximately May through September. Peaks coincide with periods of rainfall. Groundwater was below ground level for most of 1997, with some wet periods of up to a few weeks. However, the location was wet for all of 1998, with the piezometric surface exceeding ground levels. The average water elevation in 1998 was 1.04 ft higher than during the pre-operational period (Table 7).

Groundwater elevations (Figures 6 and 23) at FPZ003A were measured only by electric tape until August 1998, when a Troll data logger was installed. Utilizing all the measurements, the groundwater elevation at FPZ003A appears to have varied by nearly six feet. The average water elevation recorded during the monthly measurements in 1998 was 188.69 ft. The average recorded by data logger during the latter part of 1998 was 187.84 ft, while the monthly measurements for the same period averaged 187.37 ft. In general, then, the average elevation in 1998 was between 0.18 ft to 1.5 ft lower than the average elevation calculated from the pre-operational period (Table 7). Groundwater remained below ground level throughout the monitoring period.

FPZ004A (Figure 24) is the highest of the F-Area piezometer locations (203.10 ft msl) and is

the location closest to F-Area extraction wells. In general, the water level patterns were similar for FPZ004A and FPZ002A. The groundwater elevation remained below ground level through all three years. During the period when the data logger was not recording, electric tape measurements were consistent with data logger measurements before and after that period. Groundwater levels at FPZ004A exhibited less change during the period from April to June of 1998, when the F-Area WTU extraction wells were not operating, than during the rest of that year or during the same period in 1997. Diurnal variations were larger during the late summer months in 1998, after the extraction wells began operating again. The average water elevation in 1998 was 0.69 ft higher than during the pre-operational period (Table 7).

Groundwater elevation at FPZ005A (Figure 25) varied by less than seven inches from July 1996 (when measurements began) to June 1998. Groundwater elevation did not show much seasonal or diurnal change during that time. From mid-July through October 1998, groundwater elevation changes were more dramatic. Diurnal variations become more apparent. The average water elevation in 1998 was 0.27 ft lower than during the pre-operational period (Table 7).

The piezometric surface at FPZ005B (Figure 8 and Table 6) showed less variation than at FPZ005A. Measurements at FPZ005B generally followed the pattern of increases and decreases seen in FPZ005A, but were sometimes higher than and sometimes lower than the values measured in the deeper piezometer (FPZ005A). In locations with multiple layers of soil, it is not uncommon to find that the piezometric surface measured in a lower layer is actually higher than the piezometric surface measured in an upper layer. In this type of situation, the lower layer has a greater hydraulic head than the upper layer, resulting in an upward gradient in the groundwater.

FPZ006A (Figure 26) is the lowest of the F-Area piezometer locations (ground elevation 189.40 ft msl). Groundwater elevation changes

recorded during the period July 1998 to December 1998 were markedly smaller than during the rest of the monitoring period. In general, water levels appear to be higher in 1998 than in previous years. However, the long period from February 1998 to the first half of July 1998, when the data logger was not functioning due to animal damage, makes this determination difficult. During this period, monthly measurements ranged from 189.14 ft to 189.79 ft, slightly lower than elevations measured just before the data logger began to malfunction. The average water elevation in 1998 was 0.68 ft higher than during the pre-operational period (Table 7).

Measurements at FPZ006B closely followed the pattern of increases and decreases seen in FPZ006A (Figure 9). The piezometric surface measured at FPZ006B remained below the piezometric surface measured at FPZ006A in spite of the fact that FPZ006B is located in a shallower layer of soil. Again, this phenomenon could be explained by a greater hydraulic head in the lower layer of soil.

Groundwater elevations (Figures 10 and 27) at FPZ007A were measured only by electric tape until August 1998, when a Troll data logger was installed. Utilizing all the measurements, the groundwater elevation at FPZ007A appears to have varied by 1.5 feet. The average water elevation recorded during the monthly measurements in 1998 was 193.09 ft. The average recorded by data logger during the latter part of 1998 was 192.38 ft, while the monthly measurements for the same period averaged 192.92 ft. In general, then, the average elevation in 1998 was between 0.18 ft to 0.28 ft lower than the average elevation calculated from the pre-operational period (Table 7). Groundwater elevation at FPZ007A remained below ground elevation throughout the monitoring period.

The piezometric surface at FPZ007B (Figure 10) remained below ground elevation throughout the monitoring period, except in October 1998. Measurements at FPZ007B generally followed the pattern of increases and decreases seen in FPZ007A, but exhibited less variation.

Groundwater elevations (Figures 11 and 28) at FPZ008A were measured only by electric tape until August 1998, when a Troll data logger was installed. Utilizing all the measurements, the groundwater elevation at FPZ008A appears to have varied by only one foot. The average water elevation recorded during the monthly measurements in 1998 was 187.67 ft. The average recorded by data logger during the latter part of 1998 was 186.91 ft, while the monthly measurements for the same period averaged 187.62 ft. In general, then, the average elevation in 1998 was between 0.04 ft higher to 0.72 ft lower than the average elevation from the pre-operational period (Table 7).

Measurements at FPZ008B generally followed the pattern of increases and decreases seen in FPZ008A, but were sometimes higher than and sometimes lower than the values measured in the deeper piezometer (FPZ008A).

