Using GPS to Quantify Three Dimensional Storage and Aquifer Deformation in the Virgin River Valley, NV

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Abstract

The horizontal component of land subsidence is typically assumed to be negligible, although recently, theoretical simulations have shown that horizontal strain is significant. A field based investigation in Mesquite, NV, was undertaken from May to July, 2003, for the purpose of evaluating the significance of horizontal strain during an aquifer test. The hydraulic heads in the aquifer were monitored within a meter of the municipal pumping well used for the aquifer test and also at a distance of approximately 1,470 meters from the pumping well. Aquifer deformation in the horizontal and vertical directions were measured using GPS for the first 22 days of pumping in 10 different locations at radial distances from the well varying from 100 meters to 2500 meters. From 22 to 60 days of the aquifer test, the number of GPS stations monitoring deformation was reduced to five.

Radial displacement was measured at all monitoring stations during the aquifer test, indicating that the aquifer is moving closer to the pumping well. The greatest magnitude displacement measured 140 m from the well was approximately 10 mm at the land surface. A zone of radial compression occurred between the pumping well and the first monitoring station 140 m away from the pumping well. Vertical displacement was measured in decreasing magnitude with increasing distance from the well. Because GPS is not as precise a tool in the vertical direction as it is in the horizontal, the vertical signal of displacement is not as accurate.

Numerical simulations using the BIOT and IBS codes were performed to reproduce the aquifer test and land deformation. The model included six layers representing three hydrogeologic units: a bottom aquifer (four layers) in which pumping occurred , a top aquifer (one layer) in which the monitoring well was screened, and a semi-confining bed (one layer) between the two aquifers that

represented an equivalent thickness of interbeds and clays layers. The Biot code was used to simulate radial and vertical movements in an axisymmetrical simulation, while the IBS code was used to simulate only vertical displacement but also provided for the simulation of elastic and inelastic storage and compression.

The vertical distribution of radial displacement was simulated using the BIOT code. At the onset of pumping, the greatest radial displacement occurred in the bottom aquifer in which pumping occurred. At a distance of 2,000 m from the well, the radial displacement was uniform over all depths indicating that the differences in hydraulic diffusivity are not as important a factor at distance from the well.

The change in porosity that occurred as a result of horizontal strain was greatest in the bottom aquifer. Using the strain calculated directly from the GPS measurements at the land surface, vertical strain comprised almost 99% of the volume strain at the land surface. However, when the strain was simulated over the entire aquifer system, the radial and hoop strain contributed more than vertical strain in the bottom aquifer at a radius of 100 m from the pumping well at the onset of pumping until the aquifer reached near equilibrium, at which time vertical strain again dominated.

Acknowledgements

I have many people and organizations that I would like to acknowledge that helped to make this project possible. First and foremost, I would like to thank the National Science Foundation Hydrologic Sciences Division and the Department of Geosciences their contributions of funding to this the project. I would also like to thank UNAVCO and Jim Greenburg for loaning us the GPS Equipment and helping us set up our campaign. We would not have had such great success as without them. Finally, I would like to thank Mike Johnson and the Virgin Valley Water District for providing us the field site, data and storage for our equipment.

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1.0 Introduction

Land subsidence due to groundwater withdrawal is a known problem in unconsolidated sediments, especially in regions where surface water is scarce and reliance on groundwater is high. Traditionally, researchers view subsidence as a one-dimensional problem with deformation occurring only in the vertical direction with horizontal movement considered negligible. Until this study, little documented quantitative horizontal deformation field data existed resulting from groundwater pumping. A new well was installed by the Virgin Valley Water District in Mesquite, NV, providing an opportunity to measure aquifer deformation resulting from new stresses and strains induced by pumping. An aquifer test was performed using this well and the ground deformation at the surface around the well was measured using high precision GPS techniques. The high compressibility of the unconsolidated sediments located at this easily accessible site made this site an ideal location for measuring horizontal and vertical displacements.

1.1 Purpose and Scope

The purpose of the study was to collect preliminary surface movement data using high precision GPS to determine if significant horizontal and vertical movements occur as a result of pumping in the regional aquifer in the Mesquite area. The high precision GPS technique was evaluated to determine its effectiveness in measuring small surface movements during an aquifer test. The aquifer deformation measurements as measured at the land surface provide the information to estimate a three dimensional storage coefficient, which leads to a better understanding of aquifer management. The land surface movements are assumed to be subdued replicas of the actual aquifer movements. Using the aquifer test data, the aquifer was also modeled using two different subsidence codes to determine the most realistic conceptual model of the aquifer system, to quantify aquifer parameters and to determine the effects of long term pumping on the aquifer. The results of this study can be used to develop better aquifer management practices for aquifers experiencing deformation due to pumping.

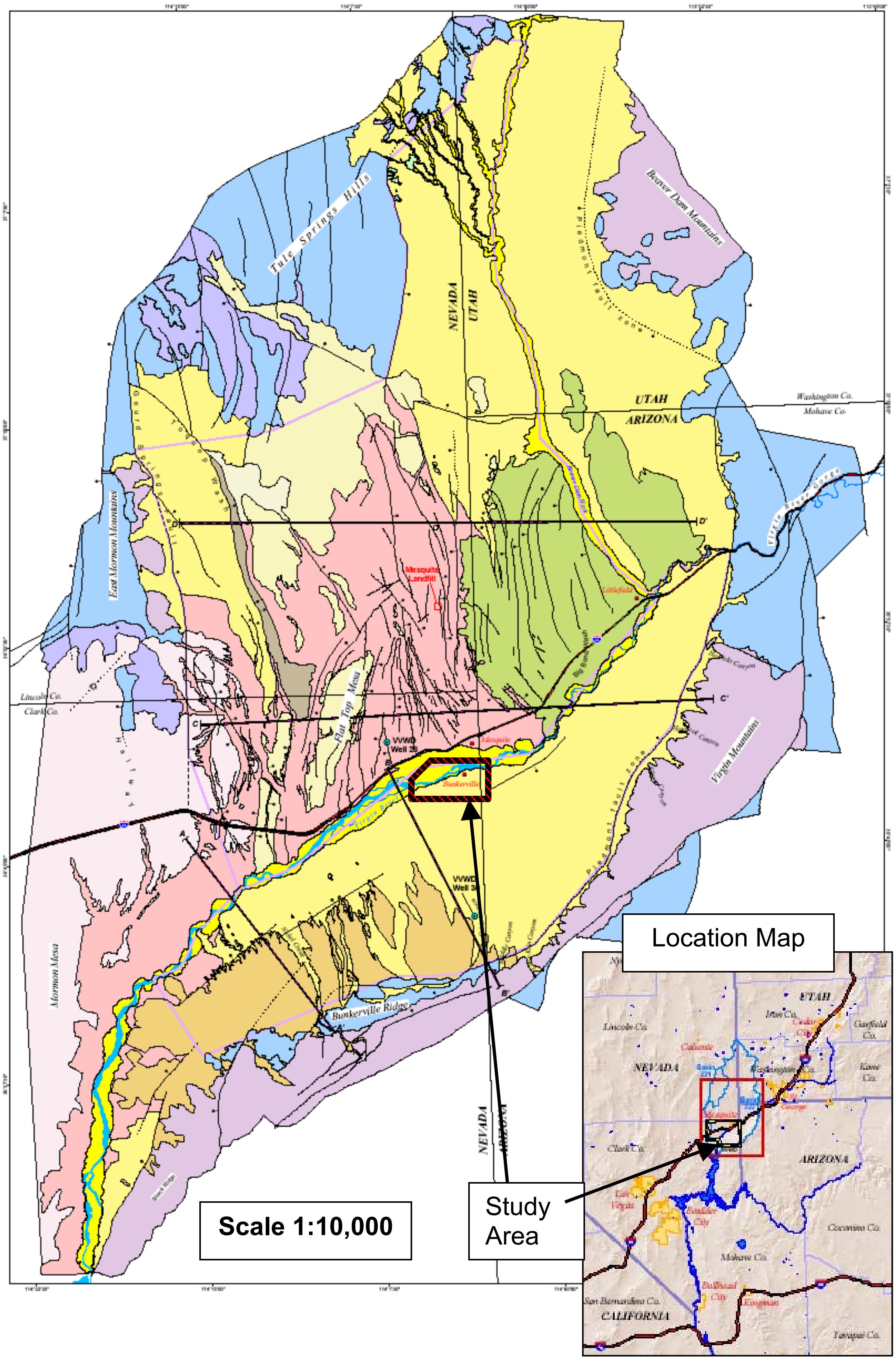
1.2 Project Goals

The goals of the project were to determine whether horizontal deformation due to an aquifer test can be measured using GPS and to use the deformation data collected to determine if horizontal displacements are important to include in the storage coefficient. The project will provide field data to support several theoretical studies that simulate horizontal strain in an ideal aquifer. The final goal of the project is to predict what impact horizontal strain could have in subsiding basins.

2.0 STUDY AREA AND EXPERIMENTAL DESIGN

2.1 A Brief Hydrogeologic Setting of Mesquite, NV

The Mesquite basin is located in one of the deepest basins in the Basin and Range Province of the southwest United States (Figure 1). The basin's depth ranges from 1600 m to 4830 m (Johnson, et al., 2002). The basin is bounded by the Tule Spring Hills, East Mormon Mountains, Beaver Dam Mountains, Virgin Mountains, and the Mormon Mesa. Highly compressible unconsolidated sediments comprise most of the basin fill, which results in the basin being susceptible to land subsidence. Figure 1 contains a regional geologic map of the Lower Virgin River Valley (Dixon and Katzer, 2002). The study area is located south of the Virgin River near Bunkerville. The surface geology in the study area is entirely Quarternary Alluvium or unconsolidated gravel, sand, and silt. There are no faults expressed at the surface in the study area.


Location Map
Scale 1:10,000
Study Area
Tule Springs Hills
Beaver Dam Mountains
NEVADA
UTAH
ARIZONA
Washington Co.
Mohave Co.
East Mormon Mountains
Mesquite Landfill
Littlefield
Lincoln Co.
Clark Co.
Flat Top Mesa
VVWD Well 29
VVWD Well 34
Mesquite
Bunkerville
Virgin Mountains
Mormon Mesa
Bunkerville Ridge
Virgin River Gorge
Piedmont fault zone
Gourd Springs Wash
Toquop Wash
Halfway Wash
Black Ridge
Iron Co.
Garfield Co.
Kane Co.
Coconino Co.
Mohave Co.
Yavapai Co.
San Bernardino Co.
CALIFORNIA
Las Vegas
Boulder City
Bullhead City
Kingman
Caliente
St. George
Cedar City

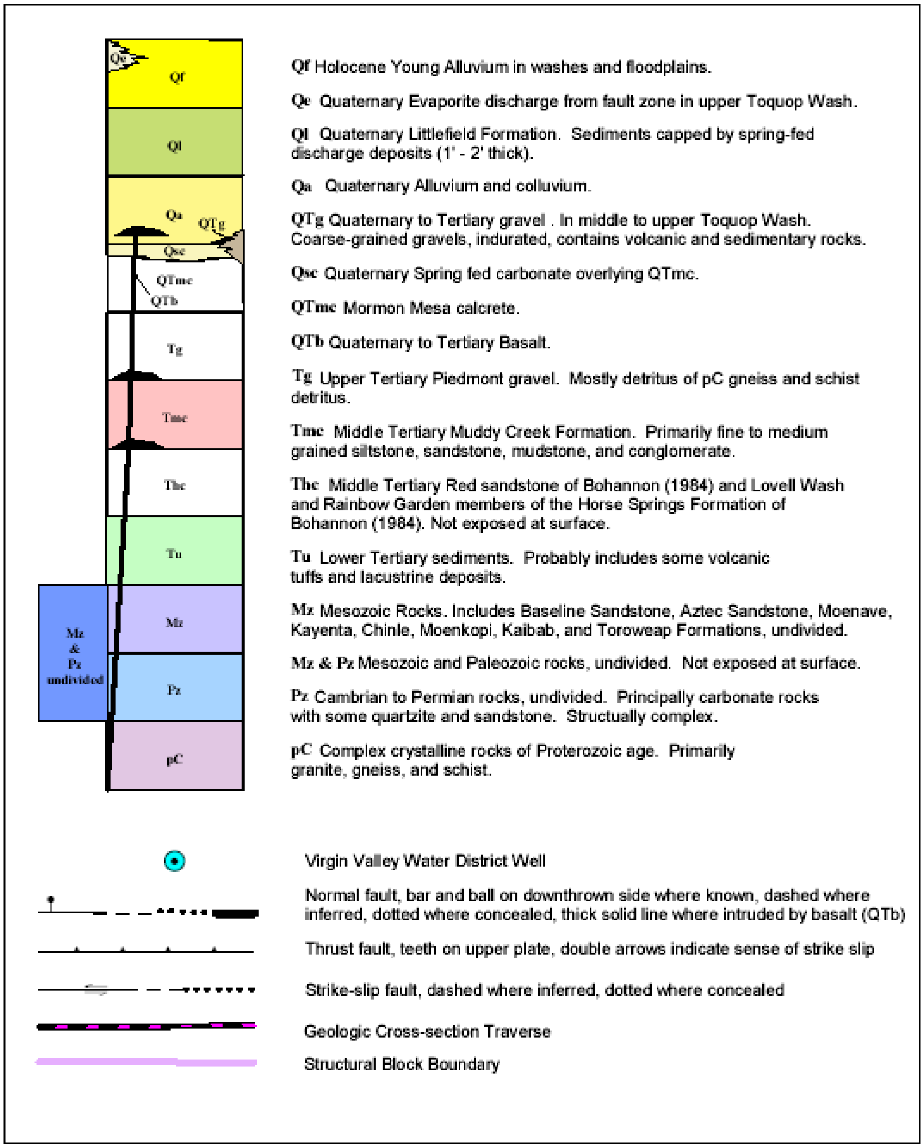
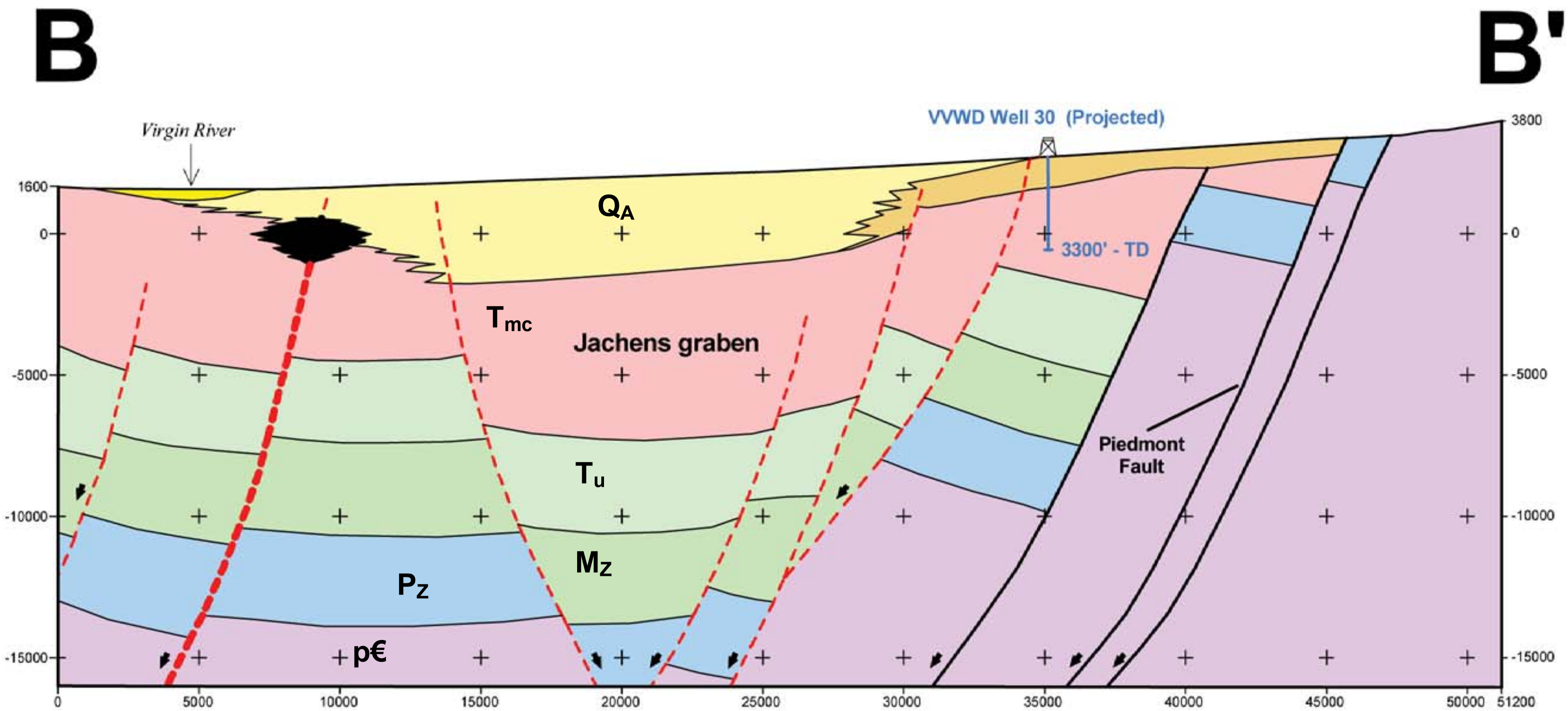


Figure 1: Geologic map of lower Virgin River Valley and explanation of geologic units
The study area is located south of Bunkerville along the Nevada/Arizona border, (see location map in lower right hand corner for reference to study area location). The surface geology in the study area is Quaternary alluvium consisting of unconsolidated gravel, sand and silt.

The basement rock of the basin is comprised of two structural blocks: the Piedmont block and Central Mesquite block. The test well is located in the sediments overlying the Piedmont structural block, characterized by striking east-northeast faults (Langenheim, et. al 2000). Figure 2 shows a cross section along the B-B' line in Figure 1. The general direction of steady-state groundwater flow through the study area is east-southwest to west-northwest. Although the cross sectional line is approximately 4 km southwest of the study area, the geometry of the cross section is characteristic of the cross section within the study area.



Cross Section B

Figure 2: A cross section along line B to B' in Figure 1
The center block, labeled here as Jachen's graben, is the Piedmont Block and is characterized by east-west faults. The geologic units are explained in Figure 1. The pink layer is the Muddy Creek Unit, which is the regional aquifer investigated in this study.

In the specific area of the study well, the three main hydrogeologic units are the underlying carbonate Paleozoic aquifer, the Muddy Creek Formation aquifer, and the Quarternary and Tertiary Alluvial Aquifer. The Paleozoic Carbonate Aquifer occurs at considerable depth (at least 2000 m) and is highly faulted and fractured similar to other carbonate aquifers in the Basin and Range. In the surrounding mountains where the carbonates outcrop, rain provides recharge to this deep carbonate aquifer. The Muddy Creek Formation overlies the carbonate aquifer and is comprised of 800 to 1500 m of unconsolidated deposits, consisting of basal gravel, overlain by fine-grained clay and silt sized deposits of Tertiary age (Johnson, et. al 2002). The Muddy Creek Formation is the confined aquifer used in at least five of the Virgin Valley Water District's municipal wells, including the study well, and has been found to have especially high transmissivities along faults. Water from the Carbonates may leak upward to provide recharge to the Muddy Creek unit; however, no direct evidence of this process has been assessed. Data from the well log of municipal well 31 indicate that the Muddy Creek Unit has several facies from the base (485 m below land surface) to the top (24 m below land surface) that include silty clay with sand stringers, silty sand with clay stringers, silty sand, silty sand with gravel, and clay, respectively (written comm., Johnson, 2003). The Muddy Creek sediments were deposited in a lacustrine environment, where four cycles of lake formation and destruction (by the Virgin River) are recorded (Dixon and Katzer, 2002). The cycles of fine grained and coarse grained sediments created a series of aquifers containing discontinuous clay interbeds separated by continuous confining units. The connectivity and transmissivities of the aquifers in the Muddy Creek unit vary significantly based on location. The Alluvium unit above the Muddy Creek represents weathered materials from mountains, which was transported from high elevations to lower elevations and deposited in the basin. The unconsolidated sediments of the unit are usually sub-angular to angular clasts that range from gravel to sand. The thickness of the alluvial sediments varies across the model area from a few meters to 25 meters. The Alluvial unit contains several perched aquifers and saturated zones; however, the water quantity and quality of the water is poor.

