Analysis of Aquifer Pump Tests in Individual Well Zones at Site 22 near Yucca Mountain, Nevada

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CONTENTS

FIGURES

FIGURES (CONTINUED)

TABLES

APPENDICES

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1.0 INTRODUCTION

This report presents field data, analyses, and interpretations for aquifer pump tests conducted in August and September 2003 as part of the Nye County Nuclear Waste Repository Project Office (NWRPO) Independent Scientific Investigation Program (ISIP). The tests were funded by a cooperative agreement with the U.S. Department of Energy (DOE) to support the evaluation of the proposed high-level nuclear waste repository at Yucca Mountain, Nevada. The purpose of the tests was to fill gaps in aquifer parameter data in alluvium and upper Tertiary sediments along a potential flow path between Yucca Mountain and populated areas of Amargosa Valley, Nevada.

Aquifer pump tests were conducted at Site 22 in Fortymile Wash, approximately 5 miles north-northwest of Amargosa Valley. The site consists of a complex of three wells: NC-EWDP-22S, a multiple-screen monitoring well that serves as the logging and pumping well in the aquifer tests described herein; and NC-EWDP-22PA and -22PB, which are nested, dual-completion piezometers that serve as observation wells. These wells were constructed in 2001 and 2002 as part of Phase III of the Early Warning Drilling Program (EWDP). Figure 1 shows the location of the Site 22 wells in relation to other EWDP wells and boreholes. Figure 2 shows the surface layout of the site. Not shown on Figure 2 is abandoned exploratory borehole NC-EWDP-22SA, which was located immediately adjacent to 22S and provided geologic data for this site. The Site 22 wells shall be referred to in this report as 22S, 22PA, 22PB, and 22SA.

Well 22S was drilled in October 2001 to a total depth of 1,196.5 feet below ground surface (ft bgs) and completed with four screened intervals, as shown on Figure 3. The intervals are labeled Screens 1 through 4; Screen 1 refers to the uppermost interval.

Detailed subsurface geologic data for 22S and other boreholes at Site 22 are found in Nye County technical report NWRPO (2003a). A comparison of the 22SA summary lithologic log in the 2003 report with the well completion diagram shown on Figure 3 herein indicates that the upper three screens in 22S are completed in alluvium consisting primarily of silty sand with gravel, and the lower screen is in a Tertiary volcanic conglomerate. Detailed geologic logs for 22SA show no evidence of obvious confining layers. However, drill cuttings collected from the depth interval corresponding to Screen 3 exhibited a strong hydrochloric acid (HCl) reaction, suggesting that the formation sediments in this screened interval are cemented with calcium carbonate. In contrast, drill cuttings from depth intervals corresponding to Screens 1 and 2 exhibited little HCl reaction, suggesting that little calcium carbonate related cementation is present.

Piezometer 22PA was drilled to a total depth of 779.8 ft bgs in January 2002, and 22PB to 1,199.7 ft bgs in February 2002. Each piezometer was completed with two screens, as shown on Figures 4 and 5. The screens in 22PA are at depths corresponding to the upper two screens in 22S; those in 22PB correspond to the lower two screens in 22S. The upper and lower screens in each piezometer are referred to as shallow or deep (i.e., 22PA shallow). Screen depth intervals and associated sand packs are summarized in Table 1. Sand pack intervals will be referred to as test zones, or zones, in this report, and corresponding zones in the monitoring well and piezometers have been assigned the same zone number.

Drilling, completion, and development procedures that may impact aquifer test results for Site 22 wells, as well as other EWDP Phase III wells, are also described in detail in NWRPO (2003a). Additional drilling-related information and metadata are on file in the NWRPO Quality Assurance Records Center (QARC).

Previous testing at Site 22 includes aquifer pump-spinner and 48-hour (hr) pump tests conducted in March 2002 (NWRPO, 2003b). These tests were conducted while simultaneously pumping all four zones in 22S. The test results from the pumping well analysis (22S) indicated a high transmissivity of 15,500 square feet per day (ft^2/day), corresponding to an average permeability of 14.5 darcy over the 369-ft productive thickness. No significant vertical head gradient was present, and all intervals contributed to production. Hydraulic communication was demonstrated between the screens in 22S and each of the matching piezometer completions. However, the calculated well efficiency of 22S was only 19 percent. The majority of the head loss was attributed to multi-layer and non-darcy flow effects as flow converged to the well. These results are referred to as “preliminary test results” herein.

In April 2002 a Westbay MP55™ casing and packer system was installed in 22S to isolate the various zones and allow individual zones to be monitored, sampled, or pumped. This installation included replacing the upper 515 feet of the 2½-inch diameter MP55 access casing with 4-inch Schedule 80 PVC pipe to facilitate pumping the well. In March 2003, the 4-inch Schedule PVC pipe was replaced with 5-inch Schedule 80 PVC pipe to permit the use of pumps with higher flow rate for the hydraulic tests described herein and for future tracer test studies.

Before beginning the August/September 2003 aquifer pump tests, background pressure and temperature were monitored in 22S, 22PA, and 22PB from July 31 to August 4, 2003. On August 5, a pump test was conducted in Zone 1 in 22S, followed by tests in Zone 2 on August 12, Zone 3 on September 9, and Zone 4 on September 23. The tests were conducted with only one screen open to the wellbore for pumping. Pumping rates for these 11-hr tests ranged from approximately 20 to 47 gallons per minute (gpm). After each test, subsequent recovery was monitored. All data were collected according to the NWRPO quality assurance (QA) program.

2.0 METHODS AND ANALYSES

2.1 Overview of Aquifer Pump Test Methods

Aquifer pump tests were conducted in accordance with NWRPO QA plans and procedures, including the following:

- Technical procedure TP-10.0, *Pumping/Injection Tests of Packed-Off Zones in Unscreened open Boreholes or in Multiple Screen Boreholes with or without Observation Wells*.
- Test plan TPN-9.1, *Pump Test of Individual Screens in NC-EWDP-22S*.
- Work plan WP-4.0, *Aquifer Testing Plan for Nye County's Independent Scientific Investigation Program*.

Before testing, Westbay MOSDAX™ pressure/temperature measuring probes were placed in each zone except the pumping zone in pumping well 22S and each of the four observation strings in the piezometers. These probes remained in place throughout the tests. In addition, a probe was attached to the tubing string above the pump to measure the pressure in the pumping zone. The probes were attached to one of two surface MOSDAX dataloggers that recorded downhole pressure and temperature information, barometric pressure, and ambient temperature. Shallow and deep piezometers in both 22PA and 22PB were instrumented with MOSDAX sensors. Three of the piezometer screens were instrumented with 30 psi sensors and the fourth with a 250 psi sensor. A nominal water density of 0.43275 pounds per square inch per foot (psi/ft) was used to convert the probe readings to equivalent piezometric surface elevations above mean sea level (amsl). The elevations of the wellheads on the three wells were obtained from the Yucca Mountain Site Characterization Project as-built survey of EWDP Phase III boreholes (YMP, 2002).

For the purposes of this report, it was assumed that the downhole distance between the wells was equal to the surface distance, and that this distance does not materially affect the results of the analyses described in the following. Deviation surveys in the wells show little or no deviation from the vertical.

In each zone in 22S, 11-hr pump tests and subsequent recoveries were used to determine transmissivity and well efficiency. For Zones 1 and 2, the well was pumped at the nominal rate of 47 gpm, while lower pumping rates of 27 and 20 gpm, respectively, were used with the less productive Zones 3 and 4. Pump rates were obtained using a 55-gallon (gal) drum and stopwatch. Readings were also taken using a multi-jet meter, and were found to be consistent with the drum and stopwatch readings.

2.2 Data Processing, Correction, and Assumptions

Where applicable, data from the Zone 1 pump test are used in the following to illustrate the approach applied to data from all pump tests. In addition, assumptions regarding start times for drawdown and recovery are summarized in the following. Finally, the significance of barometric pressure effects and problems with datalogger clock synchronization for the different pump tests are summarized and discussed in more detail in sections devoted to different pump tests.

2.2.1 Pressure Data Conversion and Scaling

As stated, MOSDAX pressure probe (i.e., transducer) readings were converted to equivalent piezometric surface elevations. The barometric pressure measured for the Zone 1 test shown on Figure 6 is scaled so that the total head difference indicated by the left y-axis is equivalent to the total pressure difference indicated by the right y-axis, assuming both are on an equivalent water head basis.

2.2.2 Transducer Resolution, Data Averaging, and Reduction

The data reported from the transducers for tests in all zones showed pressure head output steps of approximately ±0.01 ft. Figure 6 illustrates these steps for the test in Zone 1. This instrument resolution was not a problem in the pumping well, where head changes of approximately 9 ft were observed (Figure 7), but led to significant uncertainty in the observation wells, where the maximum head change in the same zone as the pumping well was typically 0.4 ft (Figure 6). Accordingly, all head data were averaged to obtain smoothed response curves (Figure 8). The same averaging process was conducted on the raw data from all pumping tests to reduce the effect of the transducer resolution (i.e., steps) on the analyses.

Zones immediately adjacent to the pumping zone (i.e., directly above or beneath) exhibited maximum head changes in the range of ±0.03 ft (Figure 8). These head changes were deemed too small for accurate analysis and therefore were not included in the analyses presented in this report. Pressure data from adjacent zones, however, are included in graphs of piezometric levels for all pump tests to graphically demonstrate the small responses in adjacent zones. For example, Figure 8 illustrates the minimal response in Zone 2 during the Zone 1 test.

2.2.3 Drawdown and Recovery Start Time Assumptions

Pressure readings were generally recorded every 10 seconds (sec) before and during pumping and recovery. Because of this recording frequency and the rapid response in the pumping and observation wells for all tests, actual start times for drawdown and recovery test phases were estimated. Start times were selected to cause drawdown and recovery data for the pumping well to follow the same trend, to the extent possible. For the Zone 1 test, it was assumed that drawdown or recovery began at a time midway between the last steady reading and the first changed reading after starting or stopping pumping. Table 2 summarizes the start times of drawdown and recovery selected for the aquifer pump tests in all four zones.

2.2.4 Datalogger Time Shift Corrections

Different dataloggers were used to record data from the pumping and observation wells for tests in Zones 1, 2, 3 and 4. The datalogger clocks were synchronized prior to Zone 1 tests, but were not synchronized for tests in the remaining zones. Therefore, a time shift was needed to correct times for the tests in Zones 2, 3, and 4. The procedures for correcting times to a common basis involved selecting the correction that obtained the best visual fit to the leaky aquifer type curves.

These correction procedures are described in Sections 2.5.1, 2.6.1, and 2.7.1 for tests in Zones 2, 3, and 4, respectively.

2.2.5 Barometric Pressure Change/Tidal Effect Corrections

It was not necessary to filter Zone 1 or 2 test data for changes in barometric pressure because the effect of these changes was very small on those tests. This is illustrated by the Zone 1 test shown on Figure 8, where the maximum (i.e., peak-to-valley) change in barometric pressure of approximately 0.045 psi, or approximately ±0.10 ft on an equivalent water head basis, led to a corresponding peak-to-valley change in the piezometric head in Zone 2 of only approximately ±0.03 ft. However, barometric pressure changes were significantly greater for Zone 3 and 4 tests and could not be ignored. The methods for correcting Zone 3 and 4 test data for trend effects caused by barometric pressure changes are described in Sections 2.6 and 2.7, respectively.

2.3 Test Analysis Methods

The analysis and interpretation of drawdown and recovery data from the pump tests described in this section were conducted in accordance with TP-9.7, *Analysis of Pressure Transient Tests*.

A standard leaky aquifer model of the aquifer system (Hantush, 1959) was selected to analyze and interpret the well tests. It will be shown in the following sections that this model accounts for the pressure stabilization observed in all tests at both the pumping and observation wells. It also accounts for the connections between different layers in the system that were demonstrated to be present, based on pressure communication in different layers while pumping other layers.

The same standard leaky aquifer analysis steps/methods were used for tests conducted in each of four zones. General methods are described in the following sections; more details are presented in sections describing individual pump tests.

It was determined that test results were not suitable for the more detailed analysis methods described in previous Nye County reports (NWRPO, 2001 and 2003b). This determination was based on the fact that observed head changes occurred so rapidly that a 10-sec sampling period was inadequate to obtain the pressure data needed for more complex analysis methods.

2.3.1 Observation Well/Model Match Approach

Hantush (1959) was used to generate a model to match the observation well response in each pump test. When analyzing the tests, both drawdown and recovery pressure responses were considered. More weight was given to recovery data, which were less affected by minor changes in the pumping rate or well efficiency of 22S.

The analysis involved first drawing a line through the inflection point of the head change data, then applying the Hantush inflection point method to calculate the transmissivity and storativity of the zone and leakance from the adjacent bed(s). The inflection point in the head change data and the calculated Hantush line are shown on Figure 9 for the Zone 1 test. The same approach was used on head change data from tests in Zones 2, 3, and 4.

Finally, although it was possible to calculate the storativity for each pump test and estimate the degree of aquifer confinement from the storativity value, it was not feasible to calculate effective porosity from storativity, due to the lack of aquifer compressibility data.

2.3.2 Pumping Well/Type Curve Match Approach

After transmissivity, storativity, and leakance were determined from the observation well response, the head changes during pumping and recovery in 22S were matched to determine the skin factor and well efficiency (Cox and Onsager, 2002). Both drawdown and recovery data from the pumping well were considered in this analysis and more weight was given to the recovery data, as done in the observation well approach. Model and measured head change matches in 22S are illustrated for the Zone 1 pump test on Figure 10. Similar figures were generated for pump tests in Zones 2, 3, and 4.

Figure 10 also shows that the pumping well response during the Zone 1 test transitioned directly from wellbore storage behavior before 0.01 hr into leakance-dominated, steady-state flow. That is, when graphed, the data form a continuous curve and not the semilog straight line required to determine transmissivity using the standard Cooper-Jacob analysis for non-leaky aquifers (Cooper and Jacob, 1946). Similar semilog curves were also obtained for data from tests in Zones 2, 3, and 4.

2.3.3 Summary of Pump Test Analyses and Data Used

A summary of the key data and analyses conducted on head change data in Zone 1 of the observation and pumping wells are provided in Appendices A-1 and A-2, respectively. Similarly, observation and pumping well data and analyses for the Zone 2 test are presented in Appendices A-3 and A-4, Zone 3 in Appendices A-5 and A-6, and Zone 4 in Appendices A-7 and A-8. The results of these analyses are summarized in Tables 3 and 4 and described in detail in the following sections.

2.4 Zone 1 Test Analysis and Results

2.4.1 Leaky Aquifer Match to Observation Well Response

Figure 9 presents the graphical results of matching the Hantush model to the observed head change data in Zone 1 of observation well 22PA. The difference between the final recovery and drawdown head changes during the test most likely results from a change in the barometric pressure during the test (Figure 8).