Groundwater elevations at HPZ001A (Figures 12 and 29) were measured only by electric tape until August 1998, when a Troll data logger was installed. Utilizing all the measurements, the groundwater elevation at HPZ001A appears to have varied by approximately 2.3 ft. The average water elevation recorded during the monthly measurements in 1998 was 202.17 ft. The average recorded by data logger during the latter part of 1998 was 203.93 ft, while the monthly measurements for the same period averaged 202.08 ft. In general, then, the average elevation in 1998 was between 0.14 ft lower to 1.63 ft higher than the average elevation from the pre-operational period (Table 7).

HPZ002A (Figure 30) is located at the highest elevation of all the H Area piezometers and is close to extraction wells HEX17R, HEX12, HEX 13, HEX 14, HEX 15, HEX 1 and HEX 2. Groundwater elevation at HPZ002A remained below ground elevation from August 1996 to November 1997. Groundwater elevation exceeded ground level for December 1997 and most of the first half of 1998, then dropped below ground level the latter half of 1998. The average water elevation in 1998 was 0.34 ft higher than during the pre-operational period (Table 7). The average groundwater elevation

from before and after the WTUs began operating varied by less than 0.1 ft.

The hydrograph for HPZ002A (Figure 30) shows an apparent change in pattern beginning as early as 1997. Until that time, diurnal changes and response to rainfall look similar to other locations. However, beginning in July 1997, changes in the groundwater elevation appear to be larger and more rapid. Sudden increases in levels were often not associated with rainfall. Rapid cycling of increases and decreases in groundwater elevation were evident in July, September, October and December 1997, March 1998, the period from June 1998 to October 1998 and December 1998. This cycling gives the hydrograph for HPZ002A a different appearance than in any other location.

Comparing these dates to the monthly pumping records for the extraction wells (Table 4) reveals a potential correlation. Of the wells listed above, only HEX-1, HEX-2, HEX-12 and HEX-17 were operated in 1997 and/or 1998. Pumping of the nearby extraction wells began in July 1997, a month when some rapid cycling of water levels can be seen. The extraction wells were not pumped in August, a month with a normal looking groundwater pattern. The extraction wells were operated from September through December 1997, though only a small amount of water was extracted; similarly, rapid cycling of the groundwater elevation was observed in September, October and December 1997. Only a small amount of groundwater was extracted from the nearby wells in January and February, 1998, a period with relatively natural variations in groundwater elevations. Extraction volumes increased in March and decreased again in April, with corresponding changes in the groundwater pattern. No water was pumped in May, another month with relatively natural variations in groundwater elevations. The extraction wells operated again from June through December 1998, with only a small amount of water being extracted in November, the only month during that period with relatively natural variations in groundwater elevations. However, the WTU did not appear to cause major changes in the average water elevation.

HPZ003A (Figure 31) is located farther from the extraction wells than other H-Area locations. The hydrograph for location HPZ003A appears smoother than other locations. Groundwater here was not subject to the rapid changes in elevation seen elsewhere. Hand measurements of the groundwater elevation taken during periods without continuous measurements were 201.39, 201.13 and 201.23 ft respectively (Figure 14). These elevations were consistent with data logger measurements for other months. HPZ003A groundwater elevations exceeded the ground elevation for the most of the monitoring period. The average water elevation in 1998 was 0.55 ft higher than during the pre-operational period (Table 7).

The piezometric surface measured at HPZ003B (Figure 14) remained above ground elevation throughout the monitoring period, except in June 1998. Measurements at HPZ003B generally followed the pattern of increases and decreases seen in HPZ003A. The piezometric surface at HPZ003A, the deeper piezometer, was generally higher than that at HPZ003B.

Location HPZ004A (Figure 32) is close to extraction wells HEX-3 and HEX-4. Groundwater elevations recorded by the data loggers at HPZ004A exhibited the greatest variation of any of the piezometers. As a result, the hydrograph shown in Figure 25 was generated using a different vertical scale than used for the other hydrographs. For the period from the onset of monitoring (August 1996) to December 1997, there was little variation in the groundwater level. During this period, groundwater elevation remained around 210 ft. During May and June of 1997, continuous measurements were not available, but hand measurements of 209.76 ft and 210.08 ft were recorded. These hand measurements were consistent with measurements recorded by the data logger before and after this period. In December 1997, the data loggers recorded a rapid drop of about five feet in groundwater elevation. From December 1997 through May 1998, rapid and large variations in the groundwater level were recorded at this site. Changes of nearly 20 feet within a 24 hour

period and greater than 14 feet in a one hour period were recorded. From June to December 1998, the changes were much smaller, in general, and the groundwater level gradually rose again to approximately the 210 ft level. Rapid peaks and declines in the elevation were recorded in August and November of 1998. The average water elevation in 1998 was 3.1 ft lower than during the pre-operational period (Table 7) as a result of the low elevations recorded in the first half of the year. However, the average water elevation during the second half of 1998 was 209.52 ft, less than one foot lower than in the pre-operational period.

Changes of this magnitude seen in HPZ004A between December 1997 and June 1998 are likely to be due to instrument error rather than actual changes in the piezometric head. The available F- and H-Area extraction well data (Table 4) is not extensive enough to determine any correlation with the unstable groundwater levels recorded during this period. Without daily WTU operation information, a correlation between the recorded groundwater elevations and operation of the WTUs cannot be ruled out, however. Repeated start-up and shut-down of the extraction system could partially explain the water level changes. However, monthly electric tape measurements during this period (Figure 15) do not corroborate the data logger measurements, instead indicating that the water levels may have remained near the 210 foot level. It is probable that the data logger was not functioning properly during this period.