The unit is used for domestic wells. Figure 3 shows fabric and grain-size distribution of the Muddy Creek and Alluvial sediments. At the study site, the Alluvial Aquifer is unsaturated and is not further considered in this investigation.

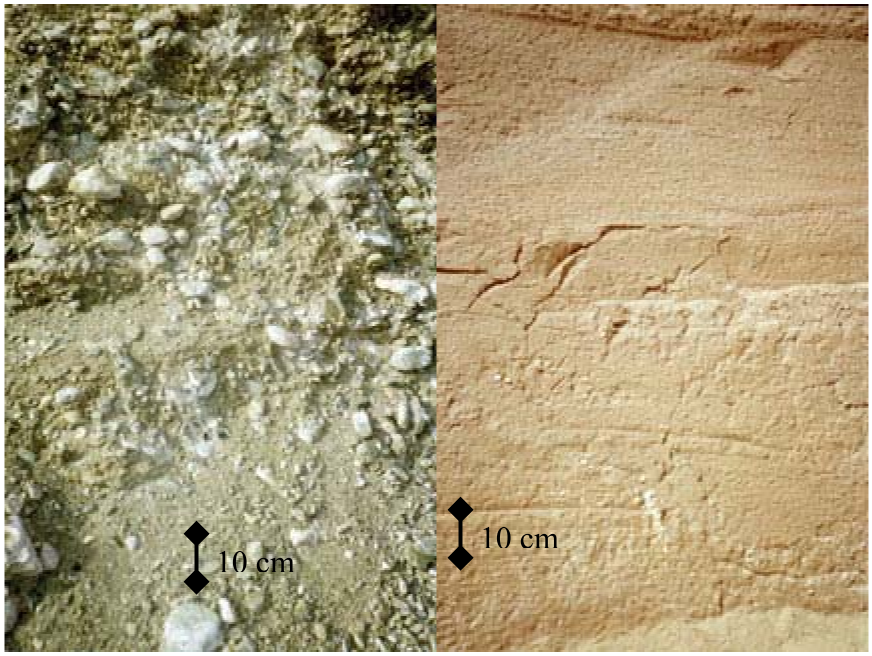


Figure 3: Alluvium and Muddy Creek Aquifer Units

An example of the alluvial aquifer unit (on left) and Muddy Creek Aquifer unit (on right). The alluvial sediments are highly variable in size, while the Muddy Creek unit is mostly finer grained sediments.

Figure 4 shows a map of the regional potentiometric surface (in feet) of the Muddy Creek Aquifer. The direction of groundwater movement follows the topographic trend of the basin discharging into Lake Mead directly into the Virgin River. In the study area, the regional gradient is almost exactly east to west.

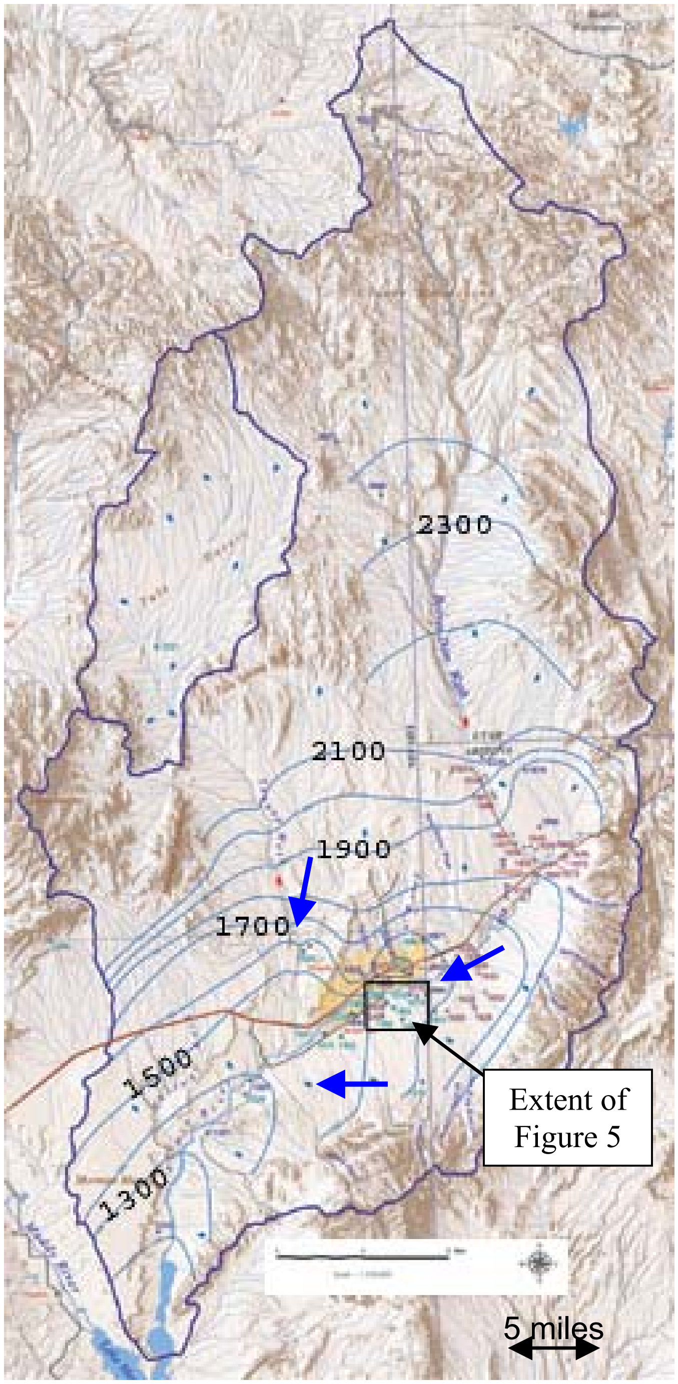


Figure 4: Regional groundwater map

The yellow shaded area represents the city limits of Mesquite. The regional groundwater flow in the study area is almost exactly east to west, and the units of equipotentials are feet. The blue arrows represent the general direction of groundwater flow. Overall, the Virgin River is a gaining stream across the whole basin indicating that groundwater is discharging to the stream. The boxed area represents the study site.

An extensive description of the geology, surface hydrology, and water budget can be found in Dixon and Katzer (2002). A larger scale map of the study area, Figure 5, includes the wells and GPS station locations.

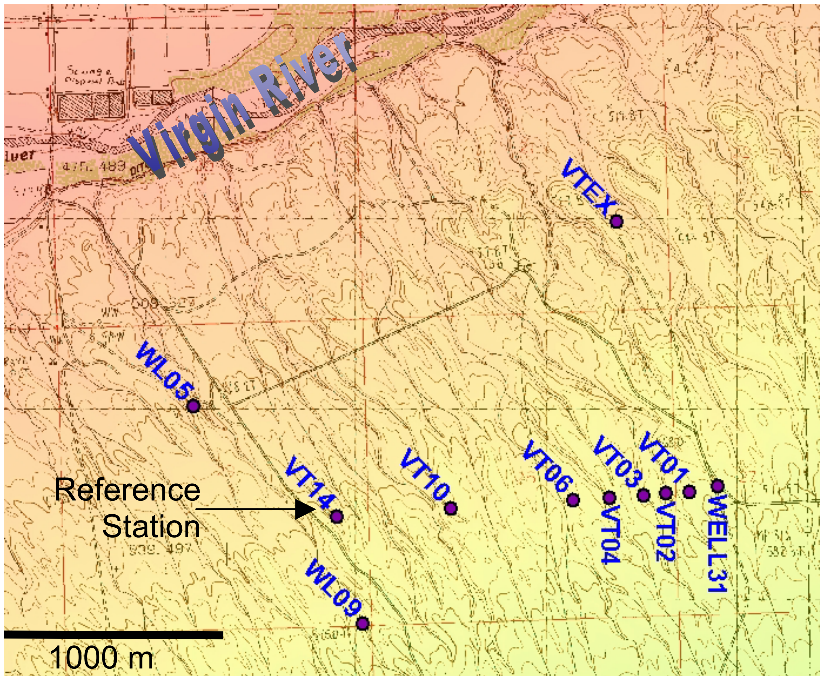


Figure 5: Map of wells and GPS receiver locations
Well 31 is the main pumping well, while VTex is an observation well and WL5 and WL9 were used as GPS stations. Vault (VT) 1 - 14 were used as GPS stations. VT14 was the reference station used to measure the relative movements of each GPS stations.

2.2 Aquifer Test Instrumentation and Design

Well 31 is a new well in the Virgin Valley Water District in an area that has little history of groundwater production or monitoring. The Water District began production of Well 31 on May 7, 2003. To monitor the aquifer during production, two pressure transducers were installed prior to the aquifer test, one in an observation well about 1 m from the pumping well and one in monitoring well VTex, approximately 1480 m from the pumping well. A barometric pressure transducer was installed into the observation hole to record the barometric changes during the aquifer test.

Well 31 is 500 m deep, has a diameter of 20 inches (0.508 m), and is screened (i.e. open to the aquifer) for 237.7 m. The screen is not continuous, with three solid-cased zones in intervals containing high amounts of clay (Figure 6). The depth to water before well production was 83 m below ground surface. Figure 6 shows a schematic diagram of the well design and stratigraphy of the well log. The aquifer is bounded by the top clay unit from a depth of 24 m to 83 m and the bottom clay (with sand stringers) unit from a depth of 481 m to at least 600 m. The well is screened only in the bottom 300 m of the aquifer. Above the well screen are four thin clay beds (3 m thick) separated by sand units. The well is screened in a silty sand unit (with and without gravel clasts) and a silty sandy unit with interbedded clay stringers.

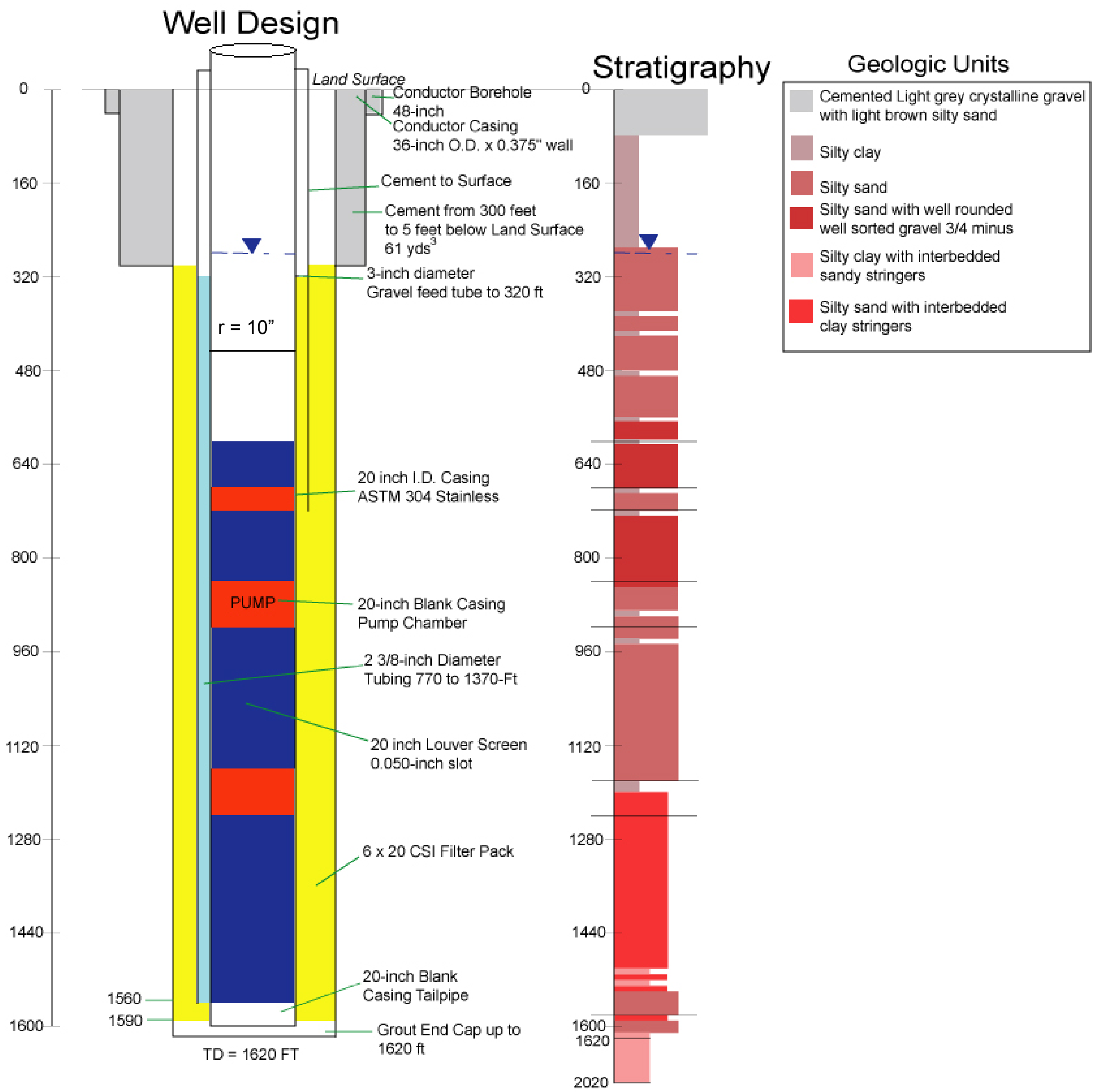


Figure 6: The design and stratigraphy of well 31
Well 31 is a municipal production well that was used for an aquifer test. Above is the well construction design and the stratigraphy from the well log. The grey crystalline gravel unit is the Alluvial unit; the rest of the units present in the well log make up the Muddy Creek Formation.

The VTex monitoring well is only 48.8 m deep and is screened (i.e. open to the aquifer) for the bottom 12 m. The water level was 48.7 m below the land surface before production began in well 31. The land surface at the two wells differs by almost 30 m, so the hydraulic head in the two wells differs only by 3 m at steady-state, which falls well within the range of the regional potentiometric gradient. While the heads in the two wells are similar, the VTex well is most likely only screened in a portion of the same aquifer as well 31. The portion of the aquifer screened in the VTex well is separated from the portion of the aquifer screened in well 31 by several discontinuous semi-confining beds.

Other Water District wells were in production at the same time as well 31. Table 1 has the production of each well in cubic m for the months before, during and after the aquifer test. In June, July, and August, the only other wells besides 31 that were in use were 33 and 27. Figure 7 shows the locations of the municipal wells compared to well 31. The closest producing well is approximately 4 kilom away, so the cone of depression around each pumping well should not intersect. Well 31 is the only well on the south side of the river in production from June-August. The production in well 30 in April and May, may have influenced well 31, but the drawdown due to pumping in well 30 has no influence on the water level in well 31. However, horizontal deformation has been shown theoretically to occur even at distances where drawdown in hydraulic head is small or non-existent (Burbey, 2002).

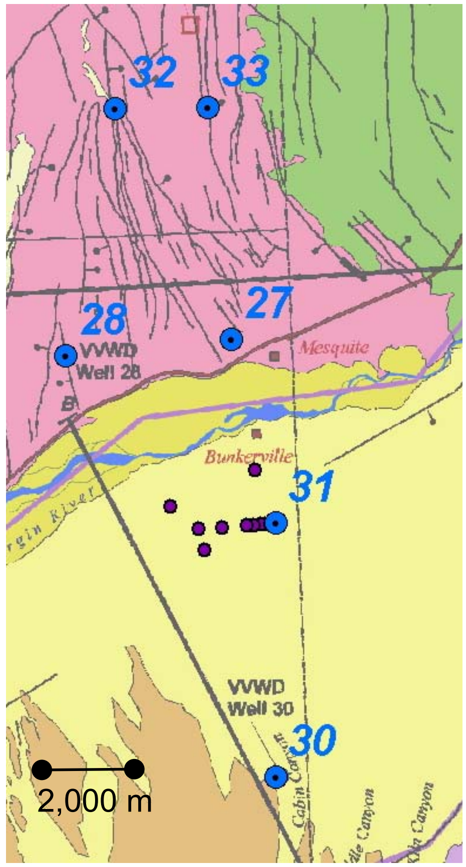


Figure 7: The location of each municipal well the region of the study well 31 The wells and their numbers are in red. The blue dots represent the GPS stations monitoring aquifer deformation. The colors in the background are the same as the key in Figure 1.

	Monthly Production 2003 in Cubic Meters					
well	April	May	June	July	August	September
27	108,497	52,805	166,051	193,928	166,495	101,651
28	104,377	42,653	0	0	0	0
30	123,915	27,642	0	0	0	0
31	0.00	32,822	267,344	280,617	283,762	267,912
33	0.00	165,496	267,505	319,262	322,567	313,279

Table 1: Monthly production of Water District wells: April – September, 2003

2.3 Monitoring Land Deformation with GPS

2.3.1 Introduction to GPS Data

The basic process of using GPS to determine a precise and accurate unknown location is similar to trilateration. The GPS receiver uses the distances to at least 4 known satellite locations to determine the position of the receiver. The satellite locations are encoded into the signal received by the GPS receiver. The receiver calculates the distance between the satellites and itself by taking the time of signal transmission (encoded in the signal), and the signal reception and multiplying it by the speed of light. The accuracy and precision of the GPS calculated position is dependent on several factors: the accuracy of the satellite position, the errors in the receiver clock, the atmospheric delays of the signal, and the reflection and refraction of the signal off of objects near the GPS receiver, referred to as multipath (Blewitt, 1997).

2.3.2 Selecting and Designing GPS Monitoring Locations

When stresses occur in an aquifer, the granular matrix of the porous media responds by deforming. The land movement on the surface represents a masked record of the aquifer matrix movement. When choosing a location for the GPS receiver and antenna, several factors were considered such as distance from the well, accessibility of the site, and the precision obtainable at the site (i.e. the site had to be located far from objects that might interfere with the antenna's ability to receive GPS signals from the satellites). In addition to selecting locations for the receivers, the duration of the GPS campaign needed to be decided based on receiver availability and well production schedule. The ground movement needed to be measured before, during, and after the well was put into production. Phase One of the campaign was the period prior to well production from April 30 to May 6. Phase Two was the period beginning on May 7 and ending on May 29 during the initial production of the well, and Phase Three was the period after the drawdown in the well had reached a new dynamic equilibrium from May 30 to July 9. During Phase Three, the number of receivers was reduced because of equipment availability. Table 2 summarizes the equipment and duration of each phase.