The match for Zone 1 was obtained with a transmissivity of 2,600 ft^2/day, corresponding to an average permeability of 12 darcy over the 72.9-ft productive thickness (Table 3). The match storativity was 0.00116. This magnitude of storativity is indicative of a confined or partially confined aquifer in Zone 1. The match leakance was 98 ft, corresponding to an average vertical permeability through the intervening layer between Zones 1 and 2 of 6 darcy. The difference between the observed and modeled head responses at late times (i.e., after 0.1 hr) is attributed to storage effects in the confining layer, or storage or finite transmissivity effects in the adjoining aquifer unit(s).

2.4.2 Type Curve Match to Pumping Well Response

Figure 10 shows the graphical results of matching the leaky aquifer model with wellbore storage and skin to the observed head change data in Zone 1 of pumping well 22S using methods of Cox and Onsager (2002). A skin factor of +12 was needed to match the observed head changes in the pumping well. The term “skin factor” is used in the petroleum industry to account for near-wellbore pressure drops, and can be related to the concept of well efficiency in groundwater studies. The modeled head change with zero skin (i.e., 100 percent well efficiency) is shown for comparison on Figure 10, and is much less than the observed head change. The skin factor of +12 leads to a calculated well efficiency of 30 percent.

In addition to drilling-related sand pack and formation damage, flow-related factors, such as inertia, turbulence, and flow convergence effects, may also cause high skin values. Probably more important in this study is the head loss due to friction in the MP55 casing system. This casing system was not originally designed for pumping at rates as high as the ones used for these tests.

Several EWDP pump tests in other wells have exhibited “stair-step” increases in measured head level during pumping, which, along with other supporting evidence, indicates progressive screen plugging (NWRPO, 2001). The fact that 22S did not exhibit stair-step increases during pumping (Figure 8) suggests that screen plugging was not responsible for the high skin value.

2.4.3 Comparison to Preliminary Test Results

Table 3 shows that the test results from Zone 1 are lower in value than those estimated from the preliminary analysis of the aquifer pump-spinner test (NWRPO, 2003b). During the pump-spinner test, leakance between layers would have been lessened because all layers were producing. The calculated transmissivity in Zone 1, based on the individual zone pump test, is 24 percent lower than the preliminary test estimate, while the calculated storativity is 28 percent lower.

2.5 Zone 2 Test Analysis and Results

A comparison of Figure 11 with Figure 7 shows that head changes in Zone 2 were slightly greater than those observed in Zone 1, during Zone 2 and 1 tests, respectively. Moreover, in both tests the head changes in zones adjacent to the pumping zone were small compared to those observed in the pumping zone of the observation and pumping wells.

Figure 12 shows that changes in barometric pressure during the Zone 2 test were less than ±0.03 ft, similar to observed changes during the Zone 1 test. Therefore, as in the Zone 1 test, it was not necessary to filter Zone 2 transducer pressure data.

2.5.1 Leaky Aquifer Match to Observation Well Response

Different dataloggers were used to record pressures in the Zone 2 pumping and observation wells. The datalogger clocks were initially assumed to be synchronized and the match for Zone 2 was obtained with 1,200-ft^2/day transmissivity, 0.00035 storativity, and 63 ft leakance. However, the calculated match curve gave a poor match for both early and late times (Figure 13). Instead of the match fitting the data, the match curve started below the observed response, then approached and matched the observed response when the head change was approximately one half of the maximum head change, and at later times again deviated below from the observed data. The technical term for this type of approach is osculation, or "kissing," instead of inflection.

In a practical sense, it appeared that the actual response was delayed at early times, to approximately 0.3 hr, but was nearly correct at late times past approximately 1 hr. A slight time adjustment would have shifted the early time data significantly to the left, mid-time data would have shifted less to the left, and late time data would be hardly affected.

Pressure data in the Zone 2 observation well showed the first significant change when the reported time was 1 minute (min) after the time when the pumping well, on a different datalogger, showed a pressure change. Thus, the maximum amount of time shift possible for the Zone 2 test was 60 sec. A good fit to the leaky aquifer type curve was obtained assuming a 30-sec time shift between the two dataloggers (Figure 14).

The match for Zone 2 was obtained with 4,600-ft^2/day transmissivity, corresponding to an average permeability of 14 darcy over the 114.7-ft productive thickness. The match storativity was 0.00035. This magnitude of storativity is indicative of a confined aquifer in Zone 2. The match leakance was 279 ft. Inasmuch as there is connection between Zone 2 and two adjacent layers, Zones 1 and 3, and the calculated leakance was very sensitive to the assumed time shift, it was considered unrealistic to calculate confining layer vertical permeability from these results.

The difference between the observed and modeled head responses at medium to late times (i.e., after 0.05 hr) shown on Figure 14 is attributed to storage effects in the confining layer(s) or possibly to storage or finite transmissivity effects in the adjoining aquifer unit(s). The difference between the late-time drawdown and recovery head changes (Figure 14) was caused by a change in barometric pressure during the test (Figure 12).

2.5.2 Type Curve Match to Pumping Well Response

After the transmissivity, storativity, and leakance were determined, head changes during pumping and recovery in the pumping well were matched to a leaky aquifer model with wellbore storage and skin to determine the skin factor (Cox and Onsager, 2002). A skin factor of +33 was needed to match the observed head changes in the pumping well (Figure 15), corresponding to a well efficiency of 16 percent.

2.5.3 Comparison to Preliminary Test Results

Table 3 shows that the test results from Zone 2 also differ somewhat from those estimated from the preliminary analysis of the pump-spinner test (NWRPO, 2003b). During that test, leakance between layers lessened because all layers were producing. Using the interpretation based on shifted time, the calculated transmissivity in Zone 2, based on the individual zone pump test, is 22 percent lower than the preliminary test estimate, while the calculated storativity is 11 percent lower.

Based on aquifer parameters calculated from the unshifted data, the head change at the pumping well would be 5.2 ft, with 100 percent well efficiency (i.e., zero skin factor). Although this possibility cannot be ruled out completely, it seems unlikely that this zone could be so productive compared to the other zones and exhibit the low transmissivity indicated by the unshifted individual zone test analysis.

2.6 Zone 3 Test Analysis and Results

A comparison of Figure 16 with Figures 7 and 11 shows that head changes in the test zone were slightly greater in Zone 3 than in Zone 1 and Zone 2, respectively. In addition, as in previous tests, head changes in zones adjacent to the test zone were exceedingly small.

Figure 17 shows that changes in barometric pressure during the Zone 3 test of up to 0.14 psi, equivalent to about 0.32 ft of water head, led to peak-to-valley changes in the piezometric levels in Zones 3 and 4 as large as 0.15 ft (Figure 17) and could not be ignored as in Zone 1 and 2 test analyses. The change in piezometric head is less than the change in barometric pressure because barometric pressure changes are filtered as they pass through the ground, which causes attenuation and a shifting in phase. This effect is known as the barometric efficiency effect. The amount of filtering depends in a complicated manner on the frequency of the pressure pulses, the transmissivity and storativity of the media, and other factors. In the analysis of another well, it was demonstrated that a much higher degree of correlation existed between the barometric pulsing effects in adjoining zones than between the barometric pressure itself and the pressure of any zone (Questa, 1998).

Figure 17 also shows that the changes in the Zone 3 piezometric levels were more strongly correlated to the Zone 4 piezometric levels than to the barometric pressure. In fact, the large change in barometric pressure on the right third of Figure 17 had a small effect on the piezometric heads in Zones 3 and 4. Except during the pumping period and early recovery, changes in head in Zone 3 were approximately 70 percent of the changes (i.e., peak-to-valley) in Zone 4 (Figure 17). Zone 3 drawdown and recovery data were therefore adjusted for barometric effects as follows:

1. The trend effects in Zone 4 at each time after the beginning of pumping were calculated as the difference between the head in Zone 4 at that time and the head in Zone 4 at the beginning of pumping.
2. The adjustment for Zone 3 at each time after the beginning of pumping was calculated as 70 percent of the Zone 4 correction calculated in step 1 above.
3. This Zone 3 adjustment was then subtracted from the Zone 3 head for each time after the beginning of pumping to determine the adjusted Zone 3 response.

2.6.1 Leaky Aquifer Match to Observation Well Response

As in Zone 2, a match was prepared assuming that the clocks in the dataloggers were measuring correctly. The initial match for Zone 3 was obtained with 9 ft^2/day transmissivity, 0.000029 storativity, and 20-ft leakance. The calculated Hantush curve gave a poor match for both early and late times (Figure 18). The curve and data osculate, rather than match, indicating a discrepancy between the times recorded by the dataloggers.

Pressure data in observation well Zone 3 showed the first significant change when the reported time was 160 sec after the pumping well, on a different datalogger, showed a pressure change. Thus, the maximum amount of time shift possible for the Zone 3 test would be 160 sec. An excellent fit to the leaky aquifer type curve was obtained assuming a 130-sec time shift between the dataloggers (Figure 19). The difference between the observed and modeled head responses at medium to late times (i.e., after 0.05 hr) is attributed to storage effects in the confining layer(s), or possibly to storage or finite transmissivity effects in the adjoining aquifer unit(s). The match for Zone 3 was obtained with 1,500-ft^2/day transmissivity, corresponding to an average permeability of 4.5 darcy over the 117-ft productive thickness. Table 3 shows that this transmissivity value is much lower than the values calculated for the upper two zones, which is consistent with moderate to strong cementation, as indicated on the summary lithologic log for this well (NWRPO, 2003a). The match storativity was 0.00010, which is indicative of a confined aquifer in Zone 3. The match leakance was 355 ft.

Since there is connection between Zone 3 and two adjacent layers (i.e., Zones 2 and 4), and the calculated leakance was very sensitive to the assumed time shift, it was considered unrealistic to calculate confining layer vertical permeability from these results.

2.6.2 Type Curve Match to Pumping Well Response

After the analysis of observation well Zone 3 head change data was completed, pumping wellhead changes during drawdown and recovery were matched to determine the skin factor. A skin factor of +17 was needed to match the observed head changes in the pumping well (Figure 20), corresponding to a well efficiency of 27 percent for this zone.

2.6.3 Comparison to Preliminary Test Results

Table 3 shows that the test results for Zone 3 are different from those estimated in the preliminary pump-spinner test (NWRPO, 2003b). During the previous test, leakance between layers lessened because all layers were producing. Using the interpretation based on shifted time, the calculated transmissivity in Zone 3, based on the individual zone pump test, is 41 percent lower than the preliminary test estimate, while the calculated storativity is 5 times greater.

Based on aquifer parameters calculated from the unshifted data, the head change at the pumping well is 332 ft, with 100 percent well efficiency (i.e., zero skin factor). This level is more than 25 times greater than the observed drawdown at the pumping well, which conclusively demonstrates that the transmissivity cannot be as low as the match of the unshifted data indicates (Table 3). This calculation supports the conclusion that the two dataloggers were not synchronized.

2.7 Zone 4 Test Analysis and Results

A comparison of Figure 21 with Figures 7, 11, and 16 shows that head changes in the test zone were slightly greater in Zone 4 than in Zones 1, 2, and 3. In addition, as in previous tests, Figure 21 shows that head changes in Zone 3 adjacent to test Zone 4 were exceedingly small.

It was shown in Section 2.6 that Zone 3 showed approximately 70 percent of the barometric effects in Zone 4. A review of the data obtained during the Zone 4 test (Figure 22) indicated that the same relationship held during the Zone 4 test (i.e., that Zone 3 showed approximately 70 percent of the barometric effects seen in Zone 4) except during the pumping period and early recovery. Accordingly, in a manner similar to that used to adjust the Zone 3 data for barometric effects, Zone 4 data were filtered for these effects by removing 1.4 times the change in the Zone 3 response.

2.7.1 Leaky Aquifer Match to Observation Well Response

The initial match was prepared assuming the clocks in the two dataloggers were measuring correctly. The initial match for Zone 4 was obtained with 330-ft^2/day transmissivity, 0.00060 storativity, and 77 ft leakance. The calculated match curve gave a poor match for both early and late time (Figure 23). The calculated leaky aquifer curve and the data osculate, rather than match, indicating a discrepancy between the times recorded by the dataloggers.

Pressure data in the observation well Zone 4 showed the first significant change when the reported time was 280 sec after the pumping well, on a different datalogger, showed a pressure change. Thus, the maximum amount of time shift possible for the Zone 2 test was 280 sec. A good fit to the leaky aquifer type curve was obtained assuming a 240-sec time shift between the dataloggers (Figure 24). The difference between the observed and modeled head responses at medium to late times (i.e., after 0.5 hr) is attributed to storage effects in the confining layer(s), or possibly storage or finite transmissivity effects in the adjoining aquifer unit(s).

The match for Zone 4 on Figure 24 was obtained with 2,000-ft^2/day transmissivity, corresponding to an average permeability of 11 darcy over the 64-ft productive thickness. The match storativity was 0.00021. This magnitude of storativity is indicative of a confined aquifer in Zone 4. The match leakance was 750 ft. Since the calculated leakance was very sensitive to the assumed time shift, it was considered unrealistic to calculate confining layer vertical permeability from these results.

2.7.2 Type Curve Match to the Pumping Well Response

After the analysis of head change data in Zone 4 of the observation well, the head change during pumping and recovery in Zone 4 of the pumping well were matched to determine the skin factor. A skin factor of +7 was needed to match the observed head changes in the pumping well (Figure 25), corresponding to a well efficiency of 15 percent.

2.7.3 Comparison to Preliminary Test Results

Table 3 shows that the test results for Zone 4 differ from those estimated in the preliminary analysis of the pump-spinner test (NWRPO, 2003b). During that test, leakance between layers lessened because all layers were producing. Using the interpretation based on shifted time, the calculated transmissivity in Zone 4, based on the individual zone pump test, is 31 percent lower than the preliminary test estimate, while the calculated storativity is only 9 percent lower.

Based on aquifer parameters calculated from the unshifted data, the head change at the pumping well would have been 9.4 ft, with 100 percent well efficiency (i.e., zero skin factor). Although the possibility cannot be ruled out completely for this zone, the shape of the unshifted observation well response as it begins to change (Figure 23) is so abrupt that it is almost certain the clocks on the two dataloggers deviated from each other.

2.8 Test and Analysis Limitations

2.8.1 Datalogger Clock Limitations

The greatest limitation with respect to the analysis of these tests concerns the inferred discrepancy between the clocks on the two dataloggers. Additional justification for making the corrections proposed in the following.

The two dataloggers used in this study were synchronized at the time that Zone 1 was tested. However, they were not synchronized while testing the remaining zones. In all tests, different dataloggers were connected to the pumping and observation wells.

Figure 26 shows that the inferred discrepancy between the clocks increases in a nearly linear fashion over time from test to test. A difference of 240 sec during the 49 days from the start of the Zone 1 test to the start of the Zone 4 test amounts to an accumulated discrepancy of 0.0057 percent, or less than 5 sec per day.

Each datalogger was connected to a different 12-volt battery and solar panel charger. Clock deviations could have been caused by variations in the output of these batteries and solar panels. (J. Walker, personal communication, January 2004).