HPZ005A (Figure 33) is close to extraction wells HEX-3 and HEX-4. Groundwater elevation at HPZ005A remained below ground elevation for the entire monitoring period. Hand measurements of the groundwater levels during those periods in which the data logger was not functioning were consistent with the data logger measurements on either end of the malfunctioning periods. The average water elevation in 1998 was 0.13 ft lower than during the pre-operational period (Table 7).

The piezometric surface measured at HPZ005B (Figure 14) remained below ground elevation throughout the monitoring period, except in

August 1997. Measurements at HPZ005B were very similar to those in HPZ005A.

Groundwater elevations (Figures 17 and 34) at HPZ006A were measured only by electric tape until August 1998, when a Troll data logger was installed. Utilizing all the measurements, the groundwater elevation at HPZ001A appeared to vary by approximately 2.2 ft. The average water elevation recorded during the monthly measurements in 1998 was 202.87 ft. The average water level calculated from data logger measurements during the latter part of 1998 was 202.73 ft, while the monthly measurements for the same period averaged 202.55 ft. In general, then, the average elevation in 1998 was between 0.58 ft to 0.86 ft higher than the average elevation calculated from the pre-operational period (Table 7). Groundwater elevation in HPZ006A remained above ground elevation throughout the monitoring period, except for the elevation measured by electric tape in May 1996.

Groundwater elevations have been measured monthly at the reference locations FHR001, FHR002 and FHR003 (Figures 18, 19 and 20) since July 1997. The pattern of groundwater elevation changes was nearly identical for FHR001 and FHR002 except for the scale; groundwater elevations ranged more than seven feet at FHR002, but only approximately three feet at FHR001. The standard deviation of groundwater elevation measurements calculated at FHR002 (Table 6) was the highest of all the piezometer locations except HPZ004A (when calculated from the data logger measurements). At all three reference locations, groundwater elevations peaked between January and June 1998. As would be expected, rainfall during this period was greater than during the latter half of 1998. Rainfall during the first half of 1998 accounted for 63% of the total rainfall in F Area and 65% of the total rainfall in H Area for 1998.

Similar groundwater elevation peaks in the first half of 1998 were evident in other piezometers. The peaks were observed clearly for FPZ002A (Figure 22), FPZ004A (Figure 24), FPZ005A (Figure 25), FPZ006A (Figure 9), HPZ002A (Figure 30), and HPZ004A (Figure 15). Peaks in

the first half of 1998 were observed to a lesser degree at HPZ003A (Figure 31) and HPZ005A (Figure 33). For FPZ003A, FPZ007A, FPZ008A, and HPZ001A, in which groundwater was measured only monthly during the first half of 1998, the hydrographs in Figures 6, 10 and 11 also show peaks in elevation during that period. In contrast with the majority of the piezometers, groundwater at HPZ006A actually peaks during the latter half of 1998. The fact that most F- and H-Area piezometers recorded piezometric changes similar to those in the reference locations might indicate that the rise in groundwater levels during this period could be simply the result of natural causes and not a result of the operation of the WTUs.

However, during the first half of 1998, the WTU extraction wells were pumping less groundwater than during the second half of 1998. Without daily WTU operation information, a correlation between the recorded groundwater elevations and operation of the WTUs cannot be ruled out.

Data collected from the continuous monitoring effort has confirmed the expected correlation between rainfall events and groundwater elevations. Figure 35 represents a typical plot of data collected from the piezometers. In general, groundwater elevation rises rapidly after a rainfall, then declines more slowly. From this figure, it can be seen that the response to rainfall was immediate as well as transient. However, more detailed study is needed to understand the magnitude and duration of the transient surge in water levels associated with rainfall.

Diurnal fluctuations in water level due to evapotranspiration are clearly shown in Figure 36. A periodic decline in water levels was observed during the middle portions of each day, which may be attributed to increased evapotranspiration demand. During the nighttime hours when evapotranspiration demands are lowest, the water levels recover. As seen in Figure 36, fluctuations of 0.1 ft were common during peak evapotranspiration periods. Diurnal changes were greater in the warmer months than in the cooler months.

Conclusions

The operation of the WTUs in the F and H Areas of SRS has the potential to lower the groundwater level near the extraction wells, potentially affecting the wetland system between the former F- and H-Area seepage basins and Fourmile Branch. However, the changes in the piezometer water elevations measured in 1998 were generally small and are expected to have had insignificant effects at this time on the wetlands (Nelson 1999). For most of the piezometers installed near the F- and H-Area seepines, groundwater levels actually increased after the WTUs began operating. These increases may be a result of increased rainfall in the operational period (an average of 4.8 inches per month for F Area and 5.0 inches per month for H Area) compared to the pre-operational period (an average of 3.9 inches per month for both areas). Sufficient information was not available to determine any correlation between the groundwater elevation increases and operation of the extraction and injection wells. Elevation trends seen in 1998 may be very different in 1999 and future years.

Overall, the average change in the 1998 water elevations, compared to the pre-operational period elevations, was a 0.28 ft increase for F-Area piezometers and a 0.32 foot decrease for H-Area piezometers. Excluding the questionable data associated with HPZ004A, the greatest decrease in average groundwater elevation in 1998 was seen in FPZ005A, with a decrease of 0.27 ft (3.2 in) from pre-operational levels. The maximum increase in average elevation in 1998 was seen in FPZ002A, which increased 1.04 ft from the pre-operational level.