Phase		Duration	Instrumentation
1	Pre-production	-7 to -1 days	10 stations
2	Initial Production	0 – 22 days	10 stations
3	Continued Production	23 to 62 days	5 stations (VT 3, 6, 10, 14, WLVX)

Table 2: Three phases of GPS campaign to monitor land deformation

The stations were set at various radial distances from the pumping well to measure land deformation (i.e. aquifer deformation) in both near field and far field

(Figure 4). Seven of the stations were placed along a water line at distances from the pumping well ranging from 150 m to 2000 m. The distance between stations was relatively small (spaced between 100 and 500 m apart), which allowed for better precision in the relative positions of each. The assumption was made that the deformation would be radially symmetrical around the well, so each GPS station represents all points at the same distance from the well as that respective station. This assumption of radial symmetry allowed for a linear array of GPS stations and greater spatial density of measuring aquifer deformation in this one dimension. The assumption of radial symmetry is based on the assumption that strains caused by forces other than pumping (e.g. tectonic or seepage forces related to regional flow) are also zero. Because initial displacement was measured before the onset of pumping, this assumption is not really well justified.

In addition to carefully designing each site location and duration, the GPS antenna type was selected to optimize the precision of the campaign. Choke ring antennas were chosen because they are designed for high precision measurements. Choke ring antennas reduce multipath by filtering out indirect phase signals, such as signals that reflect off sources (i.e. objects) near to the antenna. The antenna is mounted onto a bolt attached to a stable benchmark, whether natural (i.e. bedrock) or engineered (i.e. cement, tripod, etc). Four different benchmarks were used at the GPS site locations; all of them were engineered benchmarks.

Of the four different station set-ups, the most ideal mount for the GPS antenna was a cement pad located at access points along a water line (Figure 8). A bolt was drilled into each cement pad and marked with a measuring point. The choke ring antenna was mounted to the bolt and the antenna height for each station was measured relative to the measuring point. Along with the cement pad at each access point, a manhole existed with space inside to store the GPS receiver and battery. The manhole space protected the equipment from vandalism and the hot desert sun. At each station an air vent was attached to the water line. A 24-hour test was performed at all stations to assure that the air vent would not cause a multipath problem. The test revealed that the air vent did not cause significant multipath problems because the vent blocked most of the GPS signals from reaching the antenna, rather than reflecting them and bouncing them back to the antenna. The air vent is located to the south of the antenna, and most satellites are in the southern portion of the sky. The signal from the satellites bounces off the vent and moves away from the antenna, rather than toward the antenna. The vent acts as a mask of the signal rather than a reflector. One vent, at Vault (VT) 5, was on the north side of the antenna and caused enough mulitpath problems that a precise position was not obtainable. Therefore this vault was not used as a monitoring station during the aquifer test. Stations VT1, VT3, VT4, VT6, VT10, and VT14 had similar set ups.

Figure 8: Antenna and receiver set up for stations VT1, VT3, VT4, VT6, VT10, and VT14 along the water line

To obtain data in the far field, an antenna was placed at Well 5 and 9, two wells that are no longer in service and are approximately 2700 m and 2000 m away from well 31, respectively. To prevent vandalism, metal wire fences enclose these well sites. A tripod was used to mount the antenna higher off the ground (than the bolted cement benchmarks), but the fence still caused multipath interference (Figure 9). The precision at these sites was not as good as the sites along the vaults. Also, the tripods were not as stable as the bolted antenna mounts, because the tripod may move slightly during high winds and extreme changes in temperature.

Figure 9: Tripod and antenna at well site 5 and 9 enclosed by fences

An antenna and receiver was also placed at the VTex well site because a pressure transducer was placed in the monitoring well (Figure 10). This site used a tripod for the antenna, but was not enclosed by a fence. However, the problems in precision created by the tripod instability still existed.

Figure 10: Antenna and receiver set up at VTex well

The final antenna and receiver set-up was installed at the well 31 well house. This location was designed to be a permanent station that automatically uploads the raw GPS data onto a server. A pole attached to the side of a building acts as a mount for the antenna, keeping the antenna above the height of the roof (Figure 11).

Inside, an Ashtech receiver and a computer are used to automatically upload the GPS data onto a server.

Figure 11: Permanent station at house at well 31

2.3.3 GPS Station Data Collection Methods

The GPS station data collection methods at each station were designed to allow for easy maintenance. A technician checked battery power levels daily and changed them once the power level dropped below a certain threshold. The receiver needed to be continuously logging without losing power or it would create a new file and lose several minutes of information while it was reinitiating communication with the satellites. After approximately 3 days, the receiver was stopped for a brief period of time so the data could be downloaded onto a laptop computer. The data were then immediately copied and backed up to two zip disks. Once all the data were collected and the campaign was over, the data were processed using GPSurvey Software.

3.0 THEORETICAL LAND SUBSIDENCE AND STORAGE IN THREE DIMENSIONS

Land subsidence is the surface expression of the aquifer deforming because of pumping induced stresses. The water removed from the aquifer through the pumping well results in a change in fluid pressure in the aquifer. The change in fluid pressure is counter-acted with the expansion of water and with the rearranging (i.e., compression) of the aquifer matrix. The greater the porosity or the greater compressibility of the matrix, the greater magnitude compaction occurs. To quantify the deformation that is occurring in the aquifer as a result of pumping induced stresses, several key terms and concepts related to subsidence must be defined.

3.1 Definition of Important Terminology

Specific Storage is conceptually defined as the volume of water released from a unit volume of aquifer (or porous media) per unit change in head (Fetter, 1994). Several different methods are used to quantify storage based on the set of assumptions used. Water released from storage that comes from vertical aquifer compression and water expansion can be expressed as:

$$S_s = \rho_w g(\alpha + n\beta) \tag{1}$$

Where S_s is specific storage (1/m), ρ_w is the density of water (kg/m^3), g is the acceleration due to gravity (m/s^2), α is the compressibility of the aquifer (N/m^2), n is the porosity of the aquifer (dimensionless), and β is the compressibility of water or 4.4 x 10^{-10}N/m^2. The Cooper-Jacob method is used to quantify S_s in one-dimensional problems and is incorporated into subsidence codes such as the Interbed Storage Package of MODFLOW. In addition, specific storage can be defined in three dimensions as:

$$S_{sk} = \frac{3\rho_w g}{3\lambda + 2G} \tag{2}$$

where S_{sk} is specific skeletal storage (1/m), G is the shear modulus (N/m^2), and λ is one of Lame's constants (N/m^2) and is related to G and Poisson's ratio (Burbey and

Helm, 1999). Skeletal specific storage only refers to the storage of the aquifer matrix and neglects the compressibility of water. For one-dimensional problems, the two definitions of storage are identical. When all three dimensions are considered, the definition using Lame's constants is a better representation of storage (Burbey, 1999).

Strain is the change in volume over the total volume, defined as follows:

$$\varepsilon_V = \partial V_T / V_T \qquad (3)$$

where ε_V is the volume strain (dimensionless), ∂V_T is the change in volume (m^3) and V_T is the total volume (m^3).

Stress is defined as the sum of the pore pressure and the resulting intergranular stress that operates on the granular matrix or the total load. A more detailed discussion of stress is found in the following section 3.2, Terzaghi's principle of effective stress.

The term compressibility can refer to the compressibility of water, of the skeletal matrix or aquifer, or the grains themselves. In all these situations, compressibility is defined as strain divided by stress. For this paper, the compressibility of water will be referred to as "water expansion". The compressibility of the grains themselves is assumed to be negligible. The skeletal matrix compressibility will be referred to as aquifer compressibility or just compressibility. The matrix compressibility is defined as follows:

$$\alpha = \frac{\partial V_T / V_T}{\rho_w g \Delta h} \qquad \text{(4)(Burbey, 2001B)}$$

where α is matrix compressibility (N/m^2) and Δh is the change in hydraulic head (m). The other terms in the equation have the same definitions as in the previous equations.

3.2 Terzaghi's Principle of Effective Stress

The principle of effective stress (Terzaghi, 1925) states that when the total load (or stress on an aquifer) does not change, the change in effective or intergranular stress is equal and opposite of the change in pore pressure. The principle is represented by the numerical expression:

$$\sigma_T = \sigma_E + p \tag{5}$$

where σ_T is the total load or the weight per unit area of the atmosphere, overlying rock and water (N/m^2), σ_E is the effective or intergranular stress (N/m^2), and p is the pore pressure (N/m^2). Usually, the assumption is made that σ_T is constant unless the aquifer is being dewatered. If the assumption is valid and the derivative of the stress equation is taken, the change in effective stress can be defined as the opposite of the change in pore pressure. In terms of hydraulic head, the expression for change in effective stress is:

$$\Delta\sigma_T = -\Delta h \rho_w g \tag{6}$$

The change in effective stress is directly proportional to the change in head and results in the expansion or compression of the aquifer matrix (Sneed, 2001).

3.3 Elastic vs. Inelastic Storage and Compression

In addition to the factors discussed in previous definitions, the compressibility and storage of an aquifer system also depend on the characteristics of the porous media and the stress history of the aquifer. Finer grained aquitards have compressibilties that are several orders magnitude higher than larger grained aquifers (Sneed, 2001).

The compressibility of clay is a stress-dependent variable. When a clay confining bed or interbed is stressed at a greater magnitude than previously stressesed, compaction occurs at a higher rate than if the stresses are within the range of previous stresses. Figure 12 shows an idealized curve for a clay stress/strain relationship from Helm (1975). As the clay is initially stressed, the compaction follows the curve labeled “virgin,” or inelastic. If the head recovers, the clay will expand along the swelling or hysteresis curve. Some of the compaction that occurred is permanent or non-recoverable. When drawdown occurs again, the compaction will occur along the swelling curve in reverse. As long as the stresses (i.e. head drawdown and recovery) remain in the elastic range, the volume of water released from storage can be returned to storage, and the magnitude of matrix compaction will equal the magnitude of matrix expansion. The straight-line slope of each compaction curve is equivalent to the storage coefficient. The virgin storage coefficient can be as much as two orders of magnitude larger than the elastic storage coefficient.

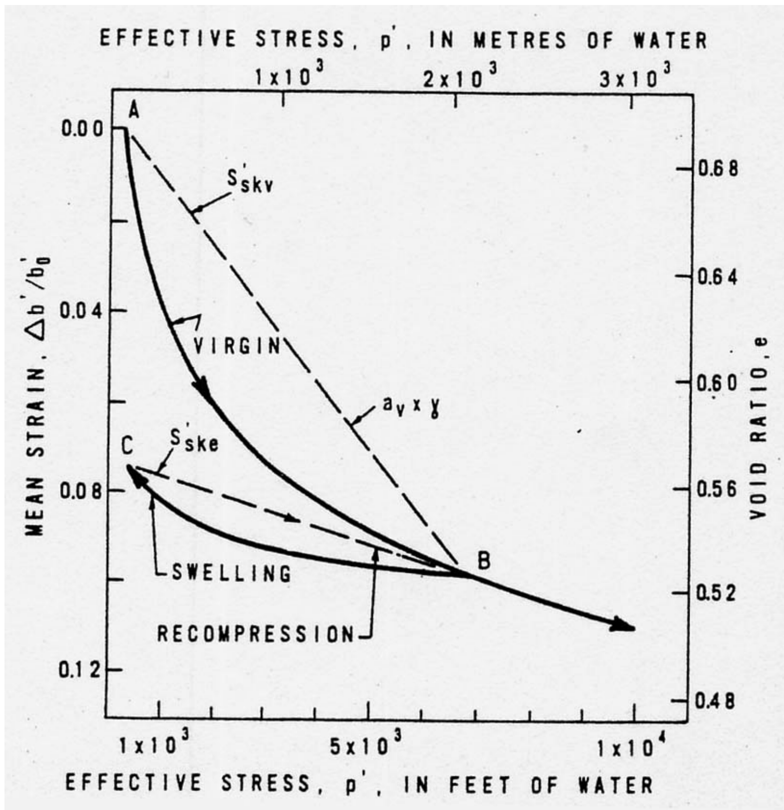


Figure 12: (Helm, 1975) Idealized mean strain vs. effective stress

3.4 Strain Around a Pumping Aquifer

When pumping begins in a well, assuming radial symmetry, radial compressional strain occurs in the aquifer at the well to some distance, L, from the pumping well. At L, the radial strain is equal to zero and at all distances greater than L from the well the strain is extensional. The distance to L depends on the hydraulic diffusivity (conductivity/specific storage) and duration of pumping. The distance to L migrates further from the well with higher hydraulic diffusivity and with time as the pumping continues and the cone of depression increases radially outward from the well. As the aquifer matrix displaces towards the well, the distance from a particular aquifer grain to the pumping well becomes slightly smaller, resulting in tangential compression (Burbey, 2001B). A diagram, shown in Figure 13, represents these processes.

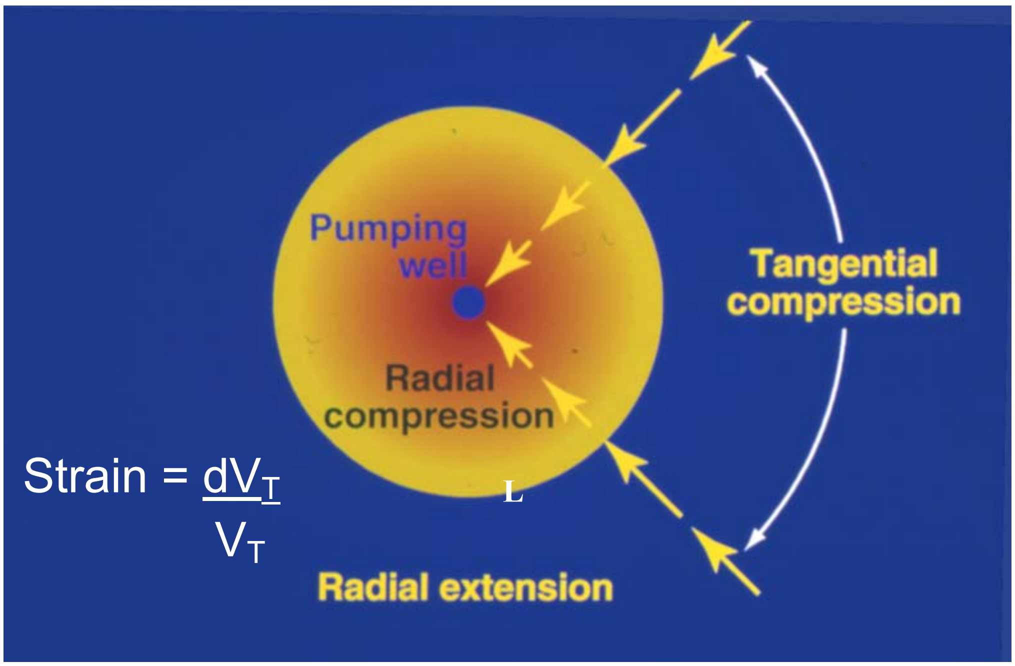


Figure 13: Horizontal strain components around a pumping aquifer
Radial compression occurs close the well, while extension occurs in the far field. Tangential compression occurs because the aquifer matrix displaces toward the well. The arrows represent displacement of the aquifer matrix.

The actual strain signature around the well is also dependent on the geologic structures and heterogeneity of the aquifer. Faults, areas of high conductivity and mechanical weakness, abrupt changes in lithology, and positions of clay beds can affect the surface and subsurface deformation distribution and magnitude (Amelung, et. al 1999, Burbey, 2002). According to Burbey (2002), simulated theoretical faults acting as barriers to horizontal flow can cause compressional strain to occur on the side of the fault nearest the pumping well, while extensional strain can occur on the side of the fault opposite the pumping well.

A numerical simulation using BIOT4 code calculated the amount of water released from storage resulting from the strain in an aquifer (Burbey 2001B). Results show that the tangential or hoop strain can be a significant contributor of water, especially at distances greater than 5000 m from the well (depending on aquifer characteristics and pumping rate). The radial strain only contributes to release of water from storage in the zone of radial compression, a zone where porosity is decreasing. In the zone of radial extension, porosity is actually increasing and water is entering storage. Figure 14 shows a comparison of the contribution of water from strain components after 20 days of pumping for a hypothetical isotropic aquifer system.

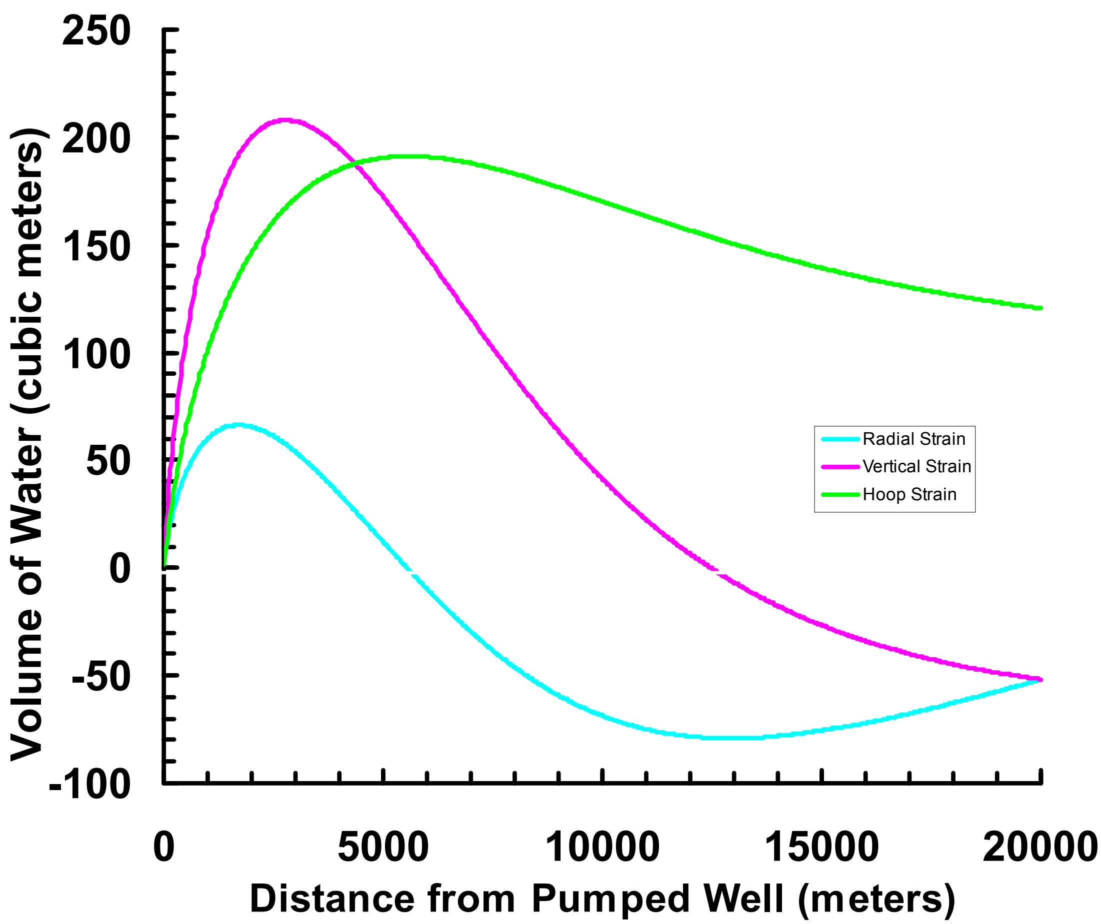


Figure 14: Volume of water released from storage by strain
The volume of water released from storage by each component of volume strain compared to the distance from the pumping well after pumping 20 days. Vertical strain component releases the most water closest to the well, while the hoop strain releases the most water further from the well. (Burbey 2001B)

3.5 Other Studies of Three Dimensional Land deformation as a Result of Aquifer Pumping

Most historical subsidence studies only consider vertical deformation when measuring land deformation or modeling aquifer systems. Horizontal deformation is usually considered insignificant despite limited field data reporting evidence of qualitative horizontal deformation (Burbey, 2001B). More recently, several numerical modeling studies provided quantitative evidence of significant horizontal strain resulting from aquifer pumping (Helm, 1994; Burbey, 1999, 2001A, 2001B, 2002; Helm and Burbey, 1999). Examination of the distribution of strain components in three dimensions in the simulations of a hypothetical aquifer shows that up to two thirds of total volume strain can result from horizontal compaction (Burbey 1999). The largest horizontal deformation and strain occur within the aquifer unit. The magnitude of horizontal deformation is a function of the pumping rate, the duration of pumping, and the hydraulic diffusivity (hydraulic conductivity/specific storage) (Burbey 2001A). Including horizontal strain in the simulation affects the distribution of flux through a confining layer as a function of distance from the pumping well (Burbey 1999).