In summary, adjustments of the recorded time are consistent with clocks that accumulate a discrepancy of 5 sec a day. Moreover, this discrepancy may be due to the batteries and solar panels used to power the clocks. These time shifts adjusted the observation well responses so that they could be analyzed using standard leaky aquifer analysis methods. If the clocks had not been adjusted, the interpretations presented and conclusions reached would have been incorrect.

2.8.2 Transducer Resolution Limitations

Limitations of transducer resolution exist with respect to both time and pressure. Pressure readings were measured, in general, at 10-sec intervals. The inherent uncertainty of up to 10 sec in the starting or stopping time of pumping, which primarily affects the wellbore storage constant, has little impact on the results.

Pressure resolution difficulty, as illustrated on Figure 6, is a greater problem. In most cases, the head change is proportional to the pumping rate, so the problem can be alleviated by increasing the pumping rate. In this case, however, it was not feasible to pump at higher rates due to access port size limitations associated with the MP55 system. The averaging procedure applied is based on the assumption that when pressure exists between two discrete reporting levels, the transducer will record one level more frequently than the other in proportion to the difference between actual pressure and reporting levels. As shown on Figure 8, this approach leads to smooth, readily interpretable data. Even with relatively highly productive 22S, overall head changes were sufficiently great that errors on the order of ±0.03 ft would have a relatively minor impact on the calculated results.

2.8.3 Model Limitations

The leaky aquifer model assumes that each zone acts as an independent aquifer, with a permeable confining layer with negligible storativity between the unit tested and an adjacent aquifer that has such sufficient permeability and storativity that no appreciable drawdown occurs in the adjoining units during the test. In this case, the screened intervals are not truly confined and the confining beds have finite storage capability. The summary lithologic log indicates that Zones 1, 2, and 3 consist of a succession of layers of silty sand and gravel (NWRPO, 2003a). The screens were installed across coarse-grained intervals that appear to have higher permeability, although the non-screened intervals were also permeable. It is apparent that a leaky aquifer model is in reality too simplistic to properly account for all known factors of this complex system.

Even so, the leaky aquifer model does provide a reasonable approximation for several important factors observed during these tests. The steady-state drawdowns observed at the pumping and observation wells are consistent with this model. The lack of significant drawdown in the adjoining layers during the tests is also consistent. Finally, the general shape of the drawdown and recovery response curves is similar to that predicted by a leaky aquifer model. Accordingly, leaky aquifer type curves were selected to provide preliminary estimates for the hydrologic parameters of this system. In future, more detailed multi-layer models, with storage in the confining layers, should be able to provide a more accurate representation of the aquifer system.

The difference between the observed and modeled head responses is an indication of the suitability of a model for analysis. In these cases, the observed late-time response (e.g., after approximately 0.1 to 0.5 hr) is poorly matched by the model calculations. The differences between the responses at medium to late times are attributed to storage effects in the confining layer(s), or possibly to storage or finite transmissivity effects in the adjoining aquifer unit(s). However, given the complexity of the system and the lack of certainty concerning the exact time shifts needed to account for differences between the clocks of the two dataloggers, a decision was made to overlook these effects.

2.8.4 Well Efficiency Limitations

Another limitation between the model and the physical aquifer system has to do with the presence of a skin factor, or non-ideal well efficiency. The skin factor calculation assumes that a head loss exists over an infinitesimally thin layer between the inside of the well and the aquifer. In reality, this head loss can occur over some distance into the aquifer, although the resulting impact is generally small.

The skin factors are sufficiently high that the causes of skin should be considered. Probably the greatest contributor to skin is the frictional head loss in the MP55 casing system, which was not designed for pumping at rates as high as those used. Other factors, such as inertia, turbulence, and flow convergence effects may also contribute to the high skin factors. There may also be some drilling-related sand pack and formation damage, but the fact that the drawdown data did not exhibit stair-step increases suggests that screen plugging, such as that observed in earlier well 19D, was not a significant factor (NWRPO, 2001).

Skin factor is a catchall term that accounts for any head losses beyond those attributable to darcian flow in the aquifer. In this case, with relatively high transmissivity in the well, these losses associated with skin amount to only approximately 10 additional ft (Figures 10, 15, 20 and 25). The calculated head loss due to friction in the MP55 casing system exceeds 10 ft in all zones.

Because of indications of low well efficiency and possible turbulence effects, the validity of the test interpretations should be examined. If the interpretations had been based on the pumping well alone, the results would certainly be questionable. However, the transmissivity, storativity, and leakance determinations were based on observation, not pumping, well response. Once those parameters were determined from observation well response, skin factor was determined from the pumping well response. Finally, it should be noted that the presence of a skin factor on the pumping well has a minor effect on the head in an observation well. However, the impact of this effect was determined using a generalized leaky aquifer model with wellbore storage and skin (Cox and Onsager, 2002) and found to be small.

2.8.5 Test Time Limitations

The short duration of these tests also limits their applicability. During short tests, the storativity is a transient value that reflects rock and fluid compressibility effects. If the tests had been run for longer periods (i.e., several months), gravity drainage effects would have made an impact on the results and the storativity would be expected to approach the specific yield.

Similarly, leakance determined from short-term tests, where transient effects in the confining layers dominate the response, should be greater than the leakance determined from longer term testing, where the flow in the confining layers will more nearly approach steady state and gravity drainage may become effective in the adjoining aquifer layers.

The limited well development prior to testing and short test duration also likely influenced the skin factor, or well efficiency, calculations. It is not possible, using the available data, to determine what portion of the skin effect results from turbulence or flow concentration in the MP55 ports, and what portion, if any, results from incomplete well development. With additional longer term pumping, the 22S may clean up and exhibit improved well efficiency.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Total transmissivity at pumping well 22S was determined to be 10,700 ft^2/day, corresponding to an average permeability of 10 darcy over the 369-ft productive thickness. No significant vertical head gradient was present. All intervals contributed to production and displayed permeabilities ranging from 4.5 to 14 darcy, as shown in Table 3.

Head changes in the observation wells during pumping of individual screens in the pumping well demonstrate the existence of hydraulic connections in these aquifer units. The summation of the individual zone analysis results for transmissivity is approximately 30 percent lower, and for storage coefficients approximately 16 percent lower, than those values obtained from a previous test (NWRPO, 2003b). The previous test, a combined test of all units at once, was complicated by changing rates from each zone due to ongoing development or cleanup during the test. Furthermore, the dataloggers for the previous test had been set to obtain data only when the pressure changed by 0.1 psi, or 10 min had elapsed since the last recorded point. With those settings, very few data points were recorded, making those data unsuitable for analysis. Accordingly, the results presented in this report are considered more representative of the aquifer properties in this area.

The calculated well efficiency varied by zone in 22S, with a range of 15 to 30 percent (Table 4). These values are consistent with the overall estimate of 19 percent obtained from the previous tests (NWRPO, 2003b). It is believed that the majority of head loss experienced in the individual zone tests is attributable to friction in the MP55 casing system.

It is recommended that more detailed multi-layer models with storage in the confining layers be considered for future work to provide a more accurate representation of the aquifer system at Site 22.

4.0 REFERENCES

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FIGURES

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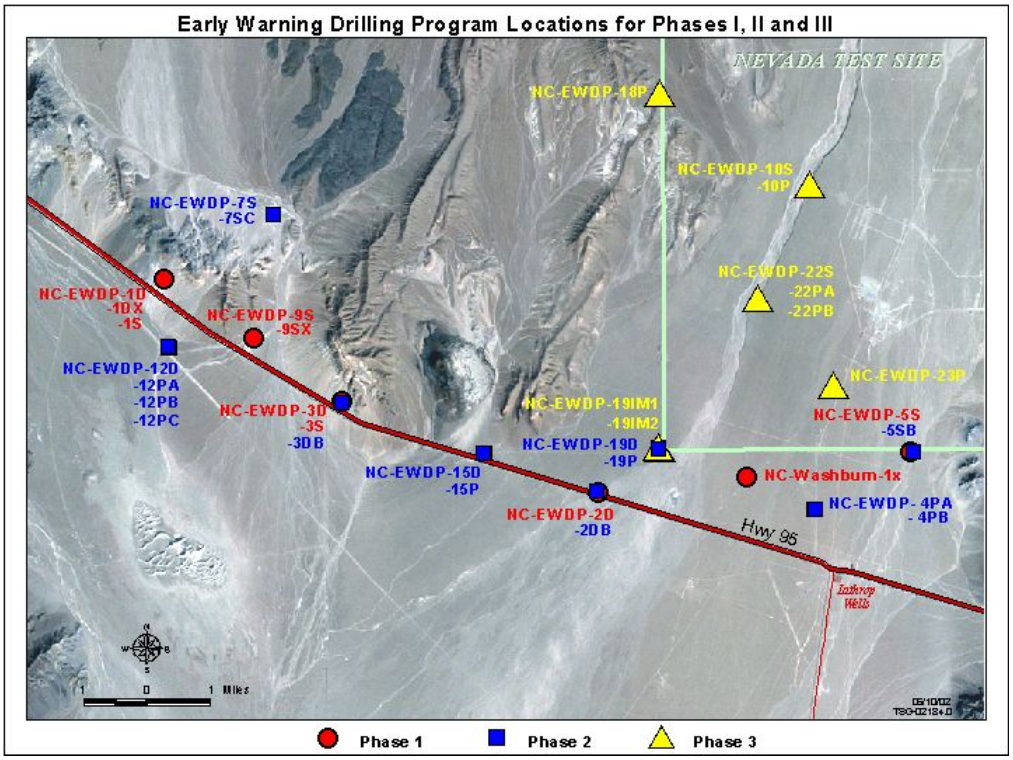


Figure 1
Location Map for the Early Warning Drilling Program

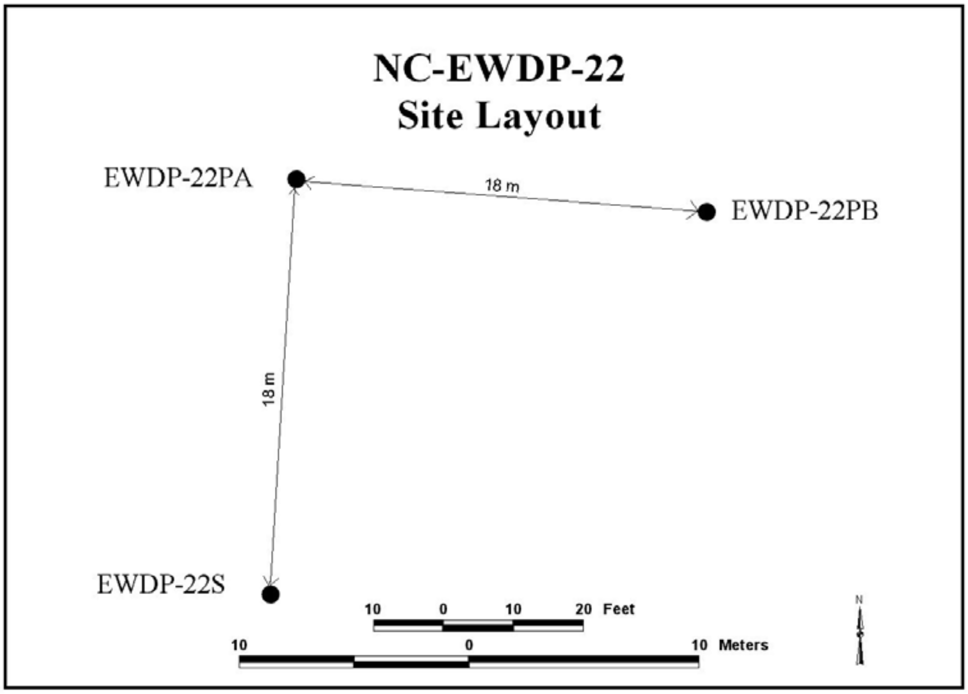
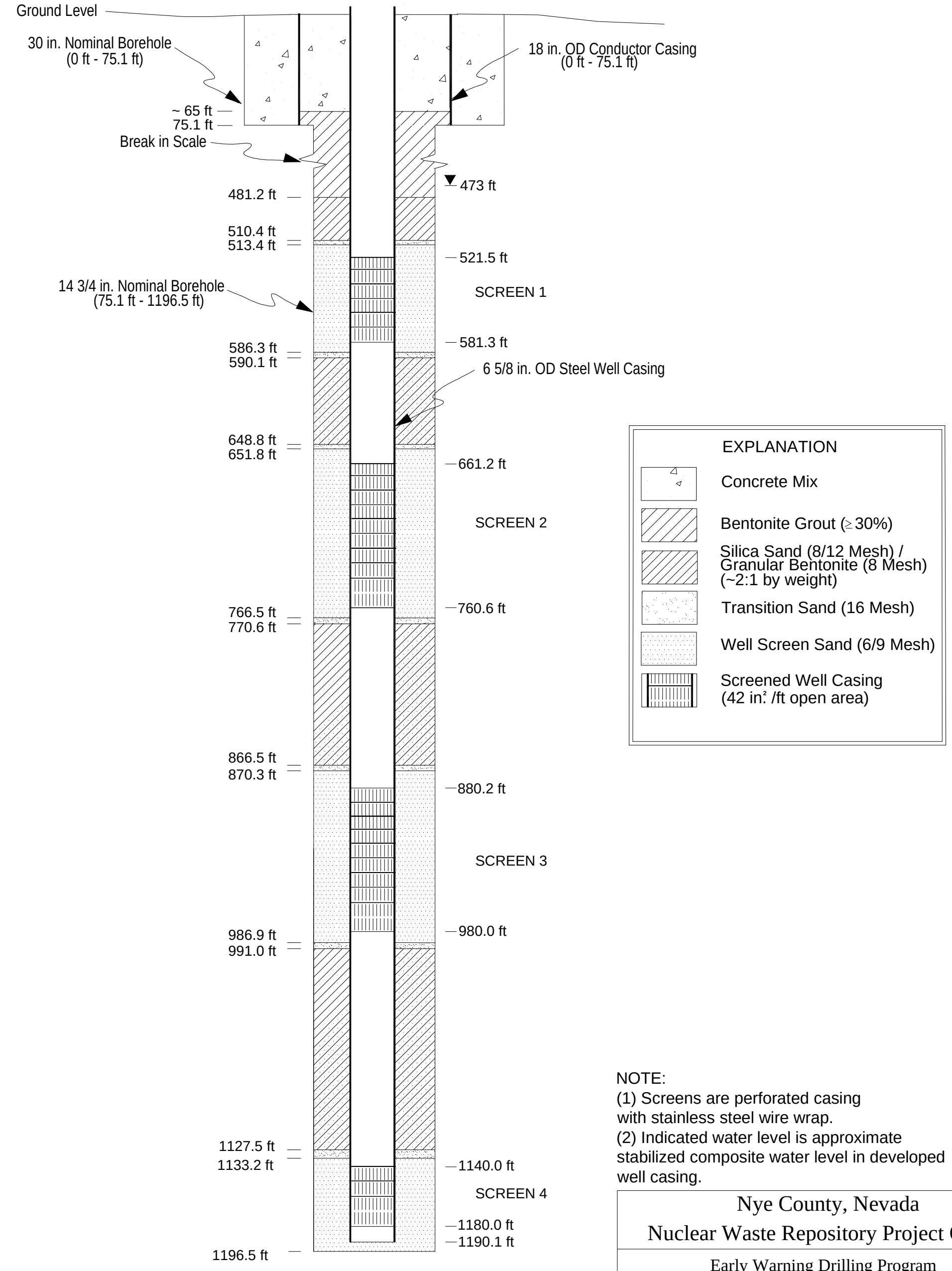


Figure 2
Layout for Site 22



NOTE:
(1) Screens are perforated casing with stainless steel wire wrap.
(2) Indicated water level is approximate stabilized composite water level in developed well casing.