Comparing statistics from the entire operational period with the pre-operational values yields similar results. The average change was a 0.10 ft increase for F-Area piezometers and a 0.22 ft decrease for H-Area piezometers. Excluding the questionable data associated with HPZ004A, the greatest decrease in average groundwater elevation in the operational period was seen in FPZ003A, closely followed by HPZ005A. Groundwater elevations at FPZ003A and

HPZ005A decreased only 0.17 ft (2 in) and 0.16 ft (1.9 in), respectively, from pre-operational levels. The maximum increase in average elevation was seen in FPZ002A, which increased 0.49 ft (5.9 in) from the pre-operational level. HPZ006A and HPZ003A followed closely with increases of 0.48 ft (5.8 in) and 0.46 ft (5.5 in), respectively.

During 1998, as well as entire operational period, most piezometers measured greater fluctuations in groundwater elevations than in the pre-operational period. Excluding the questionable data at HPZ004A, maximum and minimum elevations were as much as 2.13 ft higher and 1.54 ft lower, respectively, than in the pre-operational period.

The only information available on the pumping schedule for the WTU extraction wells at the time of this report was the total monthly volumes pumped from each extraction well. From these data, it can be inferred that the WTUs were not operating steadily or at full capacity in 1998. Thus, water elevation changes measured in 1998 may not accurately represent the changes that can be expected in the future. Without a more detailed breakdown, including system start-up and shut-down times and dates, plus extraction rates and volumes during each operating period, few conclusions can be drawn on the relative importance of rainfall versus the WTUs on groundwater elevations along the seepines.

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Table 1. Construction Information for the F- and H-Area Wetlands Piezometer Network

Piezometer	Latitude	Longitude	Ground Elevation (msl) ^b	Total Drilled Depth (ft)	Top of Casing Elevation (msl) ^b	Casing Stick Up (ft)	Total Length of Piezometer (ft)	Depth to Screen (ft)	Top of Screen Elevation (msl) ^b	Total Screened Length ^a (ft)	Length of Sump Cap (ft)	Length of Sump (ft)	Bottom of Piezometer Elevation (msl) ^b
FPZ001A	33.26827	81.68141	197.90	16.31	200.06	2.16	18.47	13.39	184.51	2.50	0.40	0	181.59
FPZ002A	33.26856	81.68131	201.20	12.27	203.41	2.21	14.48	9.35	191.85	2.50	0.40	0	188.93
FPZ003A	33.26779	81.67972	194.00	21.53	196.97	2.97	24.50	6.11	187.47	15.00	0.40	0	172.47
FPZ004A	33.27004	81.67879	203.10	11.56	205.94	2.84	14.40	8.64	194.46	2.50	0.40	0	191.54
FPZ005A	33.26910	81.67832	190.90	14.72	192.78	1.88	16.60	11.80	179.10	2.50	0.40	0	176.18
FPZ005B	33.26910	81.67832	190.90	6.95	192.88	1.98	8.93	1.95	188.95	5.00	0.40	0	183.95
FPZ006A	33.26899	81.67781	189.40	14.30	191.54	2.14	16.44	11.38	178.02	2.50	0.40	0	175.10
FPZ006B	33.26899	81.67781	189.40	7.70	191.60	2.20	9.90	2.70	186.70	5.00	0.40	0	181.70
FPZ007A	33.26978	81.67679	194.50	10.67	196.16	1.66	12.33	7.75	186.75	2.50	0.40	0	183.83
FPZ007B	33.26978	81.67679	194.50	5.40	196.40	1.90	7.30	0.40	194.10	5.00	0.40	0	189.10
FPZ008A	33.27046	81.67588	187.40	16.96	189.54	2.14	19.10	14.04	173.36	2.50	0.40	0	170.44
FPZ008B	33.27046	81.67588	187.40	10.50	189.60	2.20	12.70	3.00	184.40	7.50	0.40	0	176.90
HPZ001A	33.27431	81.65869	202.40	15.37	204.78	2.38	17.75	7.45	194.95	5.00	0.40	2.50	187.03
HPZ002A	33.27595	81.65820	218.80	12.07	220.88	2.08	14.15	6.65	212.15	5.00	0.40	0	206.73
HPZ003A	33.27452	81.65636	200.40	17.62	202.53	2.13	19.75	14.70	185.70	2.50	0.40	0	182.78
HPZ003B	33.27452	81.65636	200.40	7.43	202.80	2.40	9.83	2.43	197.97	5.00	0.40	0	192.97
HPZ004A	33.27545	81.65605	210.70	14.09	213.56	2.86	16.95	11.17	199.53	2.50	0.40	0	196.61
HPZ005A	33.27562	81.65490	213.80	9.89	215.66	1.86	11.75	6.97	206.83	2.50	0.40	0	203.91
HPZ005B	33.27562	81.65490	213.80	6.21	215.40	1.60	7.81	1.21	212.59	5.00	0.40	0	207.59
HPZ006A	33.27462	81.65424	201.70	9.41	205.29	3.59	13.00	3.99	197.71	5.00	0.40	0	192.29
FHR001	33.2691	81.62046	269.90	12.70	272.58	2.68	15.38	4.78	265.12	7.50	0.40	0	257.62
FHR002	33.2681	81.62034	275.40	17.62	277.65	2.25	19.87	7.20	268.20	10.0	0.40	0	258.20
FHR003	33.2708	81.64114	220.50	8.45	223.10	2.60	11.05	5.53	214.97	2.50	0.40	0	212.47