Most of the previous studies of three-dimensional strain have been theoretical modeling studies. The deformation data from Mesquite, NV should provide field evidence to support the previous modeling investigations. The deformation data were measured in real-time providing information to characterize three-dimensional displacement of the aquifer matrix before the onset of pumping, how the aquifer matrix deformed or changed once pumping began, and the displacement of the aquifer matrix once the drawdown in the aquifer approached equilibrium.

4.0 AQUIFER TEST RESULTS

The aquifer’s response to stresses and strains is an important tool for determining the characteristics of the aquifer. The drawdown rate and recovery rate can be used to estimate the transmissivity of the aquifer materials. The magnitude of drawdown in relation to the pumping rate can help determine the storage coefficient of the aquifer. An explanation of the data collected during the aquifer test and demonstration of using the drawdown data to characterize the aquifer follow.

4.1 Drawdown Data Collection

Data were downloaded from the pressure transducers and saved to a spreadsheet. Both pressure transducers used the same barometric correction, assuming that the barometric conditions are the same across the 1480 m distance between the wells. Both of the stations had the elevation of the land surface measured with a GPS receiver and a water level meter was used to measure the water level below land surface. The pump in well 31 was cycled on and off to meet the demand of the local municipality. The average cycle was on/off for 8 hours pumping at a rate of approximately 16,353 m^3/d when turned on. The average pumping rate when total time is considered is 9,028 m^3/d. Table 3 summarizes the key factors of the aquifer test design already mentioned in section 2.3 for reference.

Property or Condition	Description or Value
Well 31 pumping rate	0.189 m^3/s
Well 31 pumping duration	Approximately 8 hours on/ 8 hours off
Monitoring Well	Located 1 meter from well 31, contains barometric pressure transducer, screened same interval as well 31, 271 m
VTex Well	Shallow monitoring well located 1,470 m from well, screened for 21 m

Table 3: Summary of aquifer test design

4.2 Drawdown in Monitoring Well One Meter from Well 31

Drawdown in the observation hole one m from the well occurred immediately once pumping began. Each time the pump was turned on, an immediate drawdown of approximately 10 m occurred. When the pump was shut off, the water level recovered to within a meter of the water level before the current pumping period. The quick drawdown and recovery cycles are indicative of a highly transmissive aquifer. In addition to the short fluctuations in water level correlated to the cycling of the pump, the long-term water level declined approximately 5 m over the duration of the aquifer test (i.e. each time the pump was turned off the water level did not recover to its original pre-pumping level). Figure 15 shows the observed head in the monitoring well approximately one meter from well 31. A straight line is drawn for reference to aid in determining the long-term trend in the aquifer water level. After approximately 11 days, the drawdown reached near equilibrium conditions, and the long-term decline in the aquifer decreased significantly. This drawdown pattern is indicative of a leaky aquifer in which leakage occurs through an adjacent semi-confining unit.

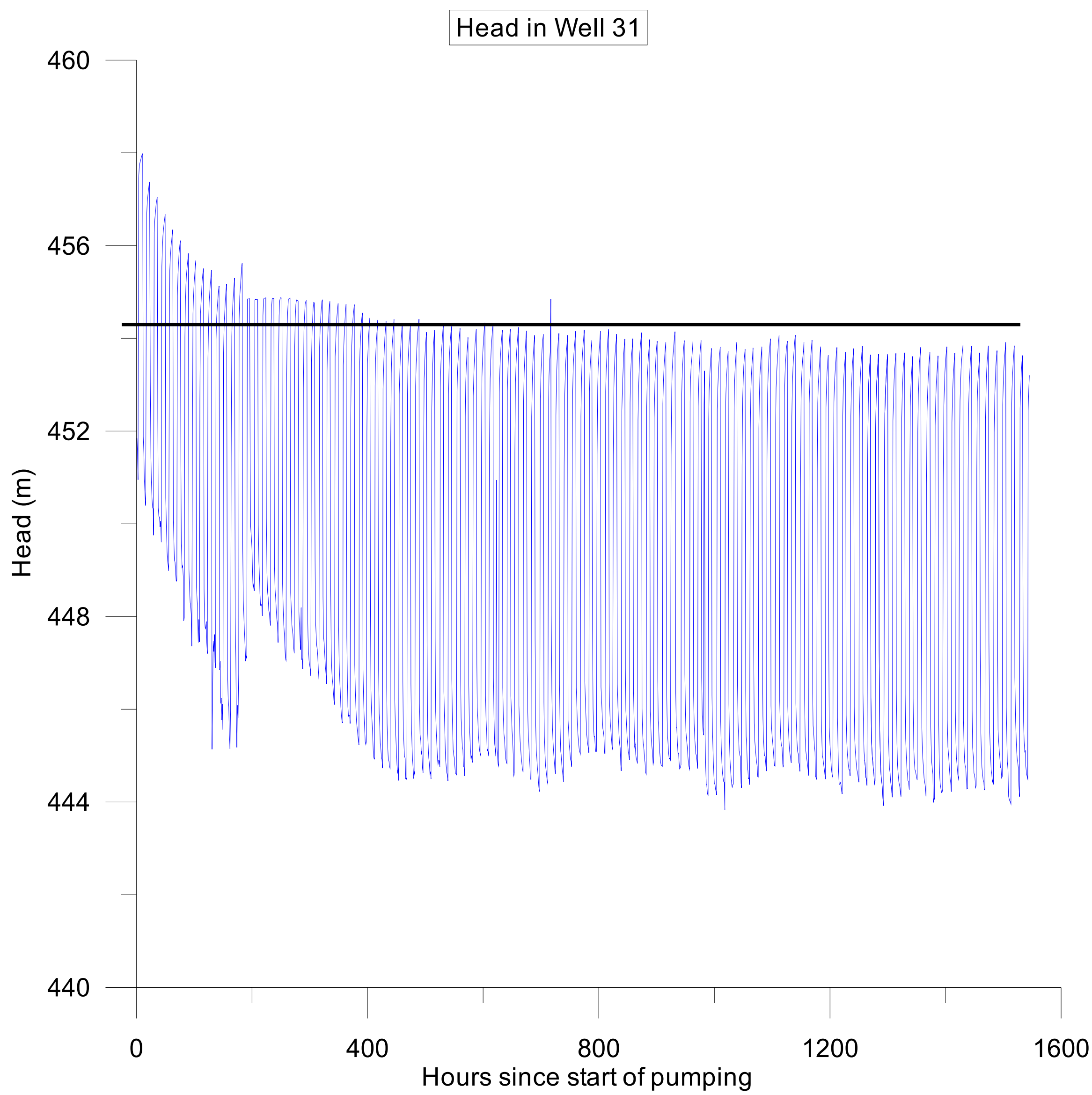


Figure 15: Drawdown in observation hole one meter from the well 31.
The pump in well 31 pumped at cycles approximately every 8 hours at 16,353 m^3/d. Zero hours corresponds to the onset of pumping.

4.3 Drawdown in Monitoring Well 1480 Meters from Well 31

Total observed drawdown in the VTex monitoring well was approximately 3 cm during the aquifer test (Figure 16). The well is approximately one tenth the total depth of well 31, although the steady-state water level in the well correlates to the regional gradient of the Muddy Creek Aquifer. The VTex well experiences daily fluctuations on the order of five cm. The small fluctuations are likely due to tidal influences and other natural phenomena occurring in the aquifer (i.e. not pumping induced). Two possible reasons for the three cm of drawdown are (1) seasonal variation in the regional aquifer or (2) a delayed response to pumping as the stress travels through the clay layers that separate the monitoring well and the pumping well. Simulations developed for the purpose of duplicating the natural aquifer test suggest that the latter reason is most likely the situation for the VTex well.

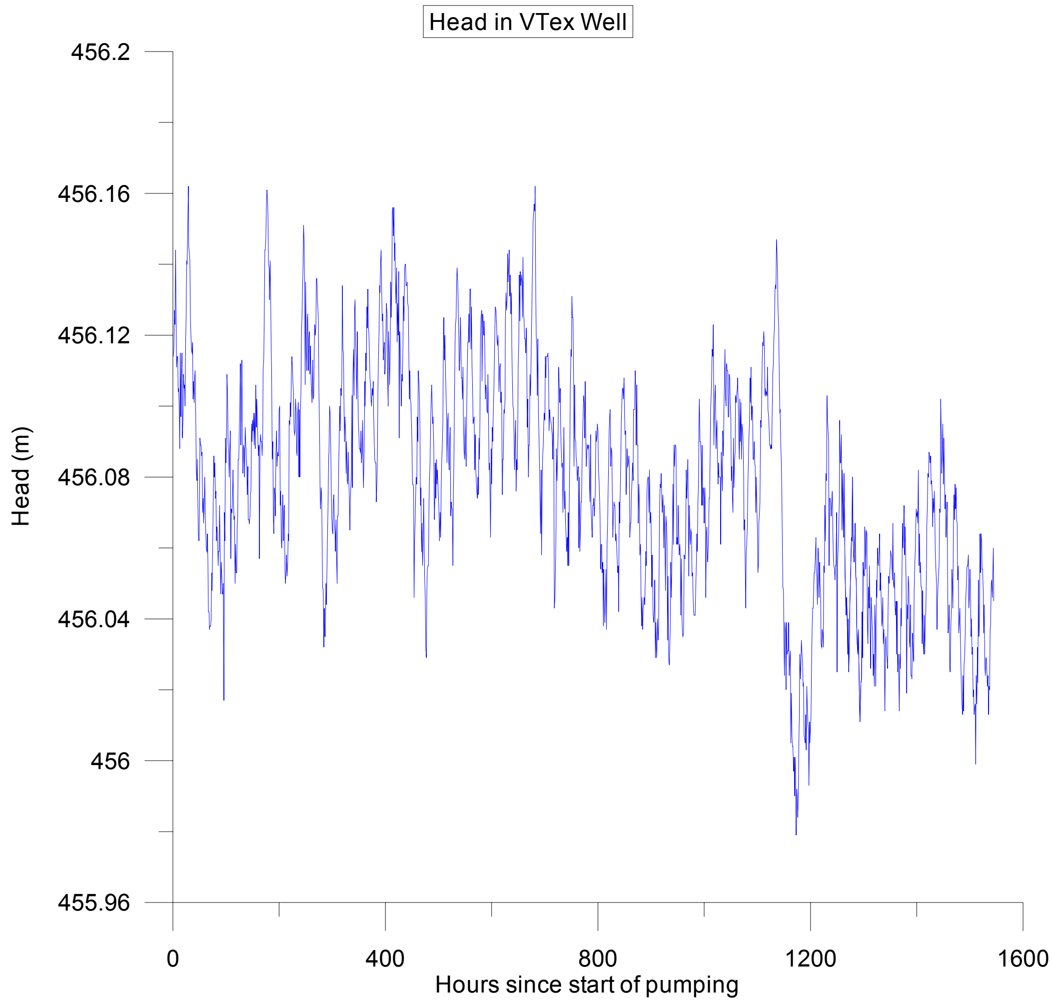
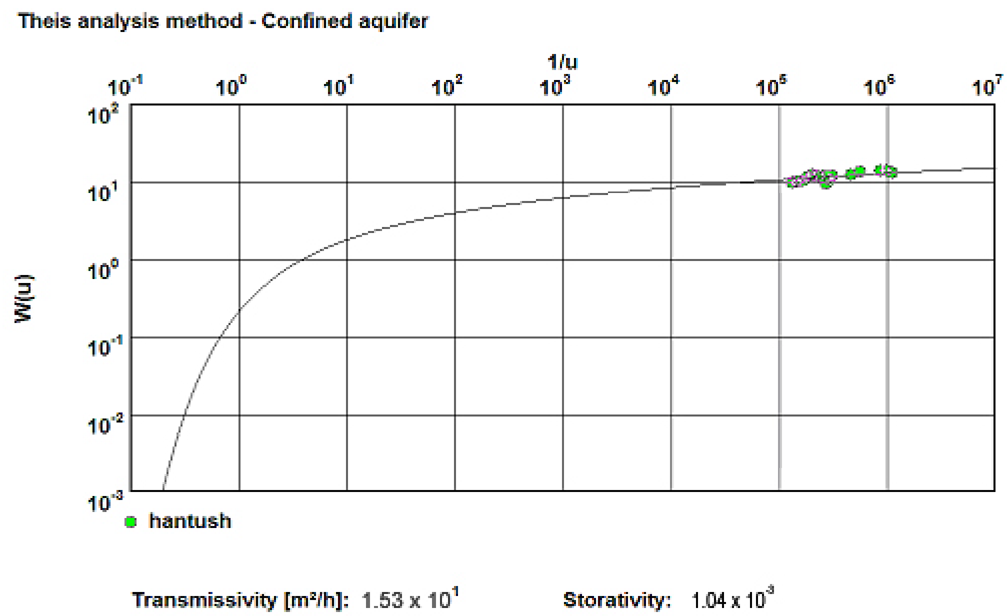


Figure 16: Drawdown in the VTex monitoring well
The total drawdown is less than 3 cm and is either due to seasonal variation in the regional groundwater table or delayed response through clay layers from pumping. Zero hours corresponds to zero days pumping.

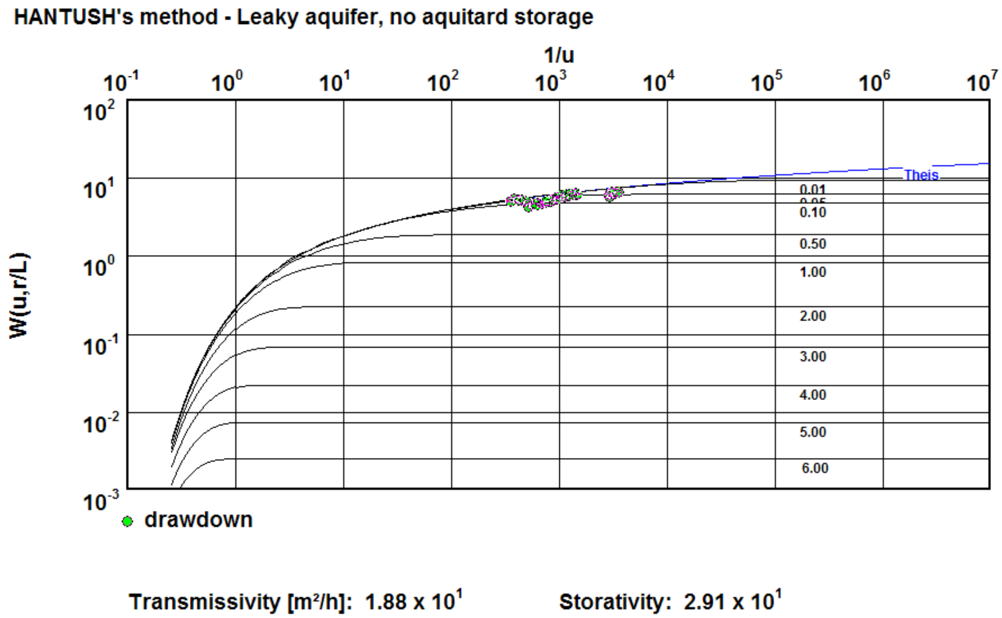
4.4 Calculation of Transmissivity and Storage

Time-drawdown data from the observation well located one meter from well 31 were used to estimate transmissivity and storage. The daily cycles and measured pumping rates were used with the Theis and Cooper-Jacob methods to determine the hydraulic characteristics of the highly responsive aquifer layers. The average drawdown and pumping rate were used with the Hantush method to obtain an estimated transmissivity and storage value for the entire aquifer system, which is represented as a semi-confined leaky aquifer. All calculations were performed using Waterloo's Aquifer Test Software. Figure 17 shows drawdown data matched to the

Theis type curve and the Hantush type curve. The Aquifer Test Software matches the drawdown to the type curve and automatically calculates transmissivity and storage values. Table 3 reports the estimated transmissivities and storage values obtained using the Theis, Cooper Jacob Straight Line, and Hantush methods. The chart also shows the published transmissivity values of Dixon and Katzer (2002) for the Muddy Creek Formation. The Theis and Cooper Jacob methods assume that the aquifer is fully confined. The Hantush method assumes a leaky confined aquifer with no contribution of water from storage in the confining layer.



(A) Drawdown data and Theis type curve to calculate transmissivity and storage. The drawdown data are taken two sets of cycles of rapid drawdown when the well was turned on.



(B) Drawdown data and Hantush type curve to calculate transmissivity and storage. The drawdown and pumping rates were averaged over time. The deviation from the Theis curve is very slight indicating that there is small leakance entering the aquifer.

Figure 17: (A) Theis and (B) Hantush type curve matches for drawdown data for calculating transmissivity and storativity

Method	T	S_s
Theis	53.3 m^2/hr	0.00117/m
Cooper-Jacob	53.3 m^2/hr	0.00104/m
Hantush	18.8 m^2/hr	0.107/m
Katzer & Dixon	77.42 m^2/hr	

Table 4: Calculated T & S_s values based on time drawdown data From the monitoring well one meter from well 31.

The value reported by Dixon and Katzer (2002) was calculated using a deep well on the top of the alluvial fan 4500 m south of the study site. The well is screened over several units so the transmissivity value represents a composite value for all the water bearing units in the Muddy Creek. The storage value calculated by the Hantush method is several orders of magnitude higher than the Theis and Cooper-Jacob methods. The Hantush value was calculated using average drawdown values and an average pumping rate, which may introduce more uncertainty in the data. Also the Hantush value represents the entire system storage, while the Cooper-Jacob and Theis method represent the storage only in the saturated units directly connected to (or screened in) Well 31.

The calculated transmissivity and storage values were used as starting points and approximate values for the subsidence modeling codes.

5.0 GPS DATA RESULTS

5.1 Background on GPS as a tool in land subsidence monitoring

Historically, spirit leveling was used to monitor benchmarks in favor of GPS because conventional leveling was more precise and accurate. In 1995, a differential GPS system (Hein and Riedl, 1995) was designed such that baselines of five to ten km were shown to be accurate to 2 or 3 mm in the vertical direction. Improvements in receivers, antennas, and removal of selective availability have recently allowed for high precision GPS surveys. Since 1998, Trimble 4000ssi receivers and geodetic choke ring antennas have been used to measure benchmarks with sub-centimeter accuracy, in the Las Vegas area. The information from these surveys have helped to better define subsidence rates and controls in the Las Vegas area (Bell et al., 2002). This earlier survey mainly focused on the vertical movement of the benchmarks.

In Albuquerque New Mexico, GPS was used to survey a network of 44 benchmarks three times over a period of 2 years (Heywood et al., 2002). The permanent deformation in the vertical direction was not greater than the precision of the GPS survey. Interferometric Synthetic Aperature Radar (InSAR) images measured only 2mm of permanent compaction, while the GPS was only able to measure to the nearest 1.3 cm in height. InSAR is a technique that uses differences in reflectors in two radar images taken at two separate times to measure the land deformation observed between images. The GPS survey was not used to identify horizontal movement. GPS was a valuable tool in the Albuquerque study and provided ground truth for the InSAR radar images (Heywood et al., 2002).