NOTE: OD = outside diameter

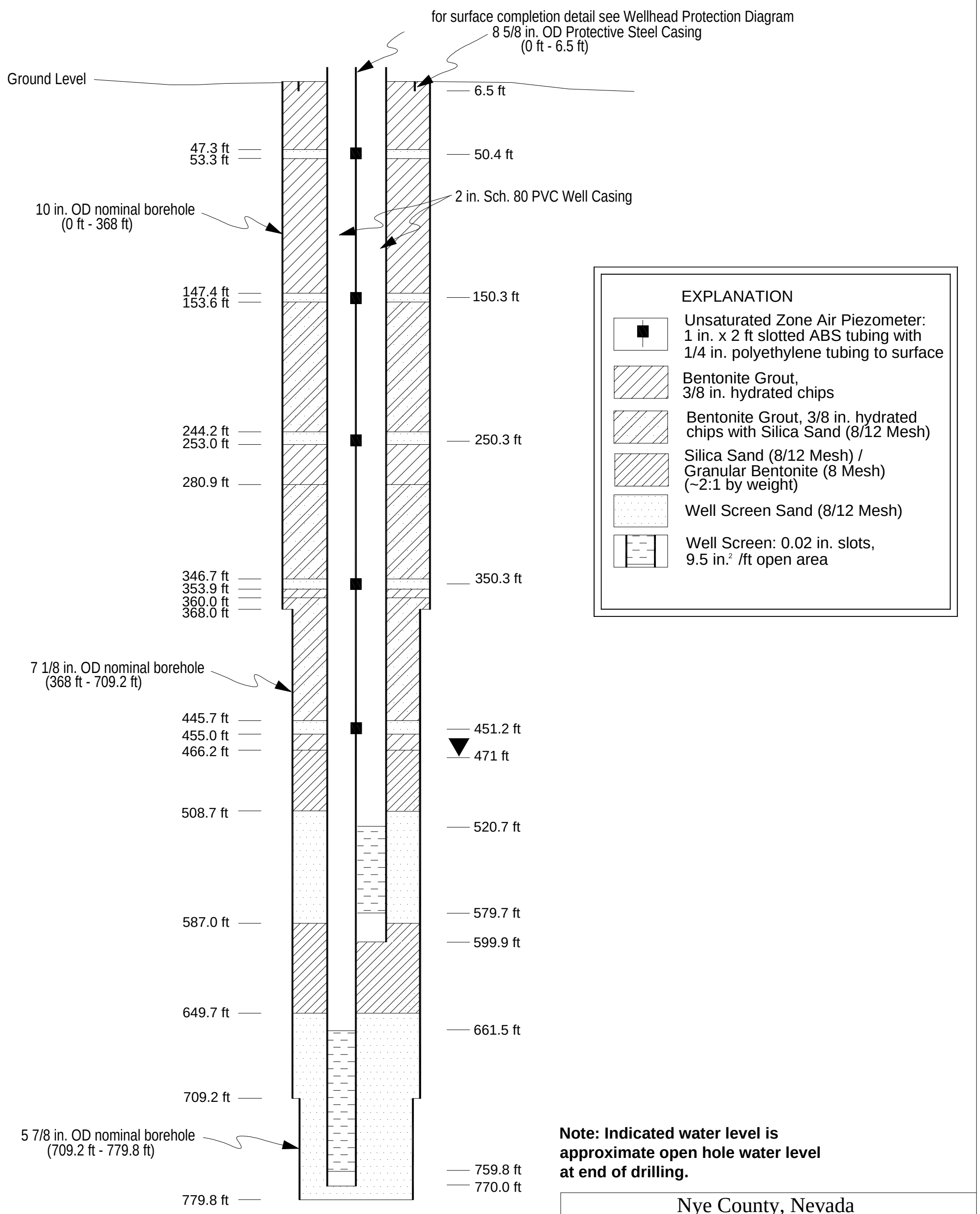
Nye County, Nevada
Nuclear Waste Repository Project Office

Early Warning Drilling Program

Well Completion Diagram
NC-EWDP-22S

Date: 9/20/02	Geologist: JSW/KDD
Scale: none	Drawn by: KJG

Figure 3
Pumping Well 22S Completion Diagram



Note: Indicated water level is approximate open hole water level at end of drilling.

Nye County, Nevada
Nuclear Waste Repository Project Office
Early Warning Drilling Program
Well Completion Diagram
NC-EWDP-22PA

Date: 9/20/02	Geologist: KDD
Scale: none	Drawn by: KJG

NOTE: OD = outer diameter;
sch. = schedule
PVC = poly vinyl chloride
ABS = acrylonitrile butadiene styrene

Figure 4
Piezometer 22PA Completion Diagram

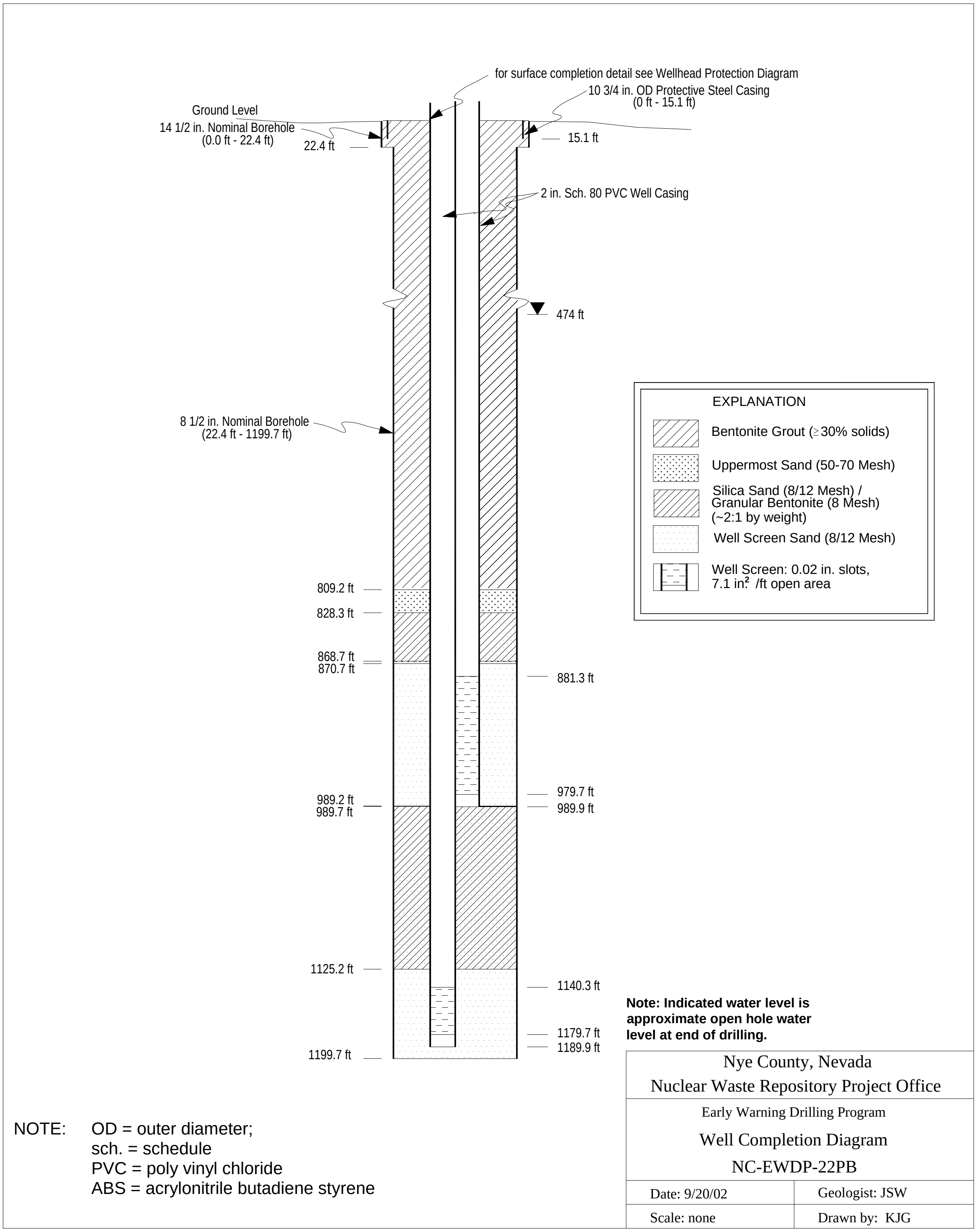


Figure 5
Piezometer 22PB Completion Diagram

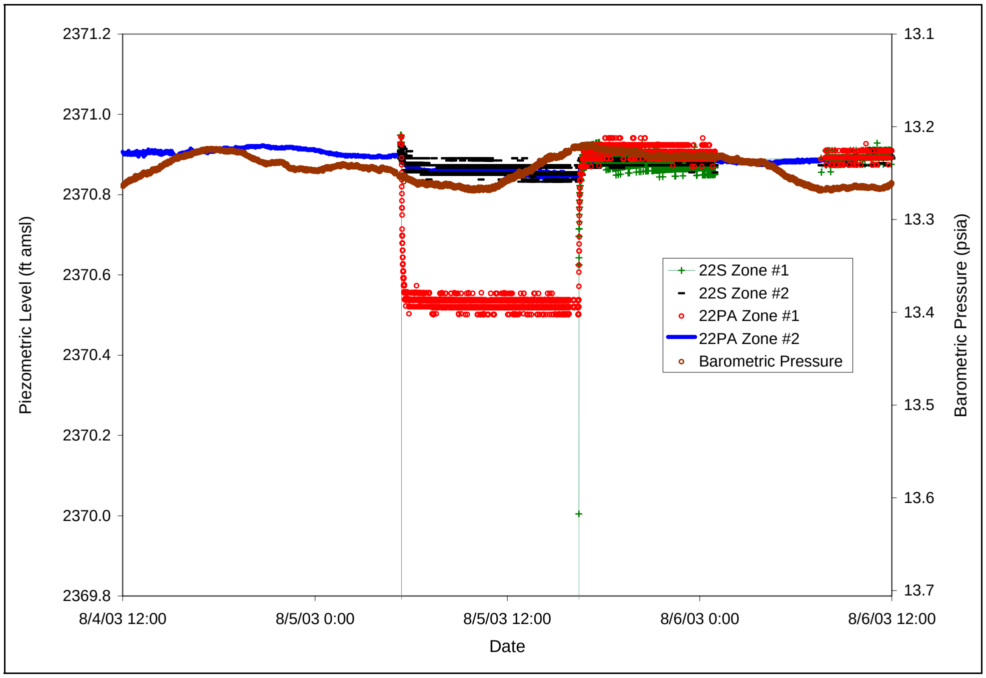


Figure 6
Observed Piezometric Levels and Barometric Pressures
Showing Zone 1 Pump Test Responses in Zones 1 and 2

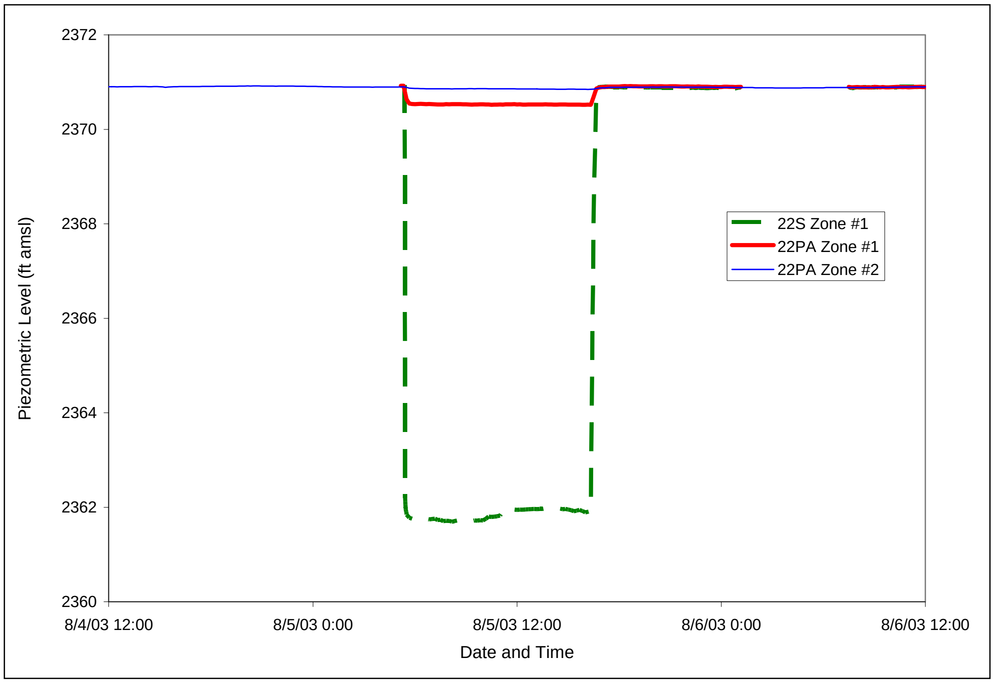


Figure 7
Piezometric Levels with Expanded Scale
Showing Zone 1 Pump Test Responses in Zones 1 and 2

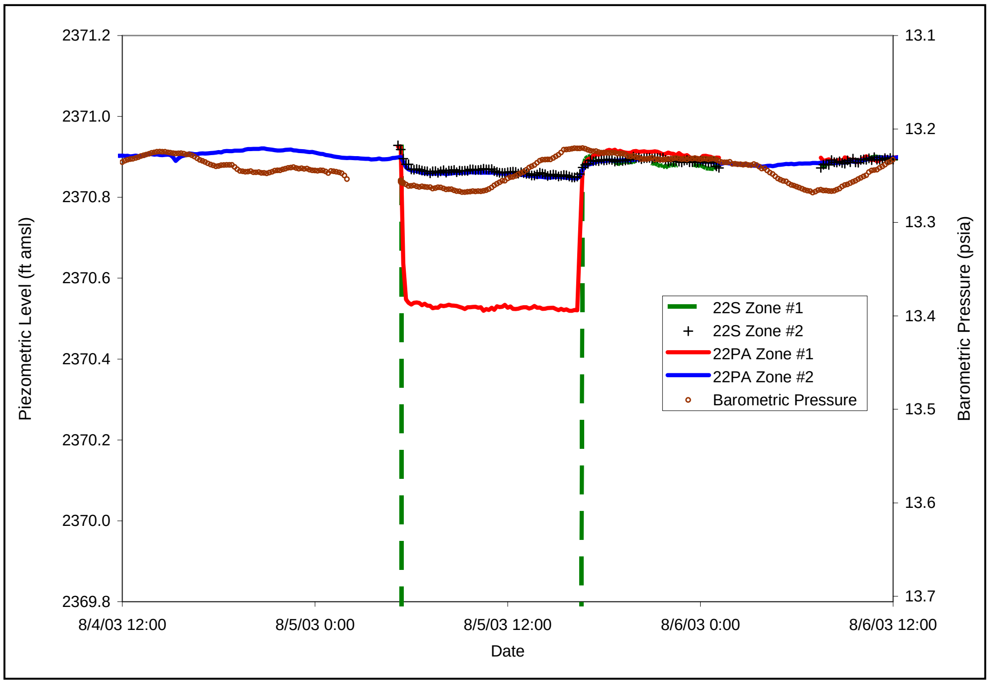


Figure 8
Averaged Piezometric Levels and Barometric Pressures
Showing Zone 1 Pump Test Responses in Zones 1 and 2