^a Slot size for all screens is 0.010 inches.^b msl - Elevation above mean sea level

Table 2. Piezometers with data logging equipment installed

Piezometer	Latitude	Longitude	Instrument Installation Date
FPZ001A	33.26827	81.68141	September 1996
FPZ002A	33.26856	81.68131	September 1996
FPZ003A	33.26779	81.67972	August 1998
FPZ004A	33.27004	81.67879	July 1996
FPZ005A	33.26910	81.67832	July 1996
FPZ006A	33.26899	81.67781	July 1996
FPZ007A	33.26978	81.67679	August 1998
FPZ008A	33.27046	81.67588	August 1998
HPZ001A	33.27431	81.65869	August 1998
HPZ002A	33.27595	81.65820	September 1996
HPZ003A	33.27452	81.65636	August 1996
HPZ004A	33.27545	81.65605	August 1996
HPZ005A	33.27562	81.65490	September 1996
HPZ006A	33.27462	81.65424	August 1998

Table 3. Groundwater Extraction (Thousands of Gallons) by the F-Area Groundwater Remediation Waste Treatment Unit, 1997 - 1998

Well ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997												
FEX-1	0	0	0	0.7	2	2	4	39	18	23	19	54
FEX-2	0	0	0	0.6	2	2	4	38	17	22	18	51
FEX-3	0	0	0	1	3	3	4	42	19	24	16	57
FEX-4	0	0	0	1	3	3	4	42	20	24	15	58
FEX-5	0	0	0	0.3	0.9	0.9	2	19	9	11	11	26
FEX-6	0	0	0	1	3	3	3	33	15	18	14	45
FEX-7	0	0	0	0.7	2	2	3	34	16	19	13	47
FEX-8	0	0	0	0.4	1	1	3	27	13	16	16	37
FEX-9	0	0	0	0.6	2	2	3	33	15	18	12	44
FEX-10	0	0	0	2	5	5	5	49	22	28	19	66
FEX-11	0	0	0	2	5	5	5	55	25	32	20	75
TOTAL	0	0	0	10	30	30	40	412	190	235	173	560
1998												
FEX-1	0	20	33	0	0	0	49	332	222	451	136	123
FEX-2	30	81	30	0	0	0	165	397	216	272	276	162
FEX-3	0	0	42	0	0	0	177	434	275	282	157	154
FEX-4	159	82	39	0	0	0	115	331	268	275	154	155
FEX-5	42	0.2	29	0	0	0	41	102	177	186	98	102
FEX-6	128	88	38	0	0	0	152	315	196	258	163	159
FEX-7	117	87	35	0	0	0	103	307	203	310	154	123
FEX-8	25	55	29	0	0	0	70	205	184	296	131	110
FEX-9	2	39	31	0	0	0	16	221	190	138	157	85
FEX-10	0	95	42	0	0	0	128	414	255	379	124	0
FEX-11	67	0	42	0	0	0	198	410	262	290	130	0
TOTAL	570	547	390	0	0	0	1213	3470	2447	3135	1679	1172

Sources: WSRC 1997a, WSRC 1998a, WSRC 1998b, WSRC 1999a

Table 4. Groundwater Extraction (Thousands of Gallons) by the H-Area Groundwater Remediation Waste Treatment Unit, 1997 - 1998

Well ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997												
HEX-1	0	0	0	0	0	0	3	0	121	30	5	29
HEX-2	0	0	0	0	0	0	0	0	18	0.2	1	19
HEX-3	0	0	0	0	0	0	2	0	87	21	4	22
HEX-4	0	0	0	0	0	0	3	0	108	25	5	32
HEX-9	0	0	0	0	0	0	1	0	43	11	2	9
HEX-12	0	0	0	0	0	0	1	0	24	8	1	0
HEX-16	0	0	0	0	0	0	3	0	112	27	5	27
HEX-17	0	0	0	0	0	0	3	0	115	28	0	29
HEX-18	0	0	0	0	0	0	4	0	147	38	0	33
HEX-19	0	0	0	0	0	0	0.4	0	17	4	0	6
TOTAL	0	0	0	0	0	0	19	0	793	193	24	205
1998												
HEX-1	27	124	300	48	0	232	34	147	90	186	6	315
HEX-2	0	0	0	0	0	23	0	0	0	0	0	0
HEX-3	21	109	285	45	0	116	320	343	412	442	25	315
HEX-4	27	117	285	50	0	198	273	229	388	300	0	106
HEX-9	14	89	69	37	0	44	186	101	263	119	6	172
HEX-12	0.8	0	78	18	0	48	170	132	192	111	12	141
HEX-16	26	116	291	0	0	141	368	264	399	498	7	183
HEX-17	3	0	189	48	0	143	491	332	577	527	7	497
HEX-18	0	0	388	52	0	235	143	147	0	0	17	310
HEX-19	14	43	45	14	0	47	157	110	173	115	10	39
TOTAL	133	599	1930	313	0	1227	2141	1806	2493	2298	90	2077

Sources: WSRC 1997b, WSRC 1998c, WSRC 1998d, WSRC 1999b

Table 5. Water Levels Measured by Electric Water-Level Tape at Individual Piezometers, September 1997 to August 1998