In Sacramento Valley, CA, GPS was used in 1994 as a survey tool to measure the vertical change in height between adjacent benchmarks (Ikehara, 1994). The accuracy obtained was better or equal to 1.6 mm and the repeatability of the measurements were obtained for baselines up to 38 km.

In 1995, GPS was used to monitor land deformation over a gas field in the Netherlands (Krijnen and Heus, 1995). The GPS antennas were mounted on 25 by 25 by 100 cm concrete pillars dug into the ground and resulted in 5-8 mm accuracy. For comparison, in this investigation at the concrete vault monitoring stations, the GPS precision was shown to be an impressive 0.2 mm in the horizontal direction and 2 mm in the vertical direction.

5.2 GPS Data Processing

The software GPSurvey was used to process the raw GPS data. Positions were recorded every 30 seconds and then the daily average position was calculated from the 172,800 daily values. Taking the average daily position also helps to remove any multipath and other sub-daily noise in the signals. Because the GPS orbits are designed to have the satellite repeat over the exact same location twice in a day, multipath can often be removed by averaging the position over a 24 hour period. Some days, the average position was not able to be resolved.

5.3 Aquifer movement in the horizontal direction

All of the displacements measured are relative to the vault 14 reference station which is located 2000 m west of the pumping well. The original coordinate system of the monitoring stations was UTM (Universal Transverse Mercator); eastings, northings, westings and southings are referring to this coordinate system. For ease of interpretation, the displacements have been converted into a radial coordinate system, assuming radial symmetry around the pumping well. Movement in the radial and tangent directions refers to the radial coordinate system.

5.3.1 Radial or Eastings displacement

Before the onset of pumping, the land surface appeared to be moving slight in a westward direction, away from the well (Figure 18). Vault 01's position at seven days prior to pumping (-7 days) was two mm east (-2 mm) of the position at time zero and was displacing in a westward direction. By -4 days the vault was two mm west (+2 mm) of the position at time 0. All the vaults displacement followed a similar pattern before pumping began, but VT01, VT02 and VT03 had the largest magnitude displacement, followed by VT04, VT06, and then VT10. Forces causing the pre-pumping displacement could be the result of horizontal seepage forces associated with the regional hydraulic gradient, tectonic forces, or strain resulting from municipal pumping from well 30 (Figure 7).

Once pumping began, vaults displaced to the east (toward the well); vaults closer to the well displaced more than those further away from the well indicating radial extension. The three vaults closest to the well move at about the same rate; vaults 04 and 06 have very similar displacements, and vault 10 has the least displacement. During the last phase of monitoring from day 22 to 62, there appears to be little displacement, most likely due to drawdown approaching equilibrium. During the entire aquifer test, well 31 represents a zero radial displacement boundary, and therefore radial compression must be occurring between the first vault and well 31. The magnitude of radial displacement as shown in Figure 18 must decrease sharply between the maximum displacement shown at Vault 01 (the closest monitoring benchmark to the well) and the 140 m that separates Vault 01 from Well 31.

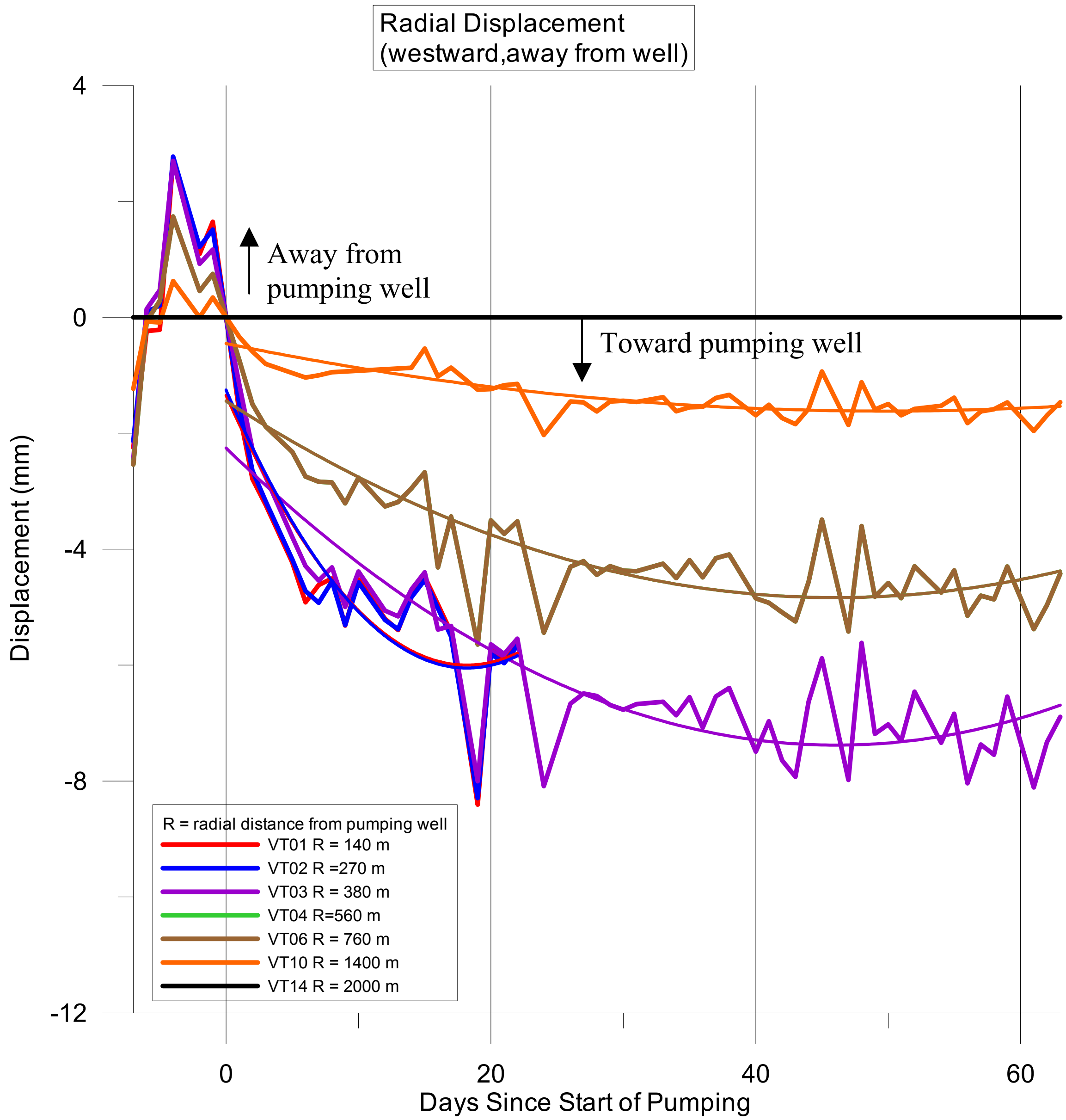


Figure 18: Radial displacement (assuming axial symmetry).
Positive displacement is westward, away from the well, while negative displacement is eastward, toward the well. Each line represents the displacement of the aquifer at the GPS station, with the radial distance from the well noted in the legend. Notice that once pumping begins all movement is towards the well and vaults closer to the well displace more than those further away. The smooth lines represent a polynomial fit to the data.

5.3.2 Tangent or Northings displacement

The displacement observed in the tangent direction was southward during pumping with greater displacement closer to the well, resulting in an apparent counter-clockwise motion of the aquifer matrix (Figure 19).

When the surveys started, the stations were displacing to the north at time zero to time four days. Each vault seems to be displacing to the north in a similar amount relative to VT14 except for Vault 10 with half the displacement magnitude (Figure 20). When pumping begins, displacement occurs to the north for two or three days, and then all stations displace in a southward direction. The significance of this rotation is uncertain due to limited data, but the rotation may indicate some anisotropy in the aquifer properties or shear strain associated with heterogeneity.

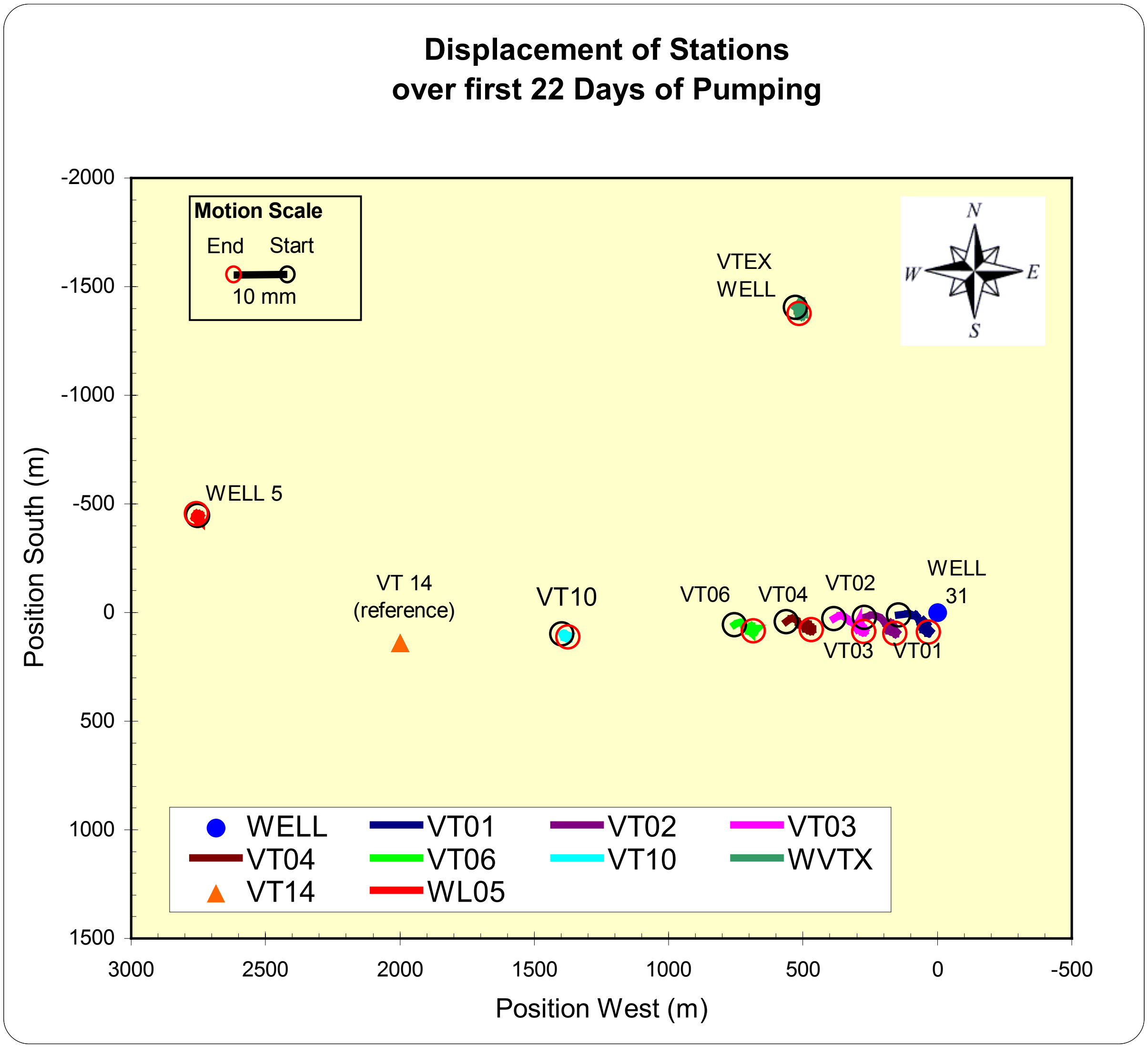


Figure 19: Horizontal displacement of aquifer during first 22 days of pumping Relative to VT14, the aquifer appears to be displacing in a counter clockwise motion. The significance of this rotation has yet to be determined.

Vaults closer to the well moved to the south more than those close to vault 14. The greatest movement (at VT01) was approximately 3.5 mm; the least movement was at VT10 and was approximately 0.5 mm. During the final 22-63 days of pumping, there was little change in the positions of the stations.

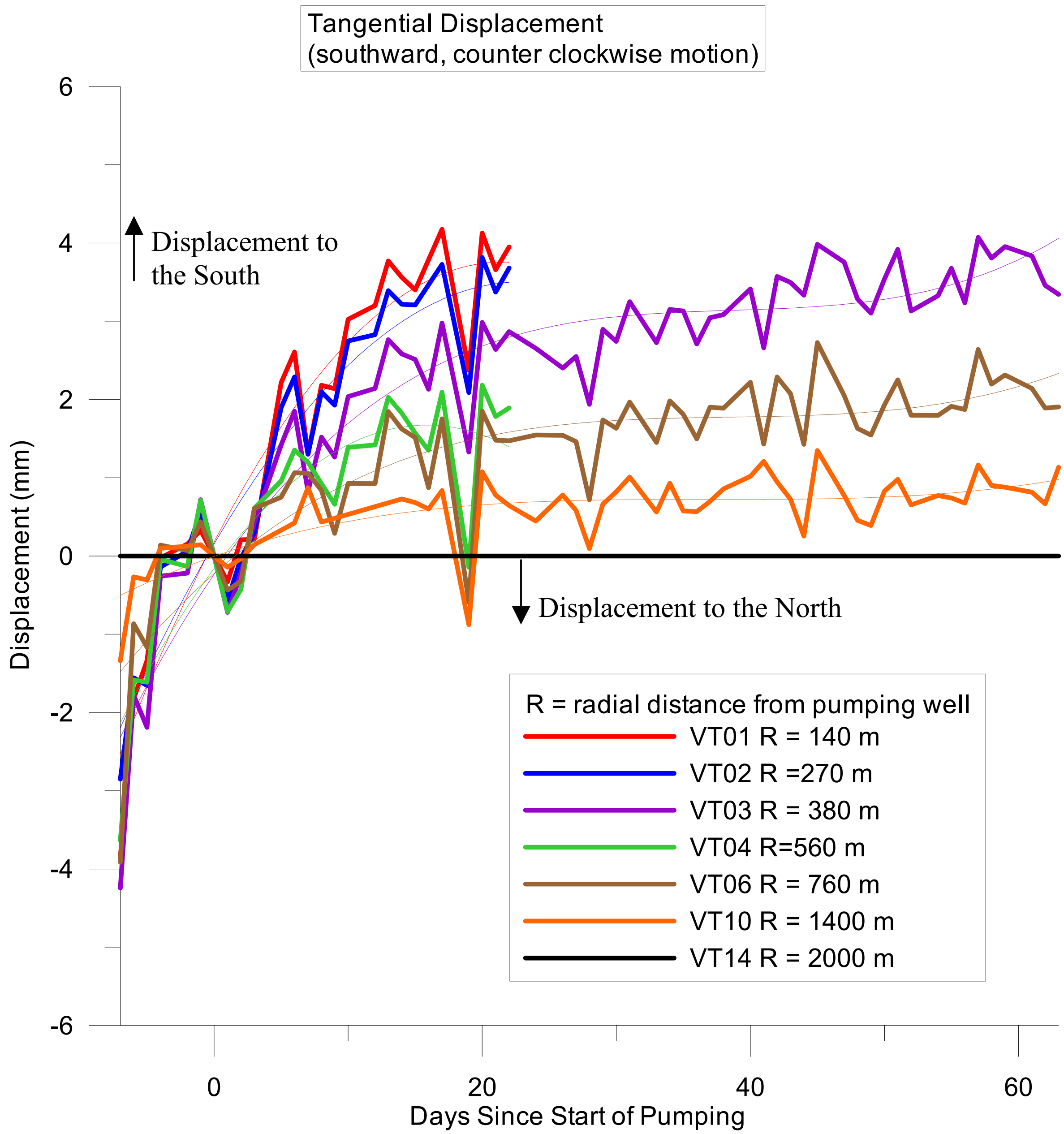


Figure 20: Displacement in a Tangent direction (Assuming radial symmetry) Negative displacement is in a northward or clockwise direction; positive displacement is in a southward or counter clockwise direction. The results from each station are plotted vs. time, with the distance to the well listed as "R" in the legend. The thinner same colored lines are the best fit polynomial equation to the data.

5.4 Station movements in vertical direction

The vertical displacement signal is not as clear as the radial and tangential displacement signals. The GPS tool is also not as precise in the vertical direction, and partially explains the less obvious displacement trends. Before the onset of pumping, the signal at all monitoring stations oscillated between positive and negative five mm (Figure 21). When pumping begins (0 days), each station closer to the well appears to subside slightly more than the adjacent station further from the well. The maximum displacement at VT01 is approximately 0.75 cm. After the first 22 days (when only 3 stations remain), a slight rebound of as much as 0.25 cm may be occurring. Vertical deformation depends on the compression of interbeds and confining beds, which may be delayed as the pressure gradients diffuse across any existing confining layers. The vertical deformation also depends on the preconsolidation stresses, which are assumed to be 0 in this case.

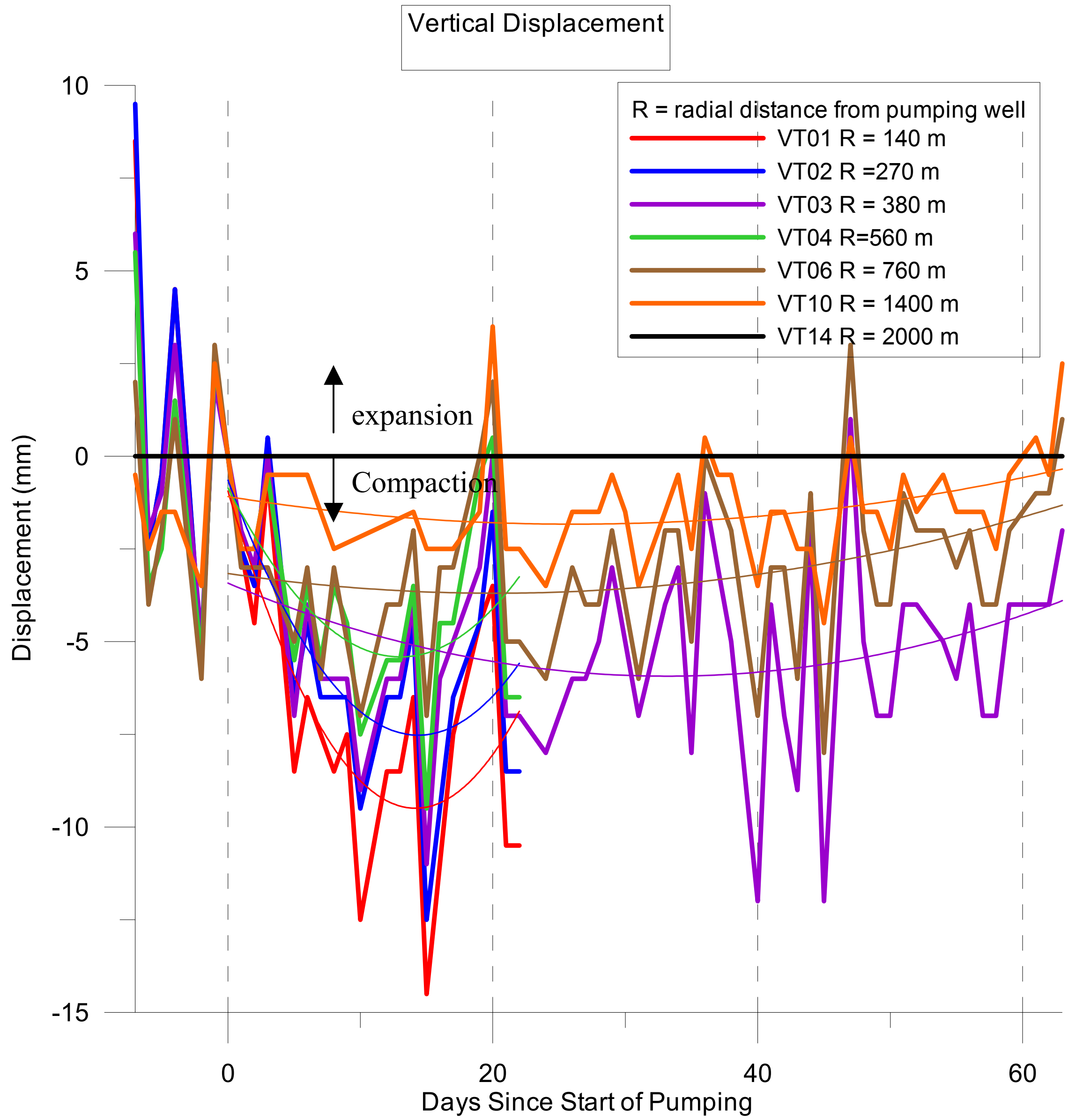


Figure 21: Vertical displacement versus days of pumping

The oscillations are greater than the horizontal displacement graphs, because the GPS precision in the vertical direction is not as good. Once pumping begins, the stations all subside, with slightly faster subsidence occurring closer to the well. The amount of subsidence seems to be slightly correlated to the distance from well. During the final phase of the monitoring (from 23 to 62 days) when the drawdown is at equilibrium, there may be a slight rebound in the vertical direction.