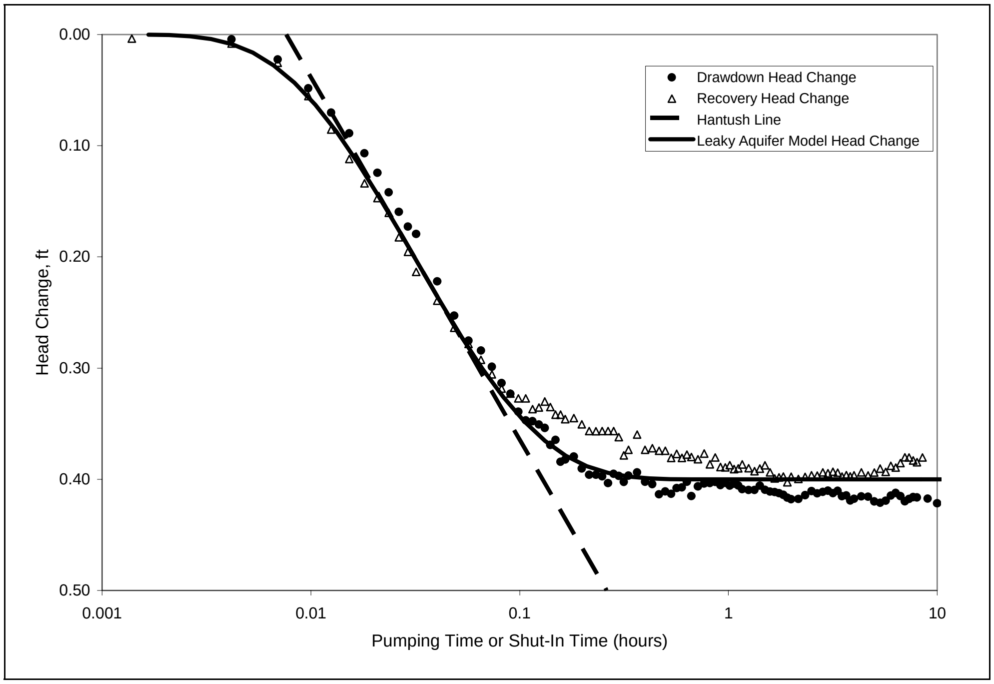


Figure 9
Comparison of Model Results to Head Changes
in 22PA Zone 1 during the Zone 1 Pump Test

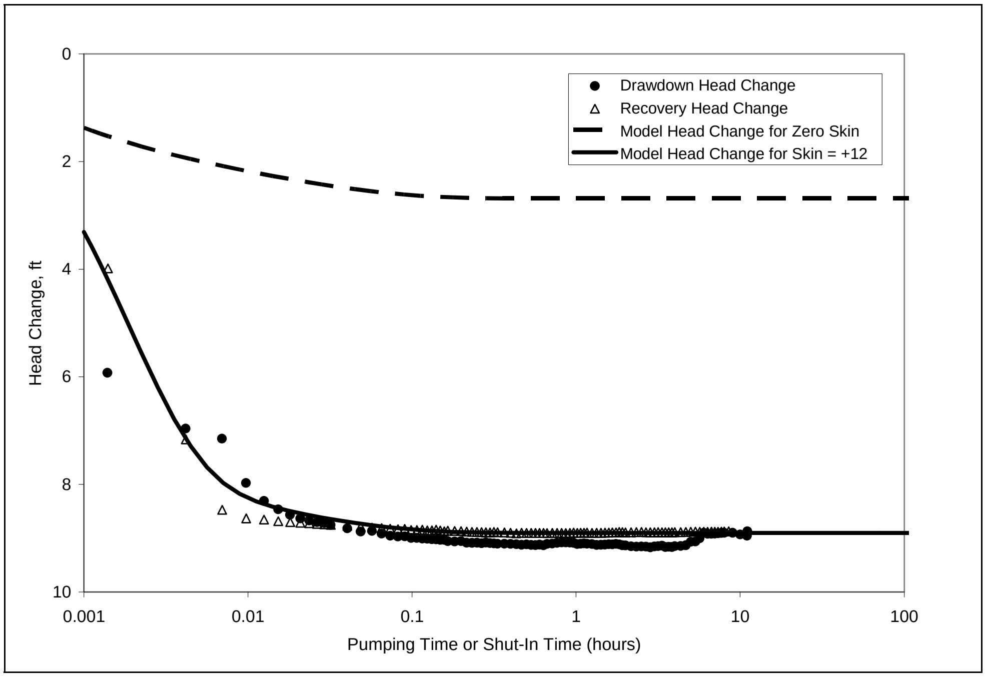


Figure 10
Comparison of Model Results to Measured Head Changes
in 22S Zone1 during the Zone 1 Pump Test

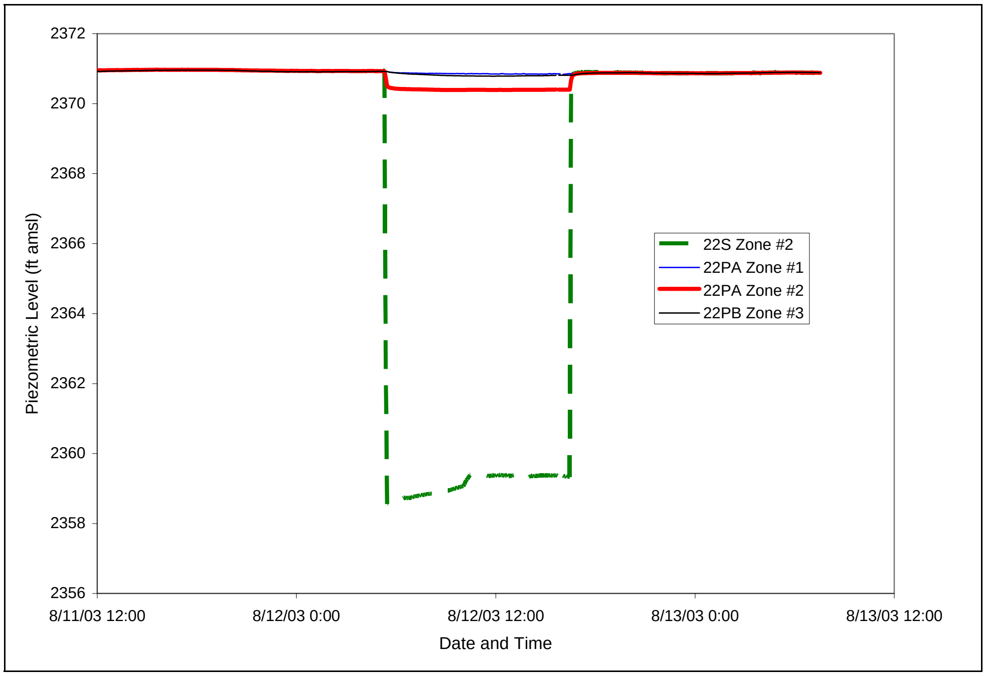


Figure 11
Piezometric Levels with Expanded Scale
Showing Zone 2 Pump Test Responses in Zones 1 through 3

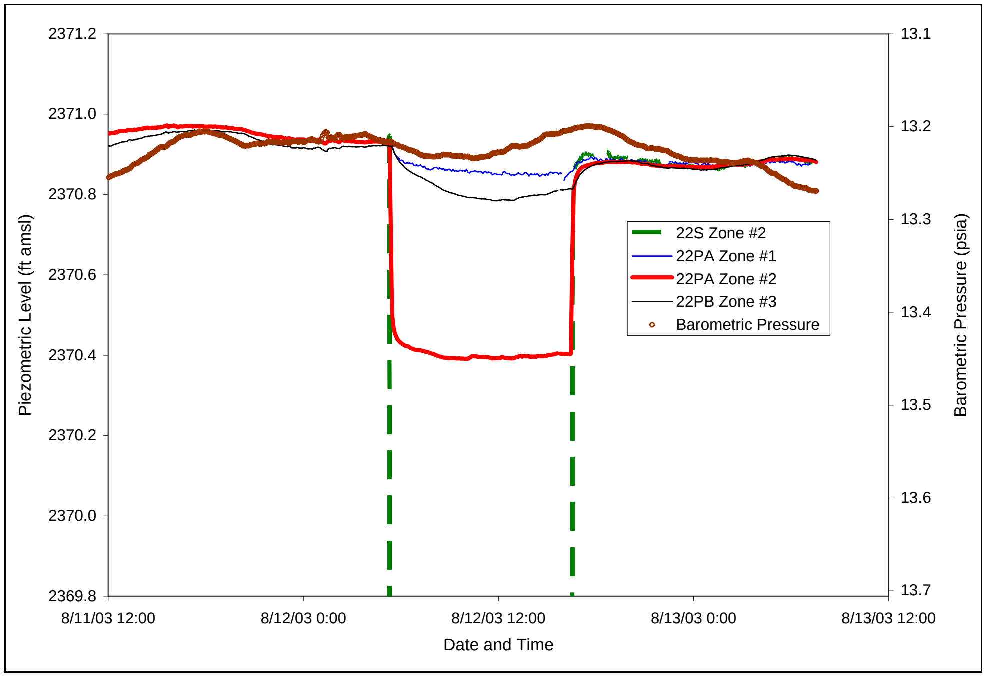


Figure 12
Piezometric Levels and Barometric Pressures
Showing Zone 2 Pump Test Responses in Zones 1 through 3

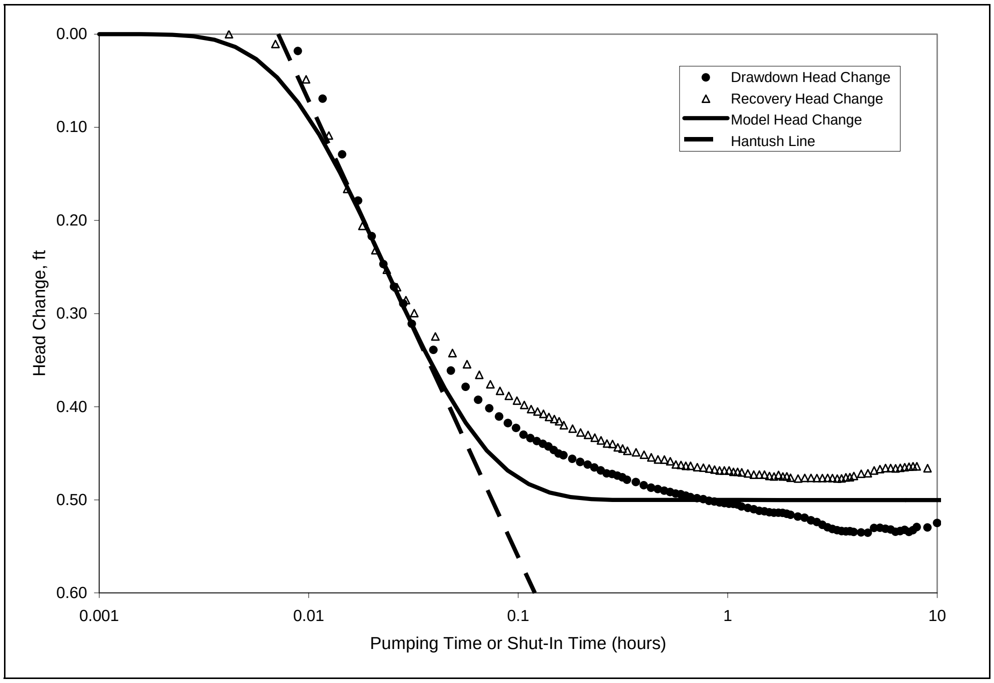


Figure 13
Comparison of Unshifted Model Results to Measured Head Changes
in 22PA Zone 2 during the Zone 2 Pump Test

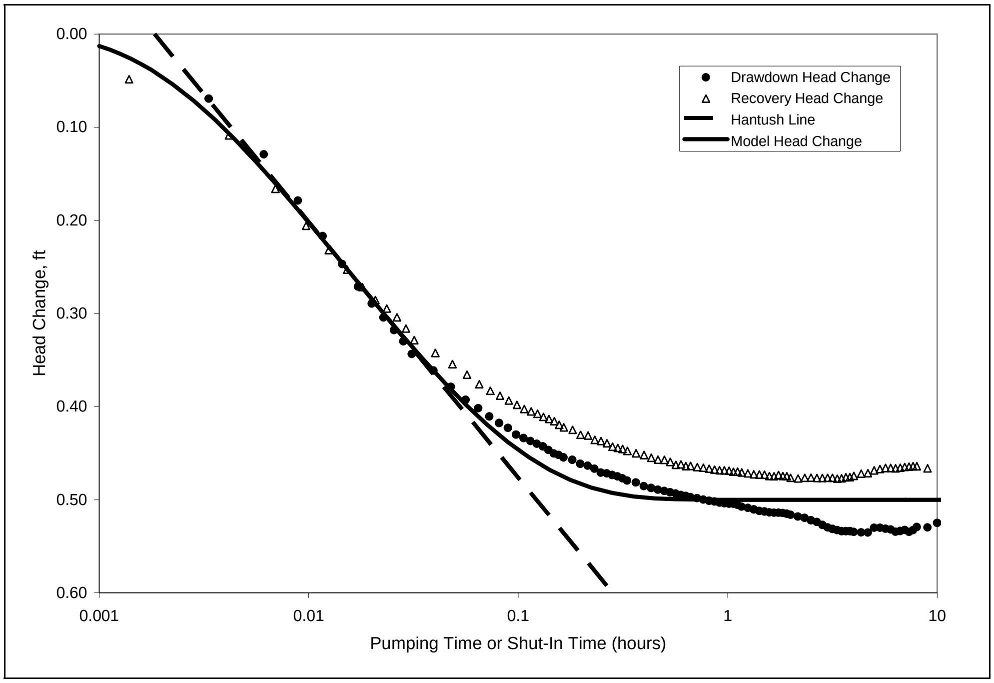


Figure 14
Comparison of Shifted Model Results to Shifted Head Changes
in 22PA Zone 2 during the Zone 2 Pump Test