Piezometer ID	Water Level Elevations (msl)												Ground Elevation (msl)
	Sep-97	Oct-97	Nov-97	Dec-97	Jan-98	Feb-98	Mar-98	Apr-98	May-98	June-98	July-98	Aug-98	
FPZ001A	197.88	197.96	197.96	197.91	198.06	198.06	198.06	198.06	198.06	198.06	198.06	198.01	197.90
FPZ002A	200.56	201.11	201.01	201.31	202.21	202.51	202.71	202.69	202.51	202.27	202.08	201.73	201.20
FPZ003A	186.12	189.32	190.07	190.82	191.97	191.77	191.77	188.02	189.25	187.09	187.57	186.33	194.00
FPZ004A	200.59	200.84	200.94	201.04	201.89	202.29	202.54	202.59	202.43	202.17	201.82	201.39	203.10
FPZ005A	190.96	191.13	191.18	191.13	191.28	191.28	191.28	191.28	191.18	191.07	191.09	191.00	190.90
FPZ005B	191.16	191.13	191.13	191.18	191.21	191.23	191.18	191.18	191.17	191.09	191.30	191.17	190.90
FPZ006A	188.14	189.34	189.34	189.49	189.74	189.79	189.74	189.69	189.14	188.66	189.14	188.60	189.40
FPZ006B	187.72	189.05	189.05	189.15	189.25	189.20	189.20	189.15	188.79	188.09	188.40	188.09	189.40
FPZ007A	192.48	193.16	193.11	193.16	193.41	193.46	193.46	193.39	193.11	192.66	193.06	192.75	194.50
FPZ007B	194.15	194.25	194.30	194.40	194.40	194.40	194.40	194.45	194.40	194.32	194.35	194.30	194.50
FPZ008A	187.54	187.64	187.64	187.69	187.79	187.79	187.79	187.74	187.64	187.63	187.60	187.58	187.40
FPZ008B	187.58	187.10	187.55	187.60	187.65	187.65	187.65	187.64	187.55	187.57	187.56	187.55	187.40
HPZ001A	202.08	202.68	202.28	202.28	202.28	202.28	202.33	202.38	202.19	202.04	202.16	202.05	202.40
HPZ002A	217.08	217.78	216.98	218.28	219.23	219.48	219.43	219.57	219.47	218.37	218.27	217.67	218.80
HPZ003A	201.08	201.53	201.53	201.58	201.73	201.93	201.93	201.93	201.58	201.23	201.53	201.53	200.40
HPZ003B	200.65	201.05	200.95	200.90	201.00	201.00	201.00	200.99	200.53	200.19	200.43	200.57	200.40
HPZ004A	210.06	210.26	210.26	210.31	210.36	210.36	210.36	210.37	210.21	210.14	210.05	210.02	210.70
HPZ005A	211.09	213.21	213.16	213.21	213.36	213.36	213.16	213.51	212.21	211.62	211.64	211.57	213.80
HPZ005B	210.98	213.30	213.10	213.25	213.40	213.40	213.30	213.29	212.19	211.59	211.56	211.50	213.80
HPZ006A	202.21	202.29	202.49	202.39	202.39	202.34	202.39	202.48	202.34	202.43	202.36	202.98	201.70
FHR001	267.69	268.33	268.68	269.48	270.43	270.48	270.48	270.36	269.88	269.18	268.36	268.07	269.90
FHR002	269.93	270.45	271.35	273.55	274.80	275.35	275.50	275.49	274.15	273.15	271.14	270.63	275.40
FHR003	219.84	220.00	220.00	220.00	220.15	220.20	220.20	220.65	220.15	220.02	219.95	219.99	220.50

Table 6. Average, Maximum and Minimum Water Levels Measurements from September 1997 to December 1998

Piez. ID	Monthly Hand Measurements					Continuous Measurements				
	Min. Water Level (msl)	Max. Water Level (msl)	Avg. Water Level (msl)	Stand. Dev. (ft)	Water Level Rel. to Ground Elev. ^a (ft)	Min. Water Level (msl)	Max. Water Level (msl)	Avg. Water Level (msl)	Stand. Dev. (ft)	Water Level Rel. to Ground Elev. ^a (ft)
FPZ001A	197.88	198.19	198.02	0.07	0.12	197.79	198.21	198.01	0.06	0.11
FPZ002A	200.56	202.71	201.83	0.64	0.63	200.38	203.36	201.94	0.68	0.74
FPZ003A ^b	186.12	191.97	188.79	1.99	-5.21	186.01	190.12	187.84	0.86	-6.16
FPZ004A	200.59	202.59	201.62	0.64	-1.48	200.35	202.89	201.64	0.66	-1.46
FPZ005A	190.96	191.28	191.14	0.10	0.24	189.45	191.57	190.92	0.50	0.02
FPZ005B	191.09	191.3	191.17	0.05	0.27	-	-	-	-	-
FPZ006A	188.14	190.19	189.25	0.53	-0.15	187.94	192.64	189.57	0.50	0.17
FPZ006B	187.72	189.88	188.84	0.54	-0.56	-	-	-	-	-
FPZ007A ^b	192.48	193.46	193.07	0.29	-1.43	191.95	192.86	192.38	0.12	-2.12
FPZ007B	194.15	194.66	194.36	0.11	-0.14	-	-	-	-	-
FPZ008A ^b	187.54	187.79	187.66	0.08	0.26	186.76	187.14	186.91	0.03	-0.49
FPZ008B	187.10	187.65	187.57	0.13	0.17	-	-	-	-	-
HPZ001 ^b A	201.87	202.68	202.21	0.18	-0.19	203.44	204.13	203.93	0.08	1.53
HPZ002A	216.88	219.57	218.18	0.98	-0.62	216.39	219.74	218.19	0.83	-0.61
HPZ003A	200.58	201.93	201.48	0.36	1.08	201.07	202.18	201.68	0.23	1.28
HPZ003B	200.19	201.98	200.87	0.39	0.47	-	-	-	-	-
HPZ004A	210.02	211.51	210.29	0.35	-0.41	197.67	218.76	207.70	3.41	-3.00
HPZ005A	211.09	213.51	212.37	0.90	-1.43	210.78	213.71	212.59	0.80	-1.2
HPZ005B	210.98	213.40	212.44	0.87	-1.36	-	-	-	-	-
HPZ006A ^b	202.09	202.98	202.43	0.21	0.73	202.33	204.30	202.73	0.28	1.03
FHR001	267.51	270.48	268.92	1.11	-0.98	-	-	-	-	-
FHR002	267.95	275.50	272.12	2.42	-3.28	-	-	-	-	-
FHR003	219.59	220.65	220.02	0.24	-0.48	-	-	-	-	-