6.0 STRAIN

After the initiation of pumping, the data collected from each GPS station location were used to calculate strain. Radial strain was calculated using the following equation (adapted from Helm, 1994):

$$\varepsilon_{i+1/2} = \sum_{i=1}^{N} \frac{dU_{i+1} - dU_i}{r_{i+1} - r_i} \tag{7}$$

where dU_{i+1} is the component of displacement at vault further from the pumping well (mm), dU_i is the component of displacement at vault closer to the pumping well (mm), and r is the radial distance from the respective vault to well 31 (m), and N is the number of vaults. The calculated value was assumed to be at a radial distance from the well at a point half way between the two stations. The calculation was conducted for each direction of displacement (radial, tangential, and vertical).

Hoop (tangential) strain (ε_H) was calculated using the following equation (adapted from Helm, 1994):

$$\varepsilon_{H_{i+1/2}} = \frac{\left(U_{i+1} + U_i\right)/2}{\left(1000\left(r_{i+1} + r_i\right)\right)/2} \tag{8}$$

where U is the displacement at the vault (mm). In this equation, the 1000 in the denominator is to convert the displacement in mm to m to coincide with the units of the radial direction r. Equation 8 represents the average hoop strain between two vaults. The hoop strain could have been calculated at each individual vault (i.e. instead of between station pairs), but a value of hoop strain is needed for the same location as radial and vertical strain to calculate the volume strain.

Areal strain (ε_A) represents the sum of the radial and hoop strain components. The following equation was used to calculate areal strain (written comm., Blewitt, 2004):

$$\varepsilon_{A_{i+1/2}} = \frac{\pi\left[\left((r_{i+1}+dU_{i+1})^2 - r_{i+1}^2\right) - \left((r_i+dU_i)^2 - r_i^2\right)\right]}{\pi\left[r_{i+1}^2 - r_i^2\right]} \quad (9)$$

Finally, the volume strain represents the sum of all three principal components of strain (radial, hoop and vertical). The volume strain (ε_V) was calculated using the following equation (Helm, 1994):

$$\varepsilon_V = \varepsilon_R + \varepsilon_H + \varepsilon_Z \quad (10)$$

During the seven days prior to pumping all stations experienced strain, but no clear defined trend exists regarding whether the strain is increasing or decreasing or whether a predominant direction to strain exists. The strain could be caused by the initial aquifer test (for one to two hours at two days before pumping), or from another distant municipal pumping well some time before the GPS monitoring system was set up. The strain could also be the result of regional tectonic movement or horizontal seepage forces due to the natural hydraulic gradient. The source of the strain is difficult to delineate because of the variation in the strain magnitudes.

6.1 Radial and Hoop Strain

A trend in the radial strain prior to pumping is not obvious. Once pumping begins the strain measured at the vaults becomes positive, indicating that extension is occurring (figure 22).

At 205 and 325 m, the strain increases rapidly to a peak and then decreases within the first 10 days of pumping. At a distance from the well of 205 meters, the strain actually appears to become slightly negative or compressional after 20 days. Further from the well, the strain increases when pumping begins and then stabilizes after 22 days to an almost constant value of strain. The maximum positive strain occurs between 570 and 660 meters and then gradually dissipates with distance from the well. The expected zone of compression closest to the pumping well is not visible, but the data from well 31 have not been processed and well 31 must represent zero radial displacement. The well casing acts as a radial strain boundary, so radial compression must be occurring between vault 1 and well 31.

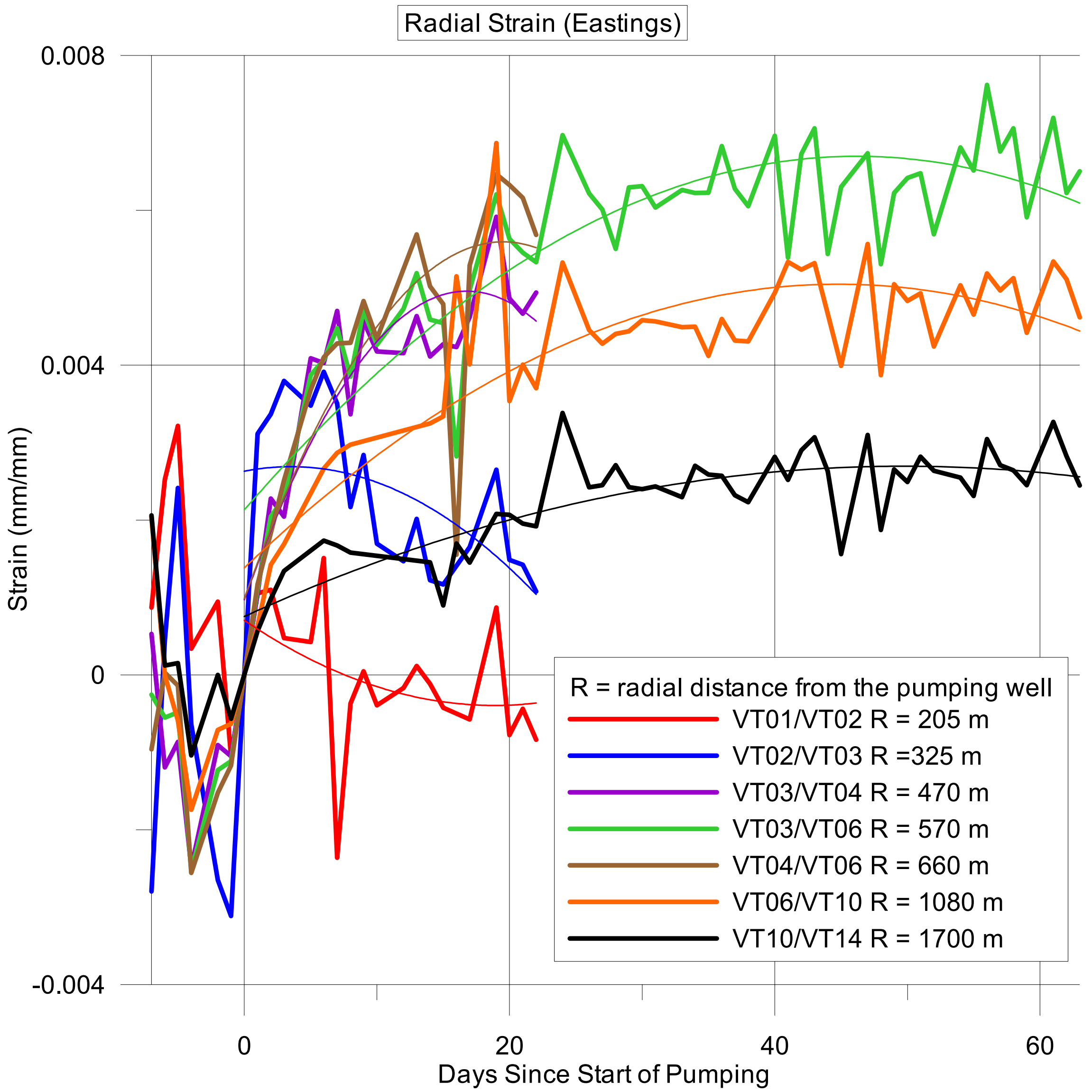


Figure 22: Radial strain versus pumping duration
The radial strain is positive indicating extension occurring from 205 m to 1700 m.
The smooth lines represent a polynomial fit to the data.

The radial strain between vault 1 and well 31 can be calculated if the assumption is made that no radial displacement occurs in the aquifer matrix at well 31 due to the well casing. The displacement at vault 1 is always towards the well so the strain between vault 1 and well 31 will always be compressive. Figure 23 includes the radial strain calculated between vault 1 and well 31. At the onset of pumping, the strain at 70 m from the pumping well is always compressional during the aquifer test , and the magnitude increases with time.

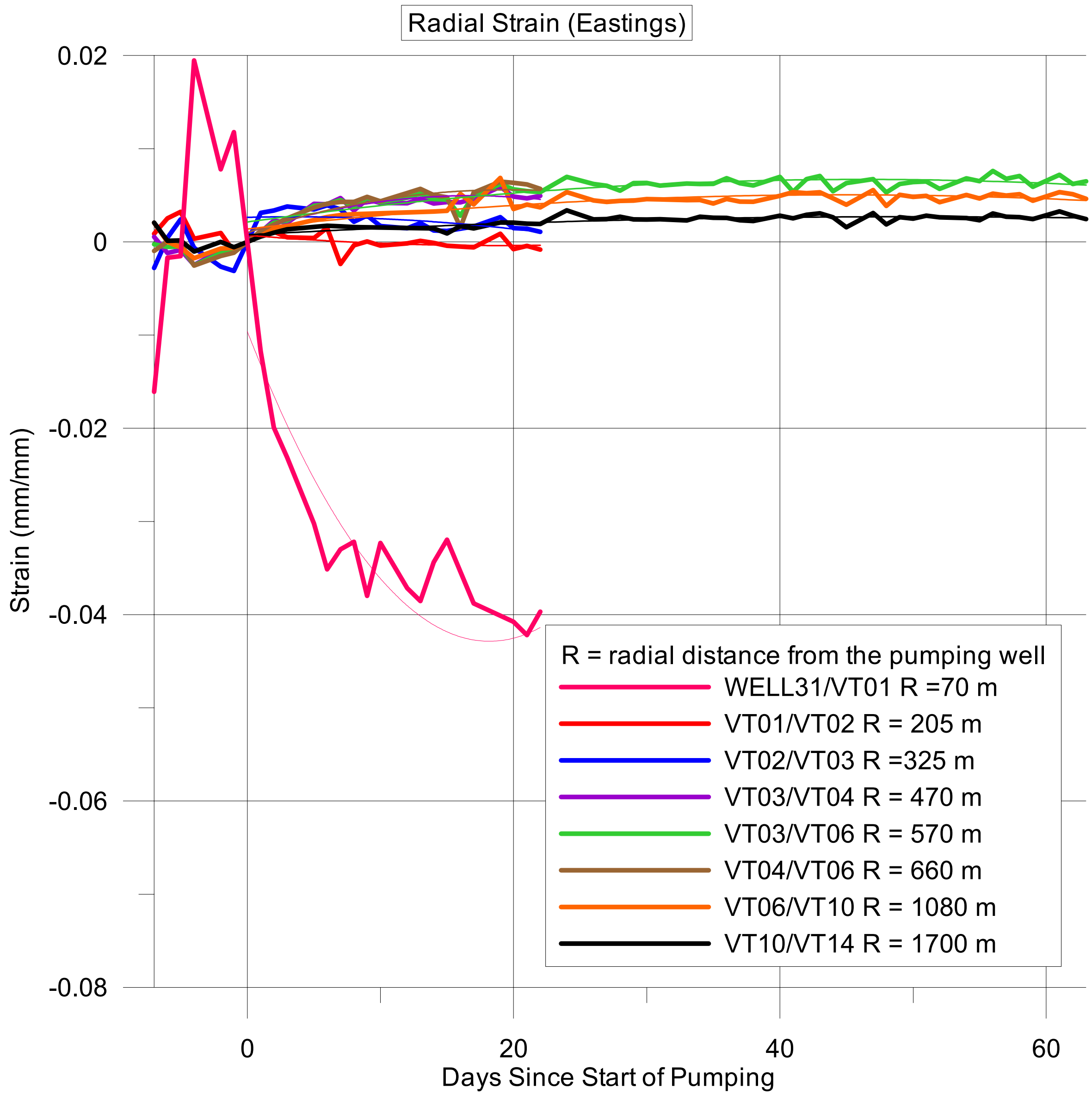


Figure 23: Radial Strain versus pumping duration including a point between well 31 and VT01. The assumption was made that no radial displacement occurred at well 31. The point between well 31 and VT01 is compressional for the entire monitoring period.

The boundary between negative and positive (compressional and extensional) strain migrates outward from the pumping well with time at a rate that depends on the pumping rate, time, and the hydraulic diffusivity (K/Ss) (Helm, 1994). The measured boundary of zero strain was between 70 m and 205 m from the well 31 at the onset of pumping. After approximately 10 days, the boundary had migrated outward to 205 m from the pumping well. Figure 24 shows the radial strain as a function of distance at one, three and 17 days.

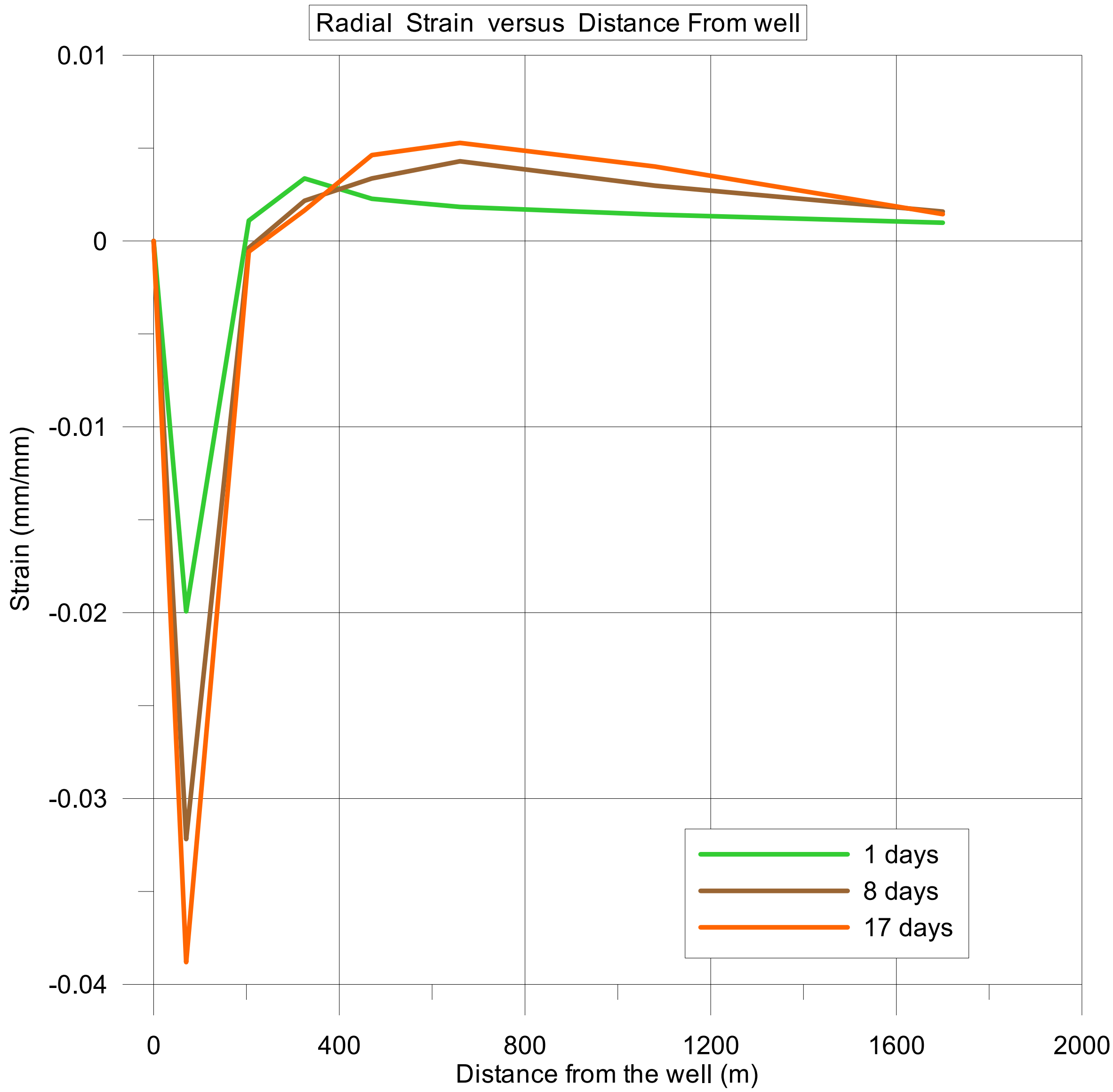


Figure 24: Radial strain versus distance from the well after pumping for 1, 8, and 17 days

The pulsed pumping scheme of well 31 is a likely factor in the slow migration of the zone of zero radial strain because while the pumping rate is zero for almost half of the time. The other factor in the slow migration is the low hydraulic diffusivity of the aquifer (Helm, 1994). The estimated storage values (section 4.4) are between two and four magnitudes greater than the estimated conductivity values, resulting in a low hydraulic diffusivity.

The hoop strain represents the tangential strain occurring as a result of converging particle path lines to the pumping well. Negative hoop strain is compressional, indicating that the aquifer matrix is displacing radially toward the pumping well. Positive hoop strain is extensional, indicating that expansion is occurring and the aquifer matrix is displacing radially away from the pumping well with more distance particles traveling farther than the particles closer to the well. Extensional hoop strain can only occur before the pumping begins, because at the onset of pumping, the aquifer matrix moves toward the well. Figure 25 shows hoop strain decreasing both with increasing distances from the well and increasing with increasing time until after 22 days when the hoop strain remains nearly steady with time.