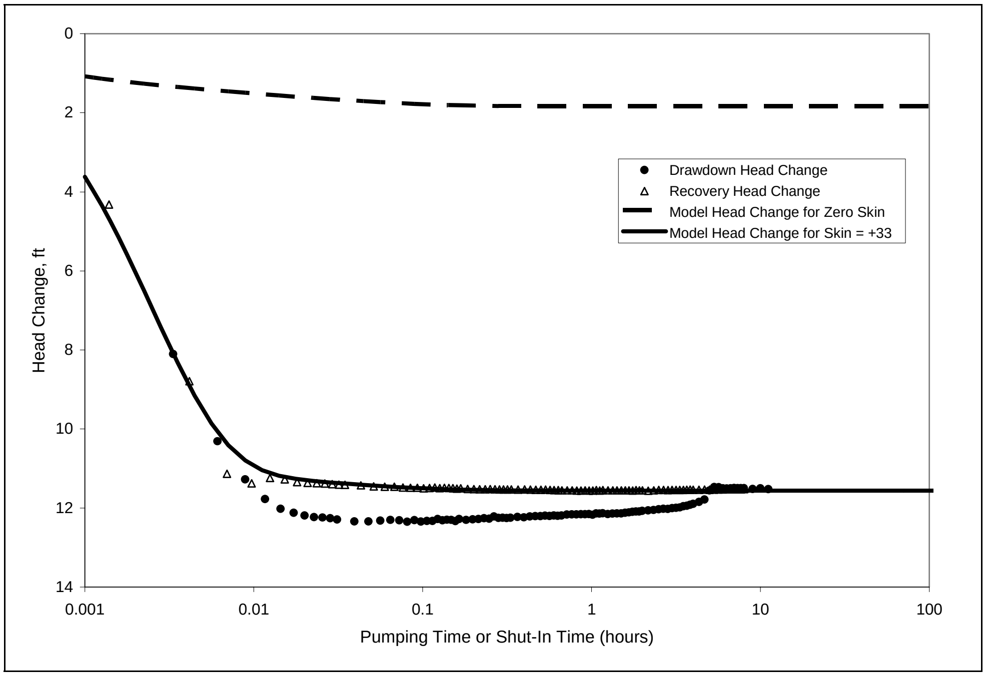


Figure 15
Comparison of Model Results to Head Changes
in 22S Zone 2 during the Zone 2 Pump Test

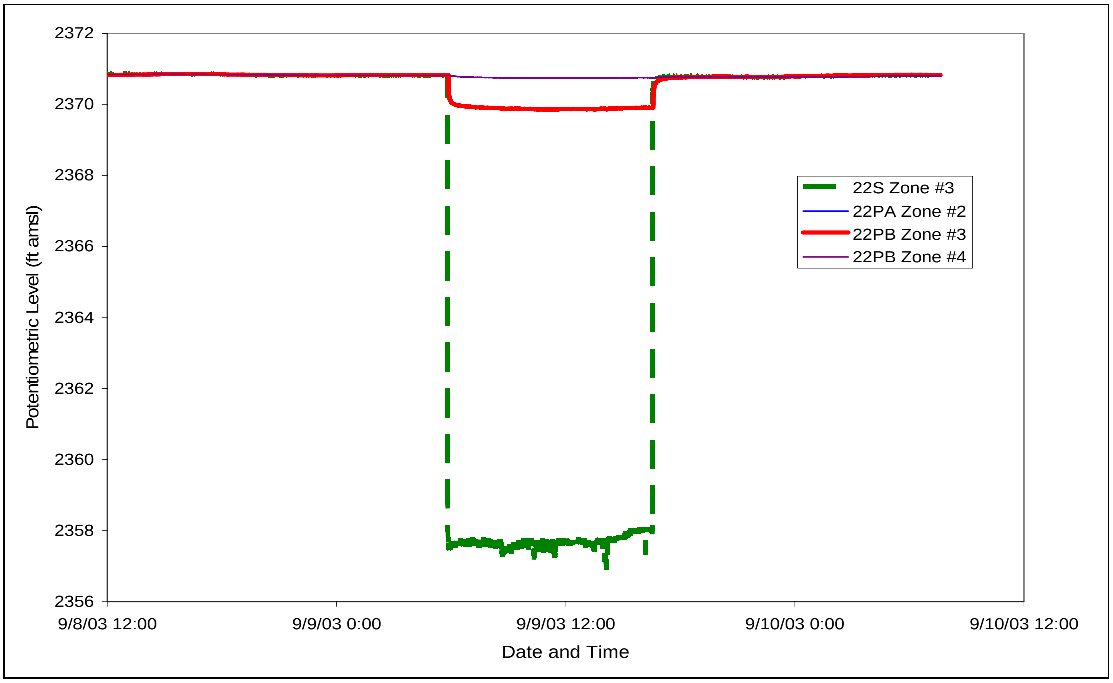


Figure 16
Piezometric Levels with Expanded Scale
Showing Zone 3 Pump Test Responses in Zones 2 through 4

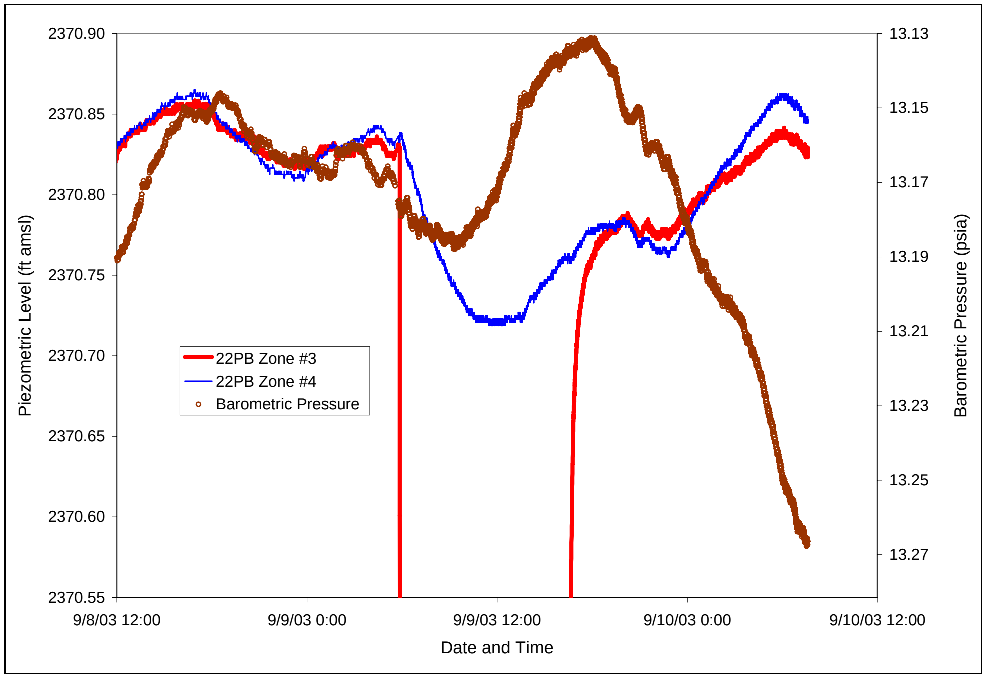


Figure 17
Piezometric Levels and Barometric Pressures
Showing Zone 3 Pump Test Responses in Zones 3 and 4

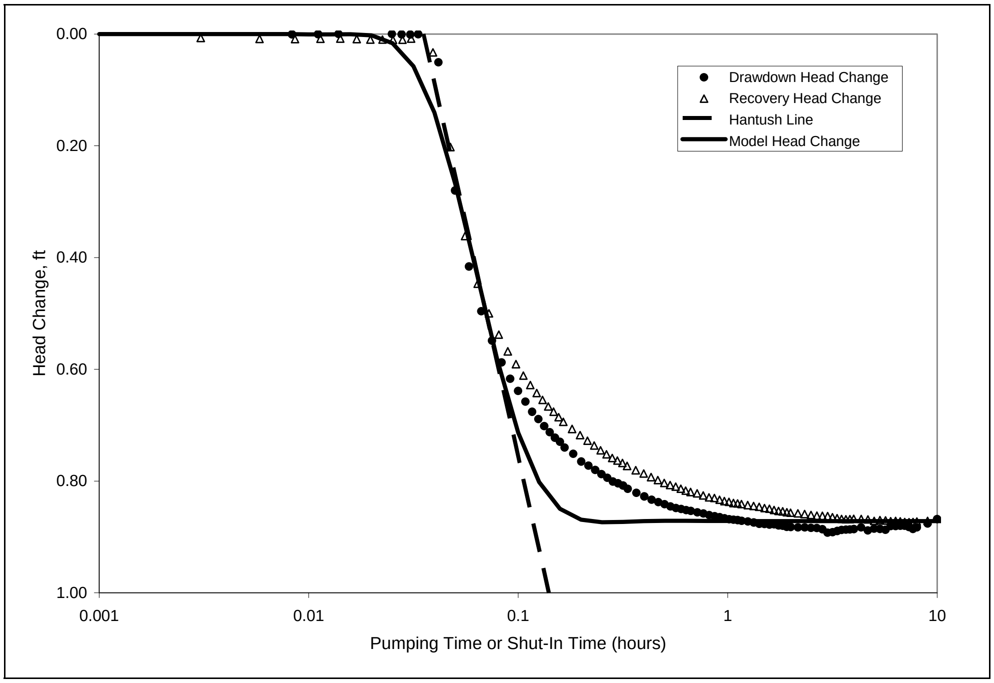


Figure 18
Comparison of Unshifted Model Results to Measured Head Changes
in 22PB Zone 3 during the Zone 3 Pump Test

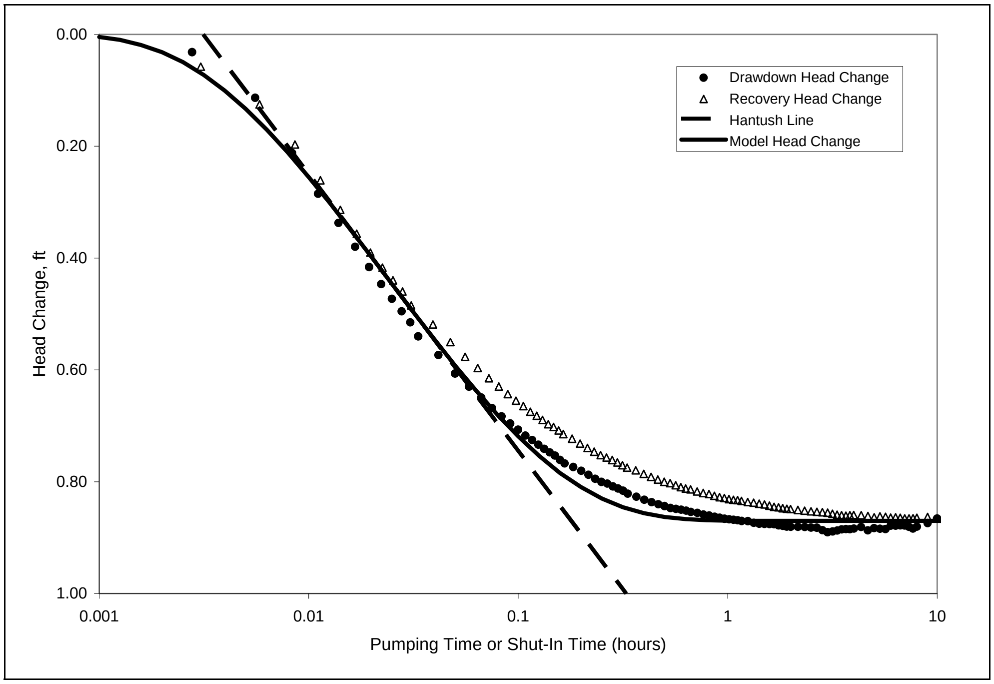


Figure 19
Comparison of Shifted Model Results to Shifted Head Changes
in 22PB Zone 3 during the Zone 3 Pump Test

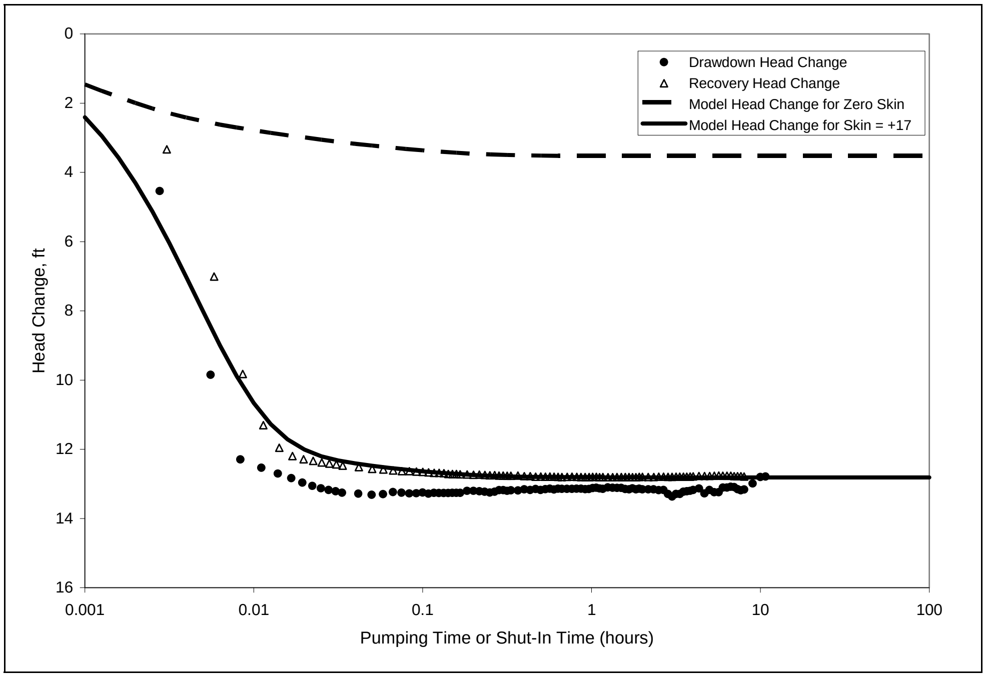


Figure 20
Comparison of Model Results to Measured Head Changes
in 22S Zone 3 during the Zone 3 Pump Test