^a Positive values indicate that the water level was higher than ground level. Negative values indicate that the water level was lower than ground level.

^b Continuous data for these piezometers represent only 5 months of measurements and were not considered to be representative.

Table 7. Comparison of the 1998 Piezometer Water-Level Statistics with the Pre-Operation Period ^a

Piezometer	<u>Maximum</u>			<u>Minimum</u>			<u>Average</u>			<u>Standard Deviation</u>		
	Pre-Op. Period ^b	1998	Difference ^c	Pre-Op. Period ^b	1998	Difference ^c	Pre-Op. Period ^b	1998	Difference ^c	Pre-Op. Period ^b	1998	Difference ^c
FPZ001A	198.10	198.21	0.11	197.80	197.95	0.15	197.91	198.04	0.13	0.08	0.04	-0.04
FPZ002A	201.91	203.36	1.45	200.97	201.58	0.61	201.21	202.25	1.04	0.22	0.42	0.20
FPZ003A	191.22	191.97	0.75	187.07	186.33	-0.74	188.87	188.69	-0.18	1.18	2.05	0.87
FPZ004A	202.46	202.89	0.43	200.90	200.98	0.08	201.21	201.90	0.69	0.15	0.54	0.39
FPZ005A	191.30	191.57	0.27	190.99	189.45	-1.54	191.09	190.82	-0.27	0.05	0.56	0.51
FPZ006A	189.81	191.94	2.413	188.50	189.59	1.09	189.15	189.83	0.68	0.26	0.08	-0.18
FPZ007A	193.34	193.46	0.12	192.66	192.66	0.00	193.02	193.09	0.07	0.17	0.28	0.11
FPZ008A	187.72	187.79	0.07	187.56	187.58	0.02	187.63	187.67	0.04	0.05	0.08	0.03
HPZ001A	202.38	202.38	0.00	202.05	201.87	-0.18	202.31	202.17	-0.14	0.08	0.14	0.06
HPZ002A	218.78	219.74	0.96	217.44	216.72	-0.72	218.03	218.37	0.34	0.27	0.82	0.55
HPZ003A	201.58	202.18	0.60	200.38	201.12	0.74	201.18	201.73	0.55	0.26	0.22	-0.04
HPZ004A	210.47	218.76	8.29	209.90	197.67	-12.23	210.12	206.99	-3.13	0.07	3.52	3.45
HPZ005A	213.67	213.71	0.04	211.48	210.85	-0.63	212.71	212.58	-0.13	0.41	0.77	0.36
HPZ006A	202.14	202.98	0.84	201.53	202.09	0.56	201.87	202.46	0.58	0.16	0.23	0.07

^a Data for FPZ001A, FPZ002A, FPZ004A, FPZ005A, FPZ006A, HPZ002A, HPZ003A, HPZ004A, and HPZ005A based on continuous measurements. Data for FPZ003A, FPZ007A, FPZ008A, HPZ001A and HPZ006A based on monthly measurements.

^b Pre-Operation period for F-Area piezometers was 1/96 – 3/97. Pre-Operation period for H-Area piezometers was 1/96 – 6/97.

^c Positive numbers indicate the value since the Waste Treatment Unit began operation was greater than the pre-operation period value. Negative numbers indicate the value since the Waste Treatment Unit began operation was less than the pre-operation period value.

Table 8. Comparison of the Piezometer Water-Level Statistics Before and After Waste Treatment Units Began Operating^a