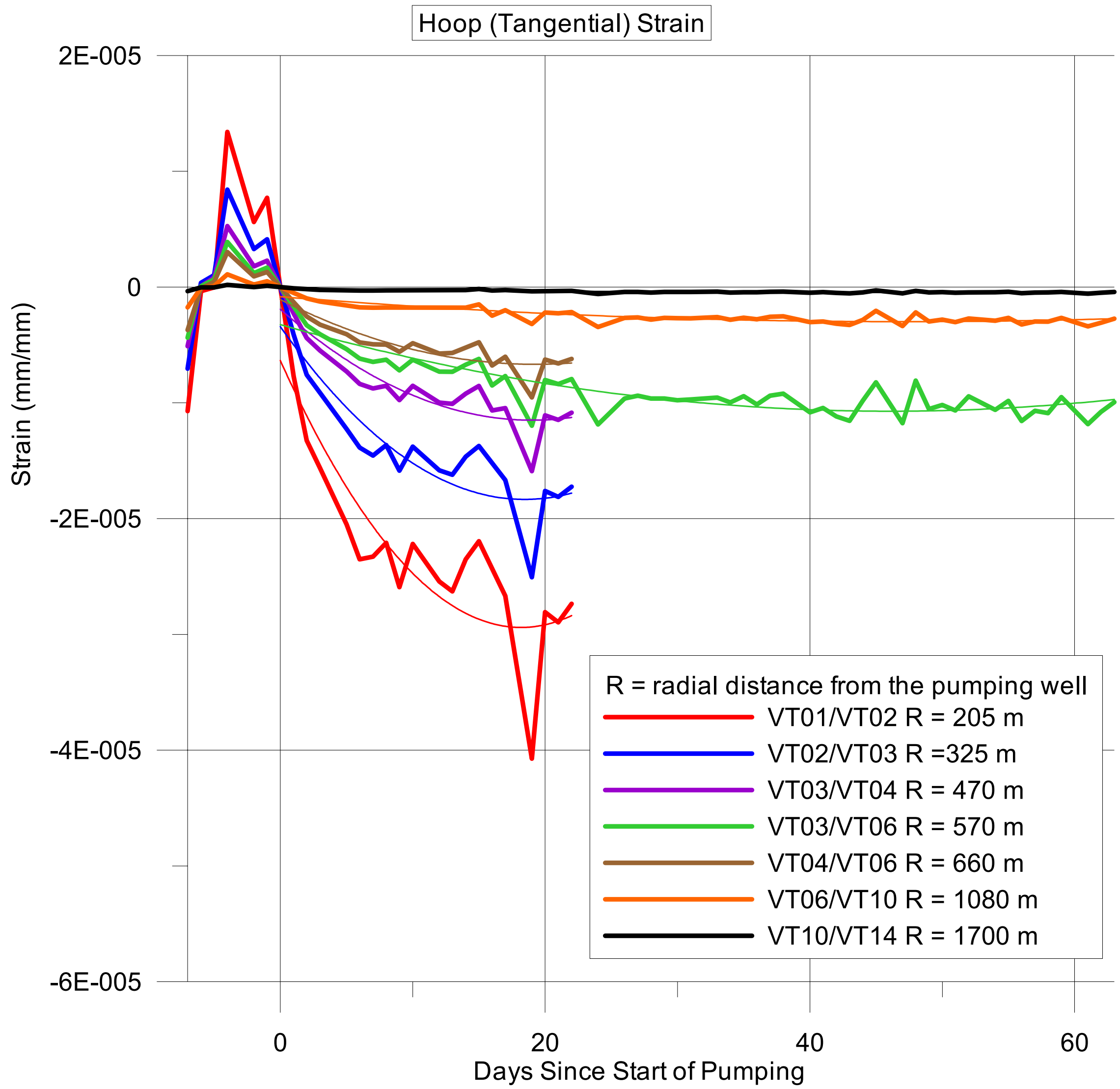


Figure 25: Hoop strain versus time

The magnitude of hoop strain is greatest at 205 meters from the well and decreases with increasing distance from the well. Hoop strain is always compressional because the aquifer matrix is moving toward the well after the onset of pumping.

Hoop strain is directly proportional to the radial displacement and inversely proportional to the radial distance from the pumping well. The hoop strain measured in the field indicates that the aquifer deformation is very similar to the theoretical models of horizontal deformation and poroelasticity (Helm, 1994). The aquifer matrix displaces (along with the water in the pore spaces) at the onset of pumping and would continue except the well casing and screen prevents radial movement.

Once the drawdown has reached near equilibrium, the strain magnitude remains nearly the same because the aquifer matrix has stopped displacing (Helm, 1994).

6.2 Vertical Strain

The measured vertical strain signal, like vertical displacement, has a significant amount of noise, making it difficult to distinguish the real signal. Prior to the onset of pumping, the strain is approximately zero (Figure 26). At the onset of pumping, at a distance of 205 meters from the well, the strain increases more than all other station pairs that are of greater distance from the pumping well. At distances greater than 205 meters from the well, the vertical strain appears to increase only slightly. At 570 meters, the strain remains almost constant at times greater than 22 days. Further from the well, the strain appears to be decreasing slightly after 22 days. The vertical strain signal appears to mirror the available hydraulic-head data with the greatest drawdown occurring closest to the well. After a period of time, the strain nearly reaches equilibrium similar to the expanding drawdown cone. In areas where little significant drawdown occurs, vertical strain is also expected to be insignificant. The data from 470 m and 570 m from the well were not used in the vertical strain plot because the strain calculated was unreasonable at these locations, most likely due to vaults 3, 4 and 6 having almost the same original elevations.

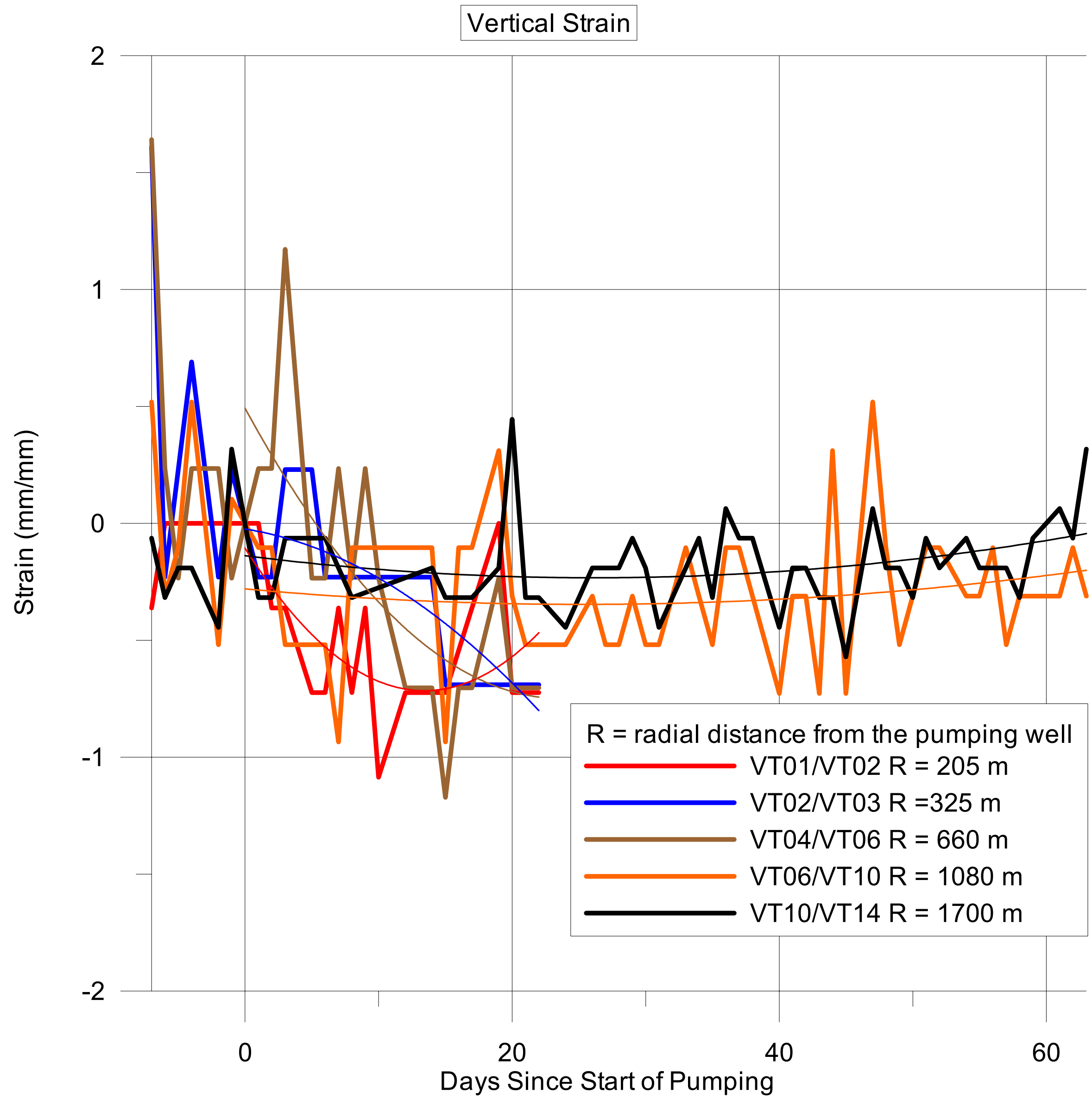


Figure 26: Vertical strain versus pumping duration
The smooth lines are polynomial fits to the field GPS data. The greatest magnitude vertical strain occurs at 205 meters from the well.

6.3 Areal Strain

Calculation of areal strain accounts for both components of horizontal strain. That is, it represents the sum of the strain caused by the fact the radius of the aquifer is getting smaller toward the well and the circumference of the circle is getting smaller toward the well. The assumption of radial symmetry is made to calculate the areal strain. This strain does not account for any shear strain that is observed in the aquifer, nor does it account for the vertical component of strain.

The calculated areal strain is negative or compressional when the area is less than about 830,000 m^2 (i.e. radial distance from the well is less than 660 meters) and extensional at areas greater than 830,000 m^2 (Figure 27). The transition from compressional to extensional strain represents the zone where porosity is not changing in the horizontal direction and therefore no release of water from storage is occurring from horizontal strain (Helm, 1994). It should be noted that the transition occurs in the zone of radial extensional strain. The peak compressional areal strain (maximum negative strain) is observed to occur 205 meters from the well.

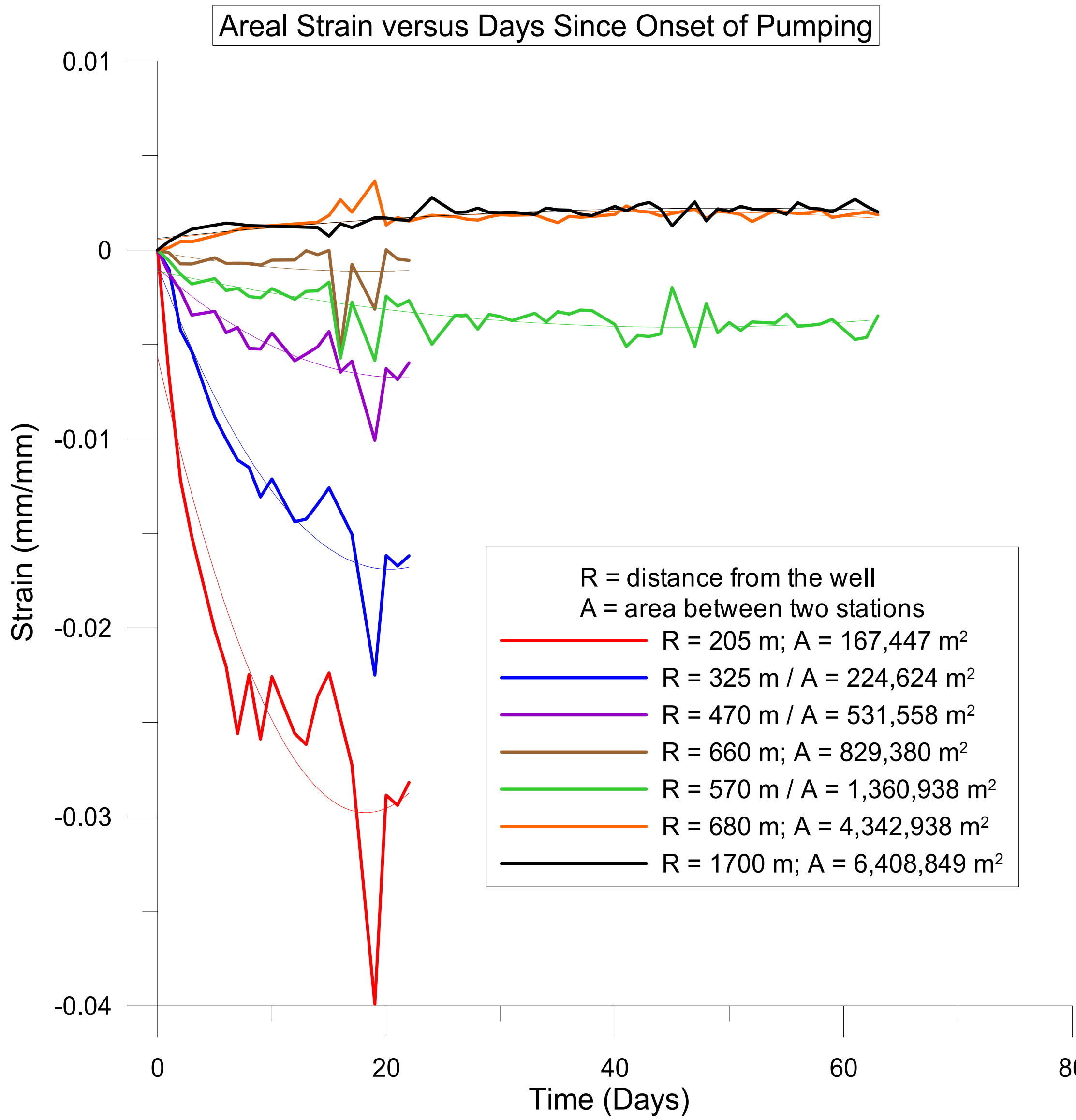


Figure 27: Areal strain versus time
The areal strain is compressive to a distance of 660 m from the pumping well; it becomes extensional with distances greater than 660 m. This transition from compression to extension represents the zone where porosity is not changing in the horizontal direction and water is not entering or being released from storage.

6.4 Volume strain

The volume strain represents the sum of all the normal strain components and can be expressed mathematically as the divergence of the skeletal displacement field (Helm, 1994).

$$\varepsilon_V = \nabla \bullet \vec{U}_S \qquad (11)$$

where ε_V is the volume strain and $\vec{U}_S$ is the displacement of the solids or aquifer matrix.

In general, the magnitude of volume strain forms a wave as a function of distance from the pumping well. The point where maximum volume strain is reached represents the location where no change in porosity is occurring, and therefore no water is being released from storage (Helm, 1994). At distances from the pumping well greater than the point of maximum volume strain, no change in porosity is occurring. At the field site, the maximum volume strain occurs after 11 days and at a distance of 205 m (or less) from the pumping well (Figure 28). At 205 m and 10 days, the volume strain is almost three times the volume strain at 1700 m, and is most likely due to the larger vertical strain close to the well.

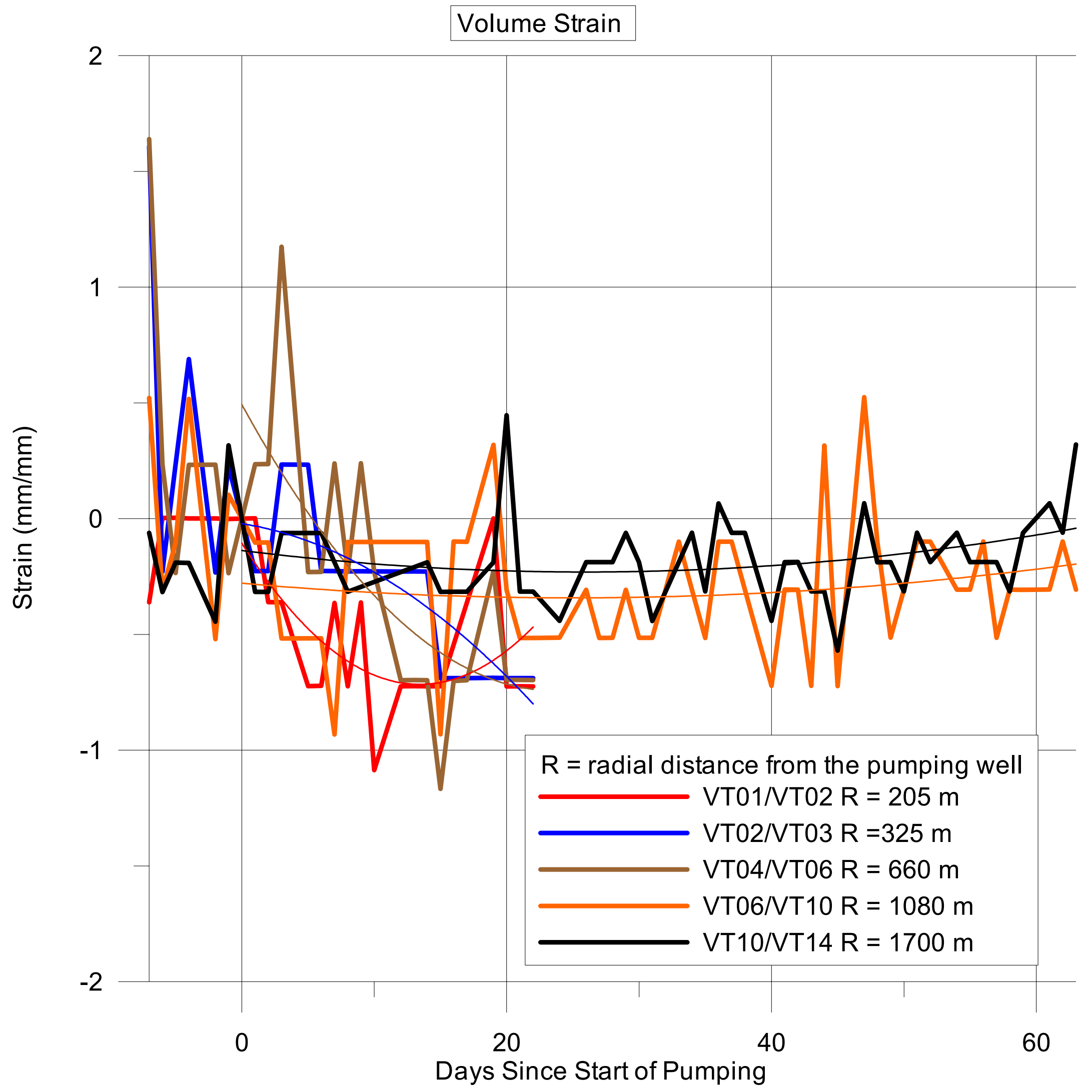


Figure 28: The magnitude of volume strain versus pumping duration
The largest volume strain occurs after 11 days and occurs at 205 m distance from the well. The smooth lines are polynomial fits to the calculated strain data.

The volume strain measured in the field deviates from the theoretical volume strain (as discussed in Helm, 1994) because the volume strain does not decrease with distance after reaching the maximum volume strain (Figure 29). After eight days, the maximum measured volume strain is observed at a distance 205 m from the pumping well. After approximately 1000 m, a minimum volume strain occurs. After 17 days, the maximum volume strain peak has moved to between 325 m and 660 m from the well. The volume strain minimum occurs at approximately 1000 meters, the same location as after eight days. The location of the volume strain maximum after 17 days correlates with the location of the point where porosity is no longer increasing or decreasing due to horizontal strain (section 6.3 Areal Strain).