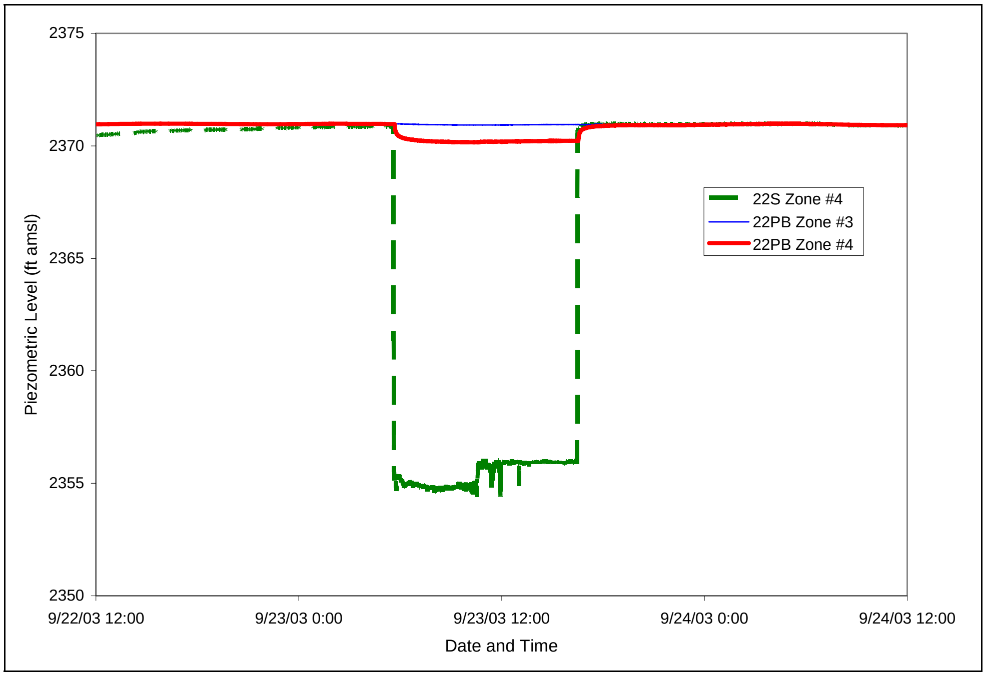


Figure 21
Piezometric Levels with Expanded Scale
Showing Zone 3 Pump Test Responses in Zones 3 and 4

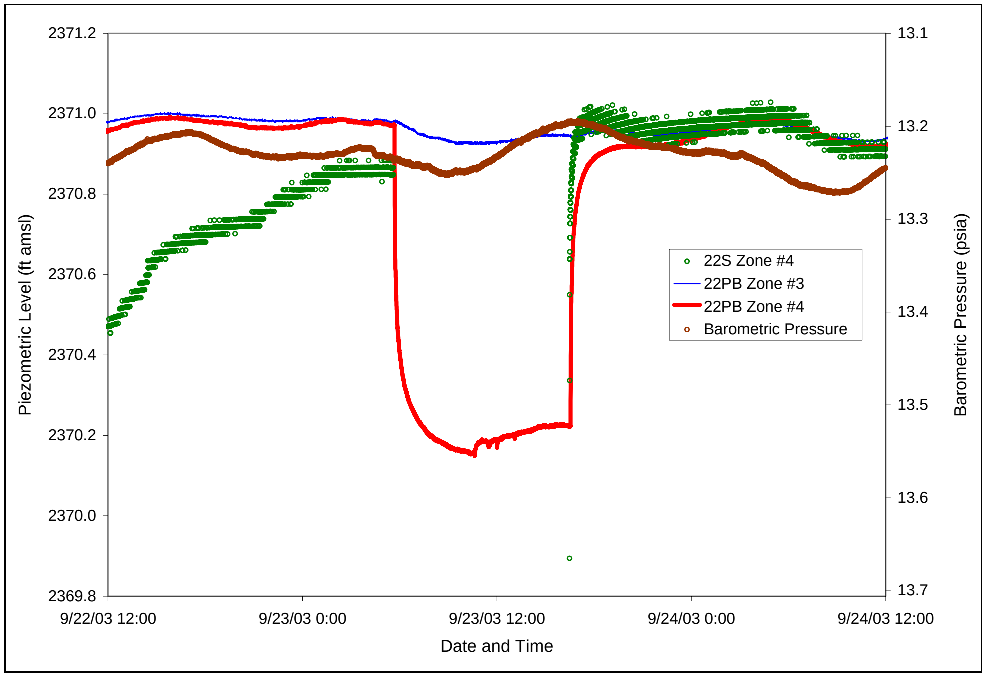


Figure 22
Piezometric Levels and Barometric Pressures
Showing Zone 4 Pump Test Responses in Zones 3 and 4

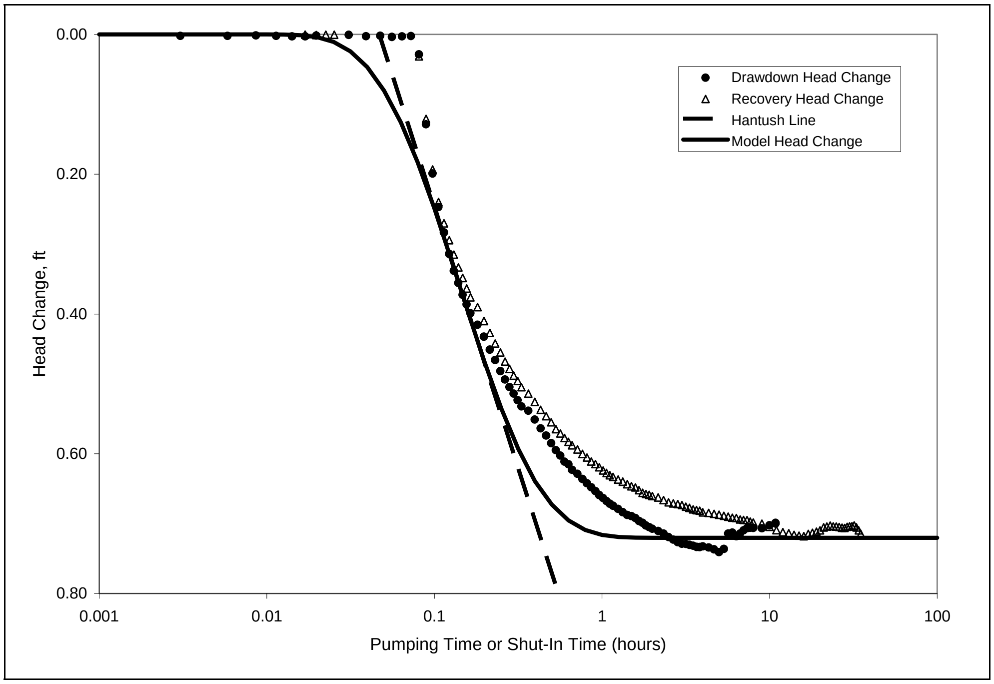


Figure 23
Comparison of Unshifted Model Results to Measured Head Changes
in 22PB Zone 4 during the Zone 4 Pump Test

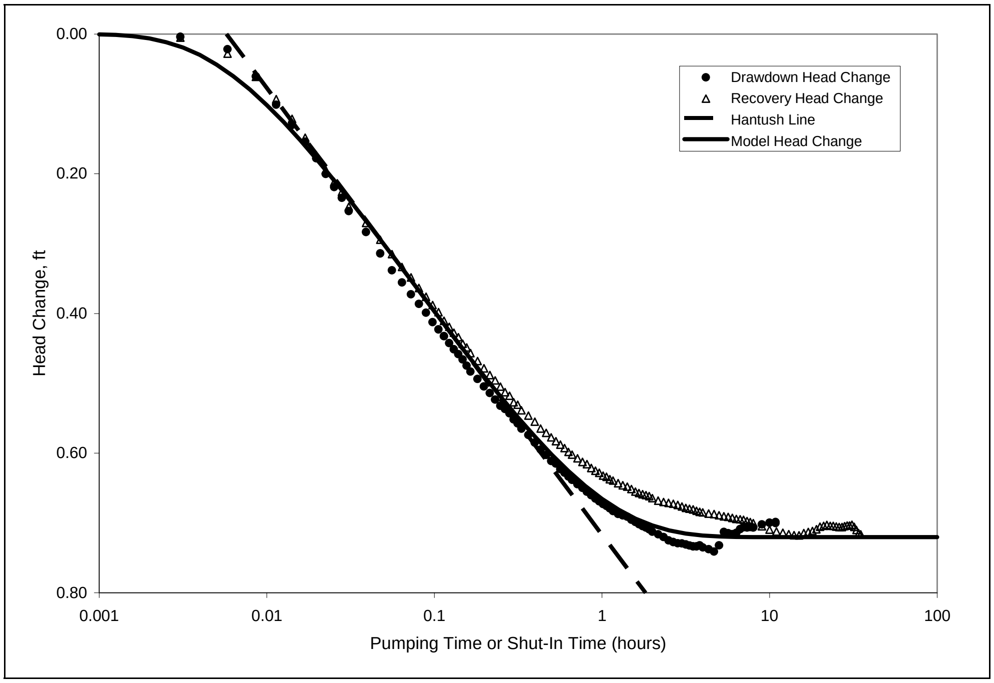


Figure 24
Comparison of Shifted Model Results to Shifted Head Changes
in 22PB Zone 4 during the Zone 4 Pump Test

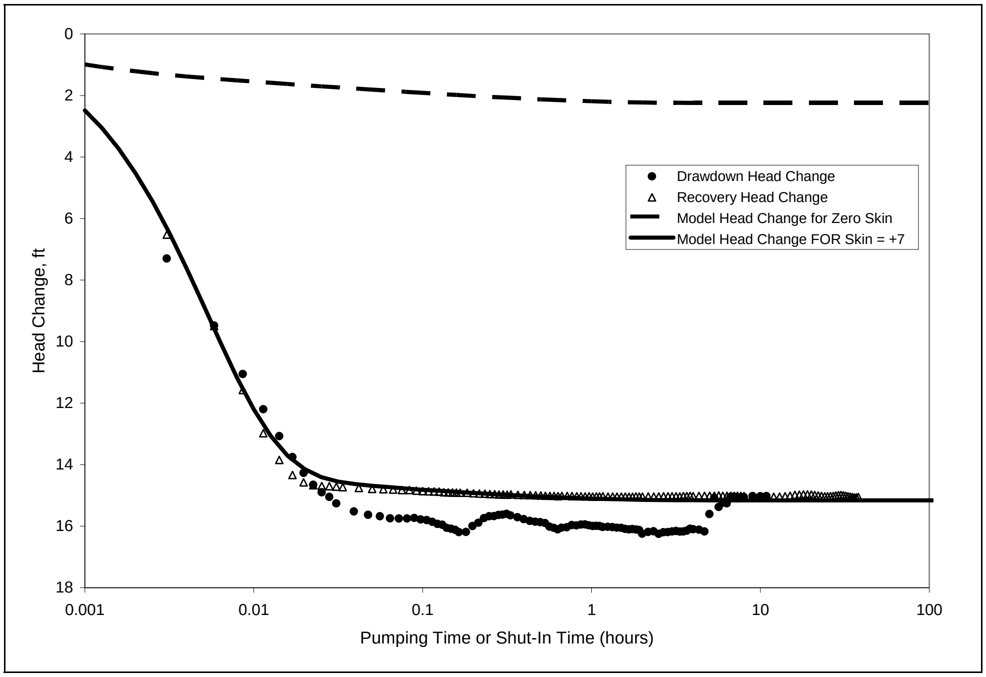


Figure 25
Comparison of Model Results to Measured Head Changes
in 22S Zone 4 during the Zone 4 Pump Test

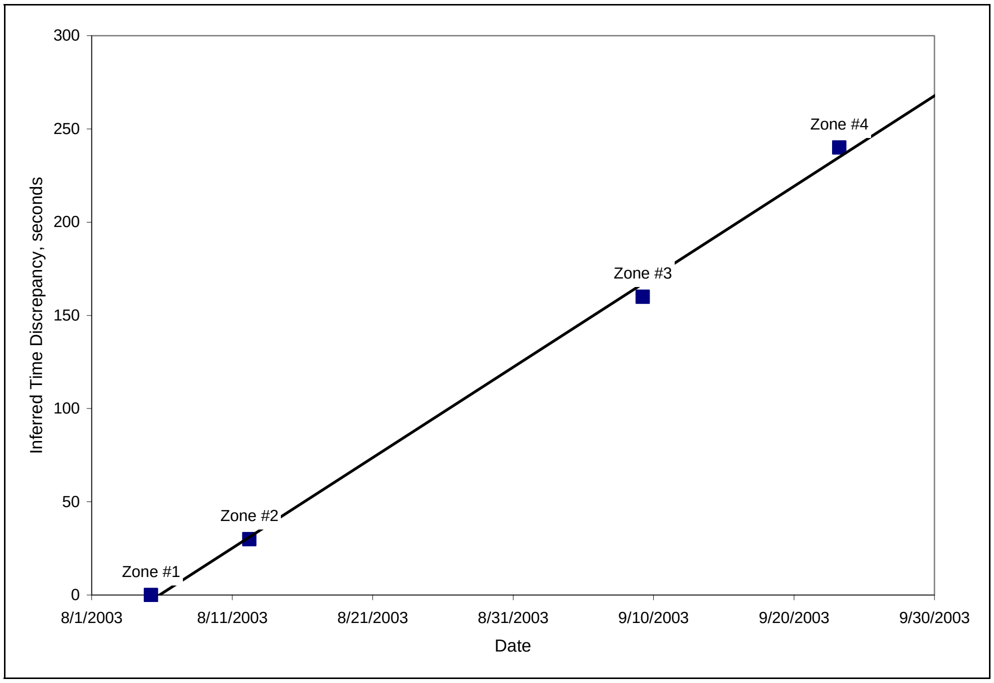


Figure 26
Inferred Discrepancies vs. Date in Datalogger Clock Times

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TABLES

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Table 1

Zones and Screen Depths in Site 22 Wells

Well Name	Well Zone	Sand Pack Depth Interval (feet below ground surface [feet bgs])	Sand Pack Height (feet)	Screen Top to Bottom Measured Depth (feet bgs)	Screen Height (feet)
22S	1	513.4 – 586.3	72.9	521.5 – 581.3	59.8
	2	651.8 – 766.5	114.7	661.2 – 760.6	99.4
	3	870.3 – 986.9	116.6	880.2 – 980.0	99.8
	4	1133.2 – 1196.5	63.3	1140.0 – 1180.0	40.0
22PA	1	508.7 – 587.0	78.3	520.7 – 579.7	59
	2	649.7 – 779.8	130.1	661.5 – 759.8	98.3
22PB	3	870.7 – 989.2	118.5	881.3 – 979.7	98.4
	4	1125.2 – 1199.7	74.5	1140.3 – 1179.7	39.4

Table 2
Start Times for Drawdown and Recovery

Pump Test	Start Time	
	Drawdown	Recovery
Zone 1	Midway	Midway
Zone 2	2 seconds after last steady reading	Midway
Zone 3	Immediately after last steady reading	2 seconds before first changed reading
Zone 4	1 second after last steady reading	1 second after last steady reading

Table 3

Summary of Preliminary and Individual Zone Tests for Site 22 Pumping and Observation Wells

Preliminary Analysis based on Combined Pump Spinner Test					
Observation Well	22PA Zone 1	22PA Zone 2	22PB Zone 3	22PB Zone 4	Total or Average
Thickness (feet)	72.9	114.7	116.6	63.3	368
Allocated Rate (gallons/minute [gpm])	44	53	23	13	133
Transmissivity (square feet/day [ft^2/d])	3,400	5,900	2,550	2,900	14,750
Permeability (darcy)	16	17.7	7.5	15.4	14.1
Storage Coefficient (dimensionless)	0.0016	0.00031	0.00002	0.00023	0.00216
Analysis based on Individual 11-hour Constant Discharge Tests of Discrete Zones					
	Test 1	Test 2	Test 3	Test 4	Total or Average
Pump Rate (gpm)	43.5	44.1	27.1	20.5	135.2
Transmissivity (ft^2/d)	2,600	4,600	1,500	2,000	10,700
Permeability (darcy)	12	14	4.5	11	10
Storage Coefficient (dimensionless)	0.00116	0.00035	0.0001	0.00021	0.00182
Leakance (feet)	98	279	355	750	371

Table 4

Summary of Pumping Well Response Analysis Results for 11-Hour Pump Tests

Results from Pumping Well Response Analysis					
	Test 1 Zone 1	Test 2 Zone 2	Test 3 Zone 3	Test 4 Zone 4	Average
Skin Factor	+12	+33	+17	+7	+17
Well Efficiency	30%	16%	27%	15%	22%

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APPENDIX A
Well Test Analysis Quality Control Checklists

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Appendix A-1
Well Test Analysis Quality Control Checklist for Zone 1 in Observation Well 22PA

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22PA Shallow String
Interval Tested: Single Piezometer w/ Screen: 521'-580'
Test Date: 8/5/2003
Datum: PVC Top @ 2852.15', Probe @ 506.57 TOC
Test Type: Pump Test
Observation Wells: 22PA Shallow
Remarks: Observation data for 22S Pump Test in Zone #1.