Piezometer	<u>Maximum</u>			<u>Minimum</u>			<u>Average</u>			<u>Standard Deviation</u>		
	Pre-Op. Period ^b	Post-Op. Period ^c	Difference ^d	Pre-Op. Period ^b	Post-Op. Period ^c	Difference ^d	Pre-Op. Period ^b	Post-Op. Period ^c	Difference ^d	Pre-Op. Period ^b	Post-Op. Period ^c	Difference ^d
FPZ001A	198.10	198.21	0.11	197.80	197.79	-0.01	197.91	197.99	0.08	0.08	0.07	0.01
FPZ002A	201.91	203.36	1.45	200.97	200.38	-0.59	201.21	201.70	0.49	0.22	0.73	0.51
FPZ003A	191.22	191.97	0.75	187.07	186.12	-0.95	188.87	188.70	-0.17	1.18	1.76	0.58
FPZ004A	202.46	202.89	0.43	200.90	200.35	-0.55	201.21	201.48	0.27	0.15	0.65	0.50
FPZ005A	191.30	191.57	0.27	190.99	189.45	-1.54	191.09	190.95	-0.14	0.05	0.44	0.39
FPZ006A	189.81	191.94	2.13	188.50	187.94	-0.565	189.15	189.36	0.21	0.26	0.53	0.26
FPZ007A	193.34	193.46	0.12	192.66	186.12	-6.54	193.02	193.03	0.01	0.17	0.27	0.10
FPZ008A	187.72	187.79	0.07	187.56	192.48	4.92	187.63	187.65	0.02	0.05	0.07	0.02
HPZ001A	202.38	202.68	0.30	202.05	201.87	-0.18	202.31	202.23	-0.07	0.08	0.16	0.08
HPZ002A	218.78	219.74	0.96	217.44	216.39	-1.05	218.03	218.12	0.09	0.27	0.80	0.53
HPZ003A	201.58	202.18	0.60	200.38	201.07	0.69	201.18	201.64	0.46	0.26	0.25	-0.01
HPZ004A	210.47	218.76	8.29	209.90	197.67	-12.23	210.12	207.98	-2.14	0.07	3.31	3.24
HPZ005A	213.67	213.71	0.04	211.48	210.78	-0.70	212.71	212.54	-0.16	0.41	0.78	0.37
HPZ006A	202.14	202.98	0.84	201.53	201.93	0.40	201.87	202.36	0.48	0.16	0.24	0.07

^a Data for FPZ001A, FPZ002A, FPZ004A, FPZ005A, FPZ006A, HPZ002A, HPZ003A, HPZ004A, and HPZ005A based on continuous measurements. Data for FPZ003A, FPZ007A, FPZ008A, HPZ001A and HPZ006A based on monthly measurements.

^b Pre-Operation period for F-Area piezometers was 1/96 – 3/97. Pre-Operation period for H-Area piezometers was 1/96 – 6/97.

^c Post-Operation period for F-Area piezometers was 4/97 – 12/98. Post-Operation period for H-Area piezometers was 7/97 – 12/98.

^d Positive numbers indicate the value since the Waste Treatment Unit began operation was greater than the pre-operation period value. Negative numbers indicate the value since the Waste Treatment Unit began operation was less than the pre-operation period value.

Figure 1. Extraction/injection well locations and piezometer locations for the water table aquifer in F-Area

Figure 2. Extraction/injection well locations and piezometer locations for the water table aquifer in H-Area

Figure 3. Reference piezometer locations

Figure 4. Water level elevations at location FPZ001A, January 1996 to December 1998

Figure 5. Water level elevations at location FPZ002A, January 1996 to December 1998

Figure 6. Water level elevations at location FPZ003A, January 1996 to December 1998

Figure 7. Water level elevations at location FPZ004A, January 1996 to December 1998

Figure 8. Water level elevations at locations FPZ005A and FPZ005B, January 1996 to December 1998

Figure 9. Water level elevations at locations FPZ006A and FPZ006B, January 1996 to December 1998

Figure 10. Water level elevations at locations FPZ007A and FPZ007B, January 1996 to December 1998

Figure 11. Water level elevations at locations FPZ008A and FPZ008B, January 1996 to December 1998

Figure 12. Water level elevations at location HPZ001A, January 1996 to December 1998

Figure 13. Water level elevations at location HPZ002A, January 1996 to December 1998

Figure 14. Water level elevations at locations HPZ003A and HPZ003B, January 1996 to December 1998

Figure 15. Water level elevations at location HPZ004A, January 1996 to December 1998

Figure 16. Water level elevations at locations HPZ005A and HPZ005B, January 1996 to December 1998

Figure 17. Water level elevations at location HPZ006A, January 1996 to December 1998

Figure 18. Water level elevations at location FHR001, July 1997 to December 1998

Note: Different Scale From Other Plots

Figure 19. Water level elevations at location FHR002, July 1997 to December 1998

Figure 20. Water level elevations at location FHR003, July 1997 to December 1998

Figure 21. Water Elevation at Piezometer FPZ001A and F-Area Rainfall

Figure 22. Water Elevation at Piezometer FPZ002A and F-Area Rainfall

Figure 23. Water Elevation at Piezometer FPZ003A and F-Area Rainfall

Figure 24. Water Elevation at Piezometer FPZ004A and F-Area Rainfall

Figure 25. Water Elevation at Piezometer FPZ005A and F-Area Rainfall

Figure 26. Water Elevation at Piezometer FPZ006A and F-Area Rainfall

Figure 27. Water Elevation at Piezometer FPZ007A and F-Area Rainfall

Figure 28. Water Elevation at Piezometer FPZ008A and F-Area Rainfall

Ground Elevation is 202.40 feet (msl)

Figure 29. Water Elevation at Piezometer HPZ001A and H-Area Rainfall

Figure 30. Water Elevation at Piezometer HPZ002A and H-Area Rainfall

Figure 31. Water Elevation at Piezometer HPZ003A and H-Area Rainfall

Figure 32. Water Elevation at Piezometer HPZ004A and H-Area Rainfall

Figure 33. Water Elevation at Piezometer HPZ005A and H-Area Rainfall

Ground Elevation is 201.70 feet (msl)

Figure 34. Water Elevation at Piezometer HPZ006A and H-Area Rainfall

Figure 35. Typical Groundwater Response to Rainfall