Source of Data

Pressure File: 080503R3.wk1,080503R5.wk1,080603R1.wk1,080703R1.wk1,080703R3.wk1
Type of Pressure Gauge: Westbay #3363 (22PA Shallow), 250 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	73	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	3.67E-05	psi $^{-1}$	Match	Interference Model Match
Temperature	78.2	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
~~Wellbore Storage~~ ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 1 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 2,600 ft^2/day
Initial Pressure: 24.07 psia, (2370.9' amsl)
Permeability: 12 Darcy
Final Flowing Pressure: 23.88 psi, (2370.5' amsl)
Skin: +0 on observation well
Extrapolated Reservoir Pressure: 24.07 psia, (2370.9' am
Effective Flow Time: 11 hours
Radius of Investigation: 3,700 ft
Average Flow Rate: 43.5 gpm
Distance to Boundary: NA
Total Flow Volume: 28,700 gal
Storativity: 0.00116 ft/ft

Remarks:
Analysis performed using leaky aquifer type curve match for interference analysis.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-2
Well Test Analysis Quality Control Checklist for Zone 1 in Pumping Well 22S

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22S
Interval Tested: Screen #1, 513.4 – 586.3 ft depth
Test Date: 8/5/2003
Datum: 22S TOC
Test Type: Pump Test
Observation Wells: 22PA (S & D), 22PB (S & D)
Remarks: Screen #1 Individual Zone Pump test

Source of Data

Pressure File: 080503R3.wk1,080503R5.wk1,080603R1.wk1,080703R1.wk1,080703R3.wk1
Type of Pressure Gauge: Westbay #2323 (22S), 250 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	73	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	3.67E-05	psi^{-1}	Match	Interference Model Match
Temperature	78.2	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
[✓ **Wellbore Storage**] ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 1 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 2,600 ft^2/day
Initial Pressure: 26.8 psi, (2370.9' amsl)
Permeability: 12 Darcy
Final Flowing Pressure: 22.9 psi, (2361.9' amsl)
Skin: +12
Extrapolated Reservoir Pressure: 26.8 (2370.9' amsl)
Effective Flow Time: 11 hours
Radius of Investigation: 3,700 ft
Average Flow Rate: 43.5 gpm
Distance to Boundary: NA
Total Flow Volume: 28,700 gal
Storativity: 0.00116 ft/ft

Remarks:
Transmissivity and storativity determined from observation well match.
Skin factor determined from pumping well match using leaky aquifer type curve for pumping well.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-3
Well Test Analysis Quality Control Checklist for Zone 2 in Observation Well 22PA

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22PA Deep String
Interval Tested: Single Piezometer w/ Screen: 650'-780'
Test Date: 8/12/2003
Datum: PVC Top @ 2852.15', Probe @ 506.57 TOC
Test Type: Pump Test
Observation Wells: 22PA Deep
Remarks: Observation data for 22S Pump Test in Zone #2.

Source of Data

Pressure File: 081203R2.wk1,081303R4.wk1,081303R3.wk1
Type of Pressure Gauge: Westbay #2845 (22PA Deep), 30 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	115	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	7.03E-06	psi $^{-1}$	Match	Interference Model Match
Temperature	79	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
~~Wellbore Storage~~ ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ **Other**]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 2 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 4,600 ft^2/day
Initial Pressure: 24.04 psi, (2370.9' amsl)
Permeability: 14 Darcy
Final Flowing Pressure: 23.81 psi, (2370.4 amsl)
Skin: +0 on observation well
Extrapolated Reservoir Pressure: 24.02 (2370.9' amsl)
Effective Flow Time: 11 hours
Radius of Investigation: 9,030 ft
Average Flow Rate: 44.1 gpm
Distance to Boundary: NA
Total Flow Volume: 29,100 gal
Storativity: 0.00010 ft/ft

Remarks:
Analysis performed using leaky aquifer type curve match for interference analysis.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-4
Well Test Analysis Quality Control Checklist for Zone 2 in Pumping Well 22S

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22S

Interval Tested: Single Piezometer w/ Screen: 871'-989'

Test Date: 9/9/2003

Datum: 22S TOC

Test Type: Pump Test

Observation Wells: 22PA (S & D), 22PB (S & D)

Remarks: Screen #3 Individual Zone Pump test

Source of Data

Pressure File: 090403R1.WK1, 090803R1.WK1, 090803R3.WK1, 090903R1.WK1, 090903R2.WK1 090903R3.WK1, 090903R4.WK1, 090903R5.WK1, 090903R6.WK1, 091003R1.WK1, 091003R2.WK1

Type of Pressure Gauge: Westbay #2323 (22S), 250 psia

Source: e-mail, L. Kryder w/ Nye Co.

Units: psia & degrees C

Rate File: Hand Input

Source: Nye County Field Notebook

Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration

Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	117	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	2.09E-06	psi $^{-1}$	Match	Interference Model Match
Temperature	80.1	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A

Length of Flow: 11 hrs

Steady State? Yes

Pseudo-Steady State? No

Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A

Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)

[✓ **Wellbore Storage**] ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]

Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures

Software Utilized: Excel

File Name: Screen 1 Analysis.xls

Location: QEC - IBM DOC

Software Utilized:

File Name:

Location:

Result Summary (Include Units)

T - Transmissivity: 1,500 ft^2/day

Initial Pressure: 26.46 psi

Permeability: 4.5 Darcy

Final Flowing Pressure: 21.26

Skin: +17

Extrapolated Reservoir Pressure: 26.26

Effective Flow Time: 11 hours

Radius of Investigation: 9,390 ft

Average Flow Rate: 27.1 gpm

Distance to Boundary: NA

Total Flow Volume: 17,890 gal

Storativity: 0.00010 ft/ft

Remarks:

Transmissivity and storativity determined from observation well match.

Skin factor determined from pumping well match using leaky aquifer type curve for pumping well.

Analyzed by: Dave Cox

Analysis Date: 8/10/2004

Appendix A-5
Well Test Analysis Quality Control Checklist for Zone 3 in Observation Well 22PB

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22S
Interval Tested: Screen #1,651.8 - 766.5 ft depth
Test Date: 8/12/2003
Datum: 22S TOC
Test Type: Pump Test
Observation Wells: 22PA (S & D), 22PB (S & D)
Remarks: Screen #2 Individual Zone Pump test

Source of Data

Pressure File: 081203R2.wk1,081303R3.wk1
Type of Pressure Gauge: Westbay #2323 (22S), 250 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	115	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	7.03E-06	psi $^{-1}$	Match	Interference Model Match
Temperature	79	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
[✓ **Wellbore Storage**] ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 2 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 4,600 ft^2/day
Initial Pressure: 26.87 psi, (2371.0' amsl)
Permeability: 14 Darcy
Final Flowing Pressure: 21.89 psi, (2358 amsl)
Skin: +33
Extrapolated Reservoir Pressure: 26.37 (2371.0' amsl)
Effective Flow Time: 11 hours
Radius of Investigation: 9,030 ft
Average Flow Rate: 44.1 gpm
Distance to Boundary: NA
Total Flow Volume: 29,100 gal
Storativity: 0.00035 ft/ft

Remarks:
Transmissivity and storativity determined from observation well match.
Skin factor determined from pumping well match using leaky aquifer type curve for pumping well.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-6
Well Test Analysis Quality Control Checklist for Zone 3 in Pumping Well 22S

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22PB Shallow String
Interval Tested: Single Piezometer w/ Screen: 871'-989'
Test Date: 9/9/2003
Datum: PVC Top @ 2851.79', Probe @ 504.98 TOC
Test Type: Pump Test
Observation Wells: 22PB Shallow
Remarks: Observation data for 22S Pump Test in Zone #3.

Source of Data

Pressure File: 090403R1.WK1, 090803R1.WK1, 090803R3.WK1, 090903R1.WK1, 090903R2.WK1 090903R3.WK1, 090903R4.WK1, 090903R5.WK1, 090903R6.WK1, 091003R1.WK1, 091003R2.WK1
Type of Pressure Gauge: Westbay #2846 (22PB Shallow), 30 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	117	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	2.09E-06	psi $^{-1}$	Match	Interference Model Match
Temperature	80.1	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
~~Wellbore Storage~~ ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 3 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 1,500 ft^2/day
Initial Pressure: 24.23 psia
Permeability: 4.5 Darcy
Final Flowing Pressure: 23.86 psi
Skin: +0 on observation well
Extrapolated Reservoir Pressure: 24.23 psia
Effective Flow Time: 11 hours
Radius of Investigation: 9,390 ft
Average Flow Rate: 27.1 gpm
Distance to Boundary: NA
Total Flow Volume: 17,890 gal
Storativity: 0.00010 ft/ft

Remarks:
Analysis performed using leaky aquifer type curve match for interference analysis.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-7
Well Test Analysis Quality Control Checklist for Zone 4 in Observation Well 22PB

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22PB Deep String
Interval Tested: Single Piezometer w/ Screen:1125'-1200'
Test Date: 9/23/2003
Datum: PVC Top @ 2851.79', Probe @ 507.62 TOC
Test Type: Pump Test
Observation Wells: 22PB Deep
Remarks: Observation data for 22S Pump Test in Zone #4.

Source of Data

Pressure File: 091803R1.WK1, 091803R2.WK1, 092203R1.WK1, 092203R2.WK1 092303R1.WK1, 092303R2.WK1, 092303R3.WK1, 092303R4.WK1, 092403R1.WK1 092403R2.WK1, 092503R1.WK1, 092503R2.WK1
Type of Pressure Gauge: Westbay #2844 (22PB Deep), 250 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	64	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	7.58E-06	psi $^{-1}$	Match	Interference Model Match
Temperature	82.3	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs
Steady State? Yes
Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
~~Wellbore Storage~~ ~~Bilinear~~ ~~Linear~~ [✓ Radial] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel
File Name: Screen 2 Analysis.xls
Location: QEC - IBM DOC
Software Utilized:
File Name:
Location:

Result Summary (Include Units)
T - Transmissivity: 2,000 ft^2/day
Initial Pressure: 23.97 psi
Permeability: 11 Darcy
Final Flowing Pressure: 23.66 psi.
Skin: +0 on observation well
Extrapolated Reservoir Pressure: 23.97
Effective Flow Time: 11 hours
Radius of Investigation: 7,710 ft
Average Flow Rate: 20.5 gpm
Distance to Boundary: NA
Total Flow Volume: 13,500 gal
Storativity: 0.00021 ft/ft

Remarks:
Analysis performed using leaky aquifer type curve match for interference analysis.

Analyzed by: Dave Cox
Analysis Date: 8/10/2004

Appendix A-8
Well Test Analysis Quality Control Checklist for Zone 4 in Pumping Well 22S

NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
INDEPENDENT SCIENTIFIC INVESTIGATION
YUCCA MOUNTAIN, NEVADA

WELL TEST ANALYSIS QUALITY CONTROL CHECKLIST

Test Information

Borehole: NC-EWDP-22S
Interval Tested: Screen #4, 1140.3 - 1179.7 ft depth
Test Date: 9/23/2003
Datum: 22S TOC
Test Type: Pump Test
Observation Wells: 22PA (S & D), 22PB (S & D)
Remarks: Screen #4 Individual Zone Pump test

Source of Data

Pressure File: 091803R1.WK1, 091803R2.WK1, 092203R1.WK1, 092203R2.WK1
092303R1.WK1, 092303R2.WK1, 092303R3.WK1, 092303R4.WK1, 092403R1.WK1
092403R2.WK1, 092503R1.WK1, 092503R2.WK1
Type of Pressure Gauge: Westbay #2323 (22S), 250 psia
Source: e-mail, L. Kryder w/ Nye Co.
Units: psia & degrees C
Rate File: Hand Input
Source: Nye County Field Notebook
Type of Flow Meter: Flow Meter Totalizer, Barrel Calibration
Units: GPM

Assumptions

	Value	Units	Source	Comments
Height / Thickness	64	ft	Comp. Log	Estimate of gravel pack intervals
Porosity	30%		Est	Alluvium
Viscosity	0.9436	cp	*Saphir*	Software value
Wellbore Radius	0.615	ft	est	Nominal Bit Size
Compressibility	7.58E-06	psi^{-1}	Match	Interference Model Match
Temperature	82.3	deg F	Measured	Avg. Pumping Temperature

Results

Cartesian Plot Analysis: N/A
Length of Flow: 11 hrs   Steady State? Yes   Pseudo-Steady State? No
Remarks: Data were averaged prior to analysis..

Log-Log Plot Analysis: N/A
Flow Regimes Noted: (Circle Appropriate Types; Include Flow Regime Plot if Appropriate)
[✓ **Wellbore Storage**] ~~Bilinear~~ ~~Linear~~ [✓ **Radial**] ~~Spherical~~ [✓ Other]
Remarks: DD & Recovery data reach steady state, indicative of leaky aquifer response.

Analysis Procedures
Software Utilized: Excel   File Name: Screen 2 Analysis.xls   Location: QEC - IBM DOC
Software Utilized: File Name: Location:

Result Summary (Include Units)
T - Transmissivity: 2,000 ft^2/day
Initial Pressure: 26.78 psi
Permeability: 11 Darcy
Final Flowing Pressure: 20.33 psi
Skin: +17
Extrapolated Reservoir Pressure: 26.78
Effective Flow Time: 11 hours
Radius of Investigation: 7,710 ft
Average Flow Rate: 20.5 gpm
Distance to Boundary: NA
Total Flow Volume: 13,500 gal
Storativity: 0.00021 ft/ft

Remarks:
Transmissivity and storativity determined from observation well match.
Skin factor determined from pumping well match using leaky aquifer type curve for pumping well.

Analyzed by: Dave Cox   Analysis Date: 8/10/2004