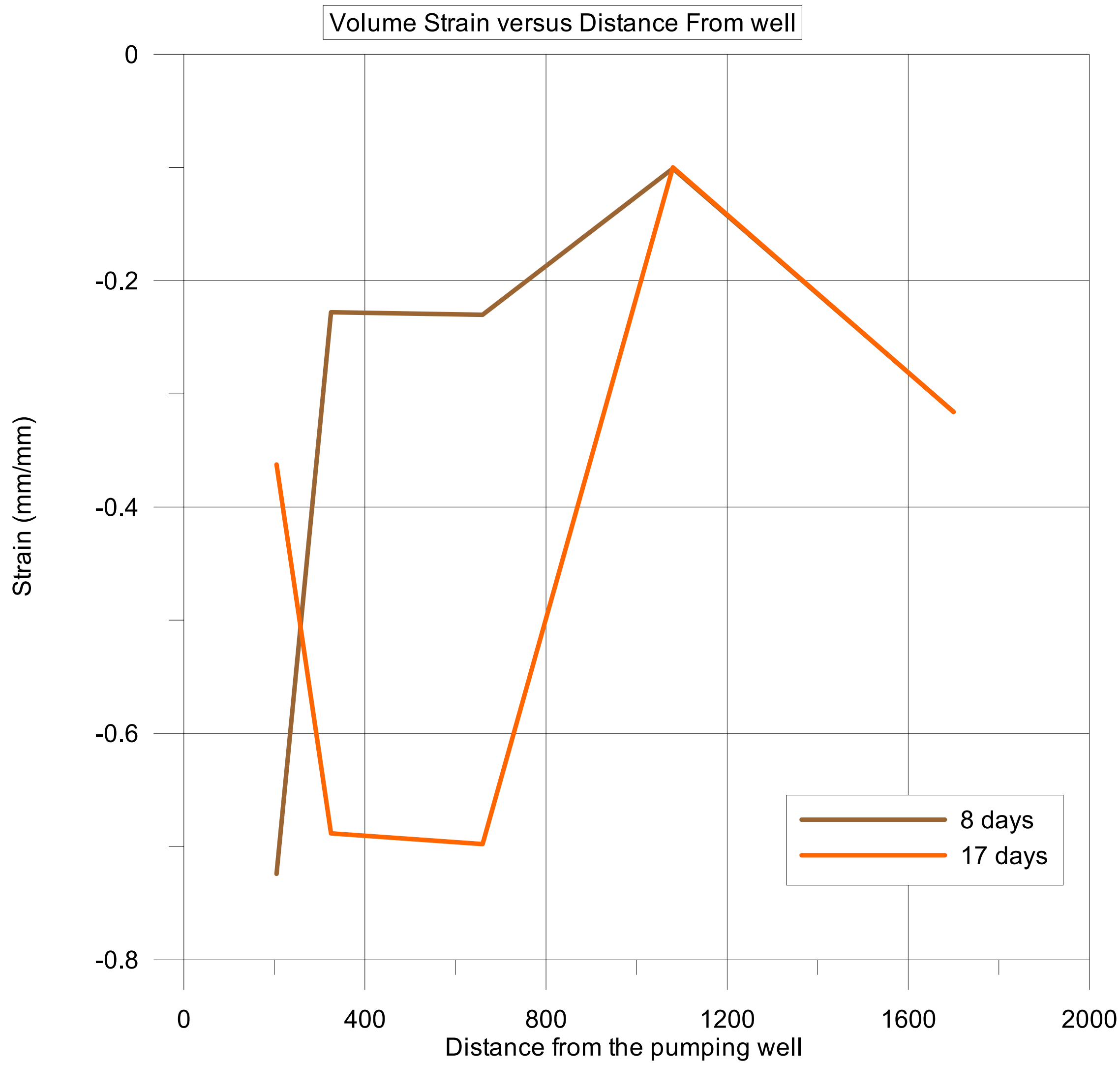


Figure 29: Volume strain versus distance from pumping well at 8 and 17 days.

The explanation of the deviation from the theoretical ideal aquifer is apparent when the different components comprising the volume strain are examined. The radial and hoop strain only constitutes a very small portion of the volume strain. In contrast, the vertical strain was calculated to be at least an order of magnitude larger than radial strain and is the major component of volume strain. Therefore, the vertical compaction is the most significant contributor to release of water from storage based on data measured in the field.

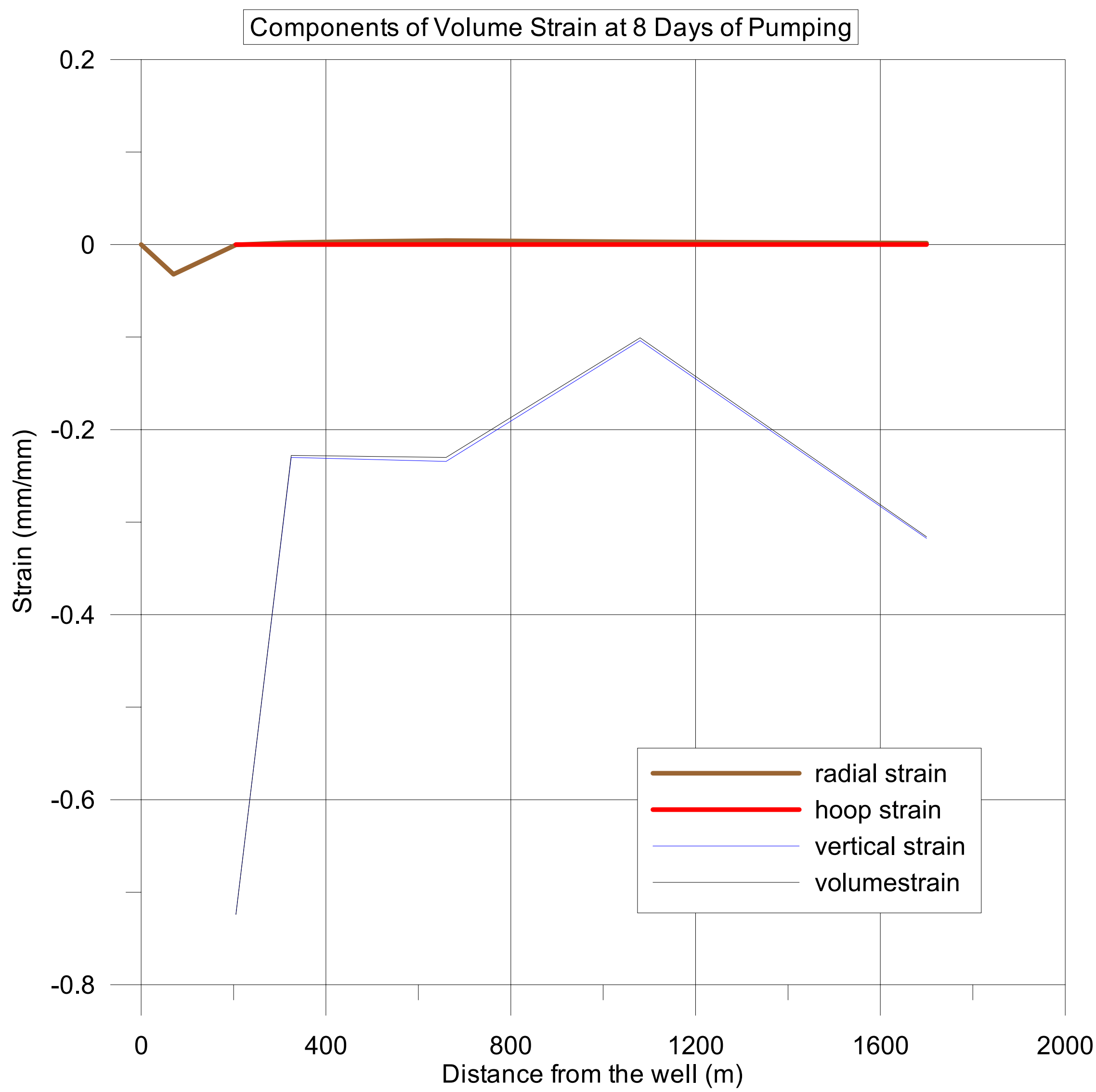


Figure 30: Radial, hoop, vertical and volume strain calculated at 8 days since the start of pumping

6.5 Shear Strain

Strain in the shear direction is negative at the commencement of pumping indicating rotation is occurring in a counter clockwise direction (Figure 31). The maximum negative strain occurs approximately 325 meters from the well. The strain at 205 m is similar to the strain at 570 meters for the first 10 days of pumping. The magnitude of strain at 205m is less than the strain at 325 m during the entire 22 days of monitoring at each station possibly because of the difference in initial strains. The explanation of the magnitude and direction of the shear strain is beyond the scope of this investigation; however, the shear strain appears to be influenced by the pumping well because the strain signature changes at the onset of pumping. The shear strain could be caused by heterogeneities in the aquifer units.

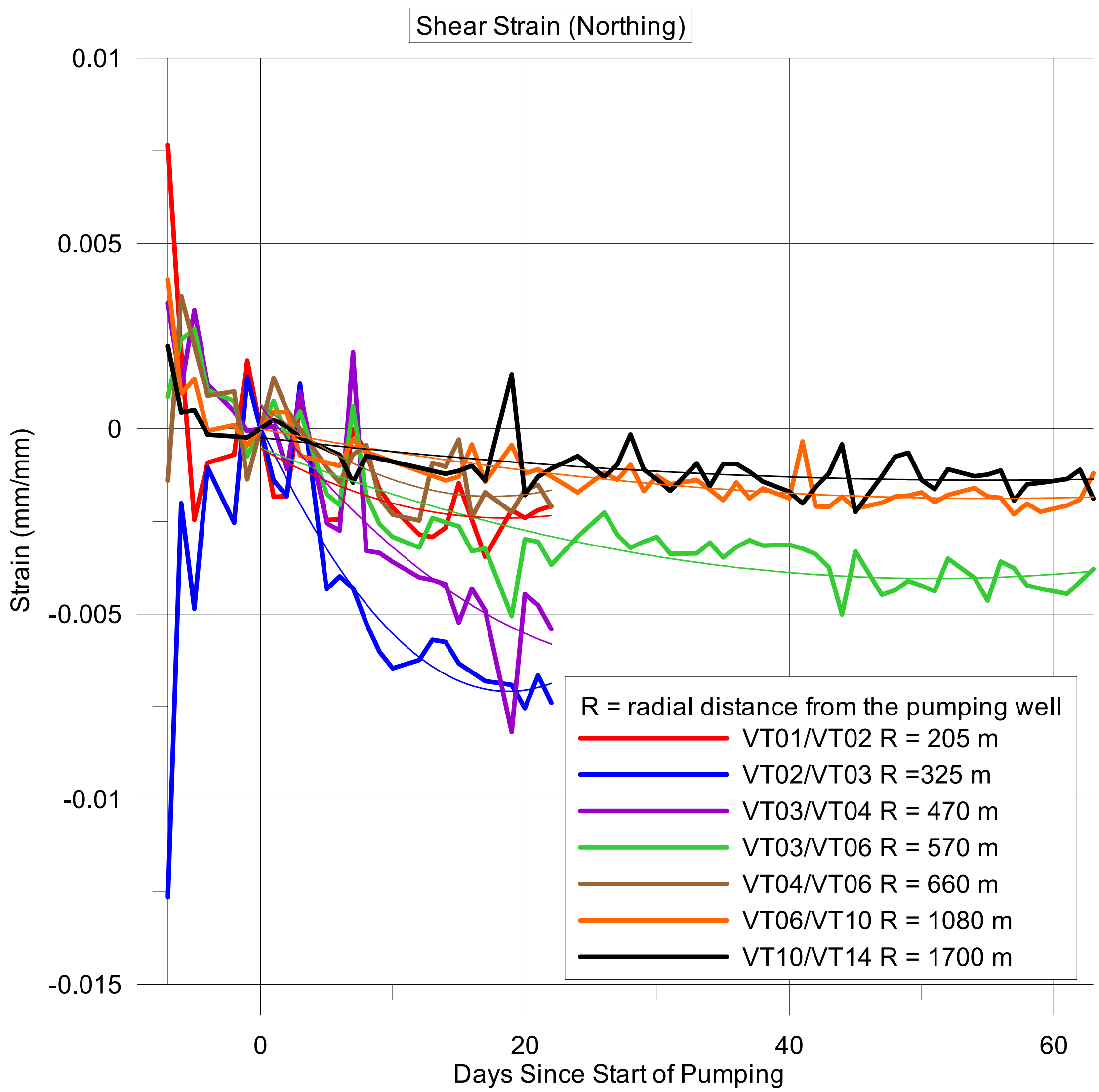


Figure 31: Shear strain versus days of pumping
The strain is negative once pumping begins, resulting in a loss of porosity. The thinner same colored lines represent a polynomial fit to the data.

Each of the previously described strain and displacement plots reveal how the aquifer deformation is expressed at the land surface. However, the plots reveal little information about how strain and displacement may be occurring at depth. The only information about the aquifer at depth is the drawdown data during the aquifer test, the well log stratigraphic information and the transmissivity and storage values calculated from the aquifer test. The information on aquifer deformation at the land surface and the information about the aquifer at depth were incorporated into a numerical simulation of the aquifer in order to gain a better understanding of how the strain and displacement fields may be behaving in both the vertical and horizontal directions within the aquifer . The BIOT4 code (Smith and Griffiths, 1988) will be used to simulate the radial and vertical displacements and strains. The Interbed Storage Package (IBS) (Leake and Prudic, 1991) of MODFLOW will be used to simulate the aquifer test the inelastic and elastic behavior of the aquifer resulting from the observed pumping rate and cyclic pattern. The IBS code only simulates vertical compaction according to the theory of Terzaghi.

7.0 Modeling

A numerical simulation of the aquifer using the available field data is useful for evaluating the strain and stress relationships in areas of the study site that were not observed during the aquifer test. The purpose of reproducing the aquifer-test results in a simulation is two-fold: (1) to obtain strain and displacement information in each model layer representing the aquifer system, and not just at the land surface and (2) to obtain aquifer properties and characterize aquifer behavior to stresses induced by pumping. A useful numerical simulation must be based on all available field data and an accurate conceptual flow model. A conceptual model is an accurate representation of the flow system including the geology, boundary, and initial conditions. The conceptual model helps to simplify the field problem and organize the associated data so it can be more readily analyzed (Anderson and Wossner, 1992). Once the conceptual model is designed, the model must be divided into discrete elements and layers. The aquifer parameters (such as storage and conductivity) must be calibrated so the solution matches the field data. MODFLOW –2000 (Harbough and McDonald, 1988) allows for parameter estimation, but unfortunately insufficient data were available to conduct a tractable inverse model to estimate parameters.

7.1 Conceptual Model

Logs from well 31 and other research done in the area (Dixon and Katzer, 2002) shows that the Muddy Creek Aquifer is a highly variable unit with grain sizes ranging from clay to gravel. The aquifer also exhibits a rapid drawdown/recovery curve during cyclic pumping, indicating a large hydraulic conductivity. Finally, the aquifer system reached near-equilibrium conditions (i.e., net drawdown nearly stopped) after only 11 days of pumping. The rapid response and near equilibrium of the drawdown suggests a mildly leaky aquifer with a large aquifer hydraulic conductivity. Based on the observed drawdown data in well 31 and the VTex well, the most likely conceptual model, as shown in figure 32, is that well 31 is screened in one aquifer which is separated from the aquifer that the VTex well is screened in by a series of semi-confining clay beds.

For the purpose of this study, the conceptual model for the Muddy Creek aquifer is simulated using three model layers having different storage and transmissivity properties (Figure 32). The topmost layer is 94 m thick and represents the sandy aquifer that contains the VTex well. The middle layer is 27 m thick and represents equivalent thickness of the semi-confining beds that separates the lower alluvial Muddy Creek aquifer from upper alluvial Muddy Creek aquifer. Helm discusses the validity of modeling the equivalent thickness (Helm, 1975) as opposed to each individual clay bed to simplify the model and reduce computational time. The bottom layer is 271 m thick and represents the main producing aquifer in which well 31 is screened and is composed of highly transmissive sands. Figure 32 represents a conceptualization of the hydrogeologic setting used for simulating the study area.

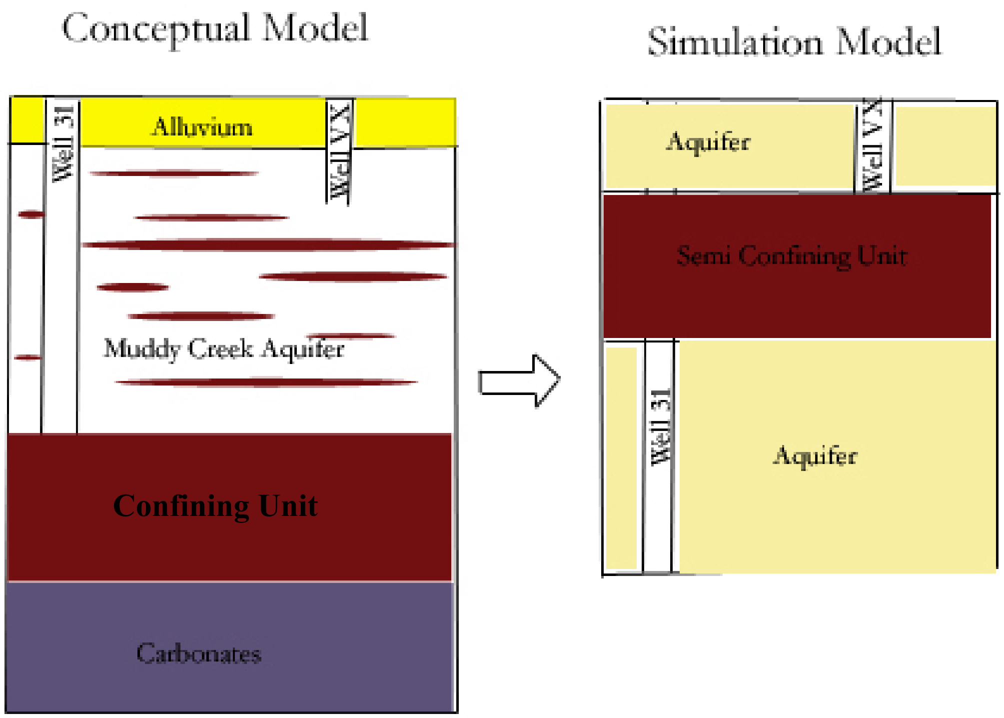


Figure 32: The conceptual model of the Muddy Creek aquifer
The conceptual model summarizes the flow system in the study area. The simulation model diagram displays how the conceptual model was transformed into model layers for the numerical simulation of the aquifer test.

The boundary conditions of the conceptual model used in the axisymmetric BIOT code, includes the pumping well as a flux boundary which is related to the pumping rate and the thickness of the unit. In addition, the pumping well is assumed to be a zero radial-displacement boundary and a vertical traction boundary. The outer boundary representing the perimeter of the model was selected far enough from the pumping well that its influence in the simulation was considered to be negligible. A zero radial-displacement and no-flow boundary were selected along with a vertical traction boundary. No sources of water were simulated to enter the aquifer system and the only sink of water in the system is the pumping well. In the three dimensional areal model using the (IBS) Interbed Storage Package (Leake and Prudic, 1991), the pumping well was placed in the center of the model with the outer boundary condition selected to be km from the pumping well. More details in the exact model areas and boundaries will be discussed with the individual model simulations.

7.2 Subsidence modeling using BIOT4 code

7.2.1 Introduction to BIOT code

The BIOT code is a finite-element axisymmetric or plane strain flow and deformation model. The original form of the BIOT code in this investigation was first introduced by Smith and Griffiths (1988). This finite-element model calculates strain, stress, displacement, and drawdown. The model assumes the standard assumptions of the linear poroelasticity of a saturated domain and that the initial heads and stresses are zero. In 1994, Hsieh modified and updated the BIOT code to a format similar to MODFLOW (BIOT2); in 1996, Burbey fixed some errors and converted the code to PC format (BIOT4). The three governing equations are (Smith and Griffiths, 1988):

$$G\left(\frac{\partial^2 U_r}{\partial r^2}+\frac{1}{r}\frac{\partial U_r}{\partial r}-\frac{U_r}{r^2}+\frac{\partial^2 U_r}{\partial z^2}\right)+\frac{G}{1-2\upsilon}\frac{\partial}{\partial r}\left(\frac{\partial U_r}{\partial r}+\frac{U_r}{r}+\frac{\partial U_Z}{\partial z}\right)-\alpha\rho_f g\frac{\partial h}{\partial r}=0 \qquad (12)$$

$$G\left(\frac{\partial^2 U_Z}{\partial r^2}+\frac{1}{r}\frac{\partial U_Z}{\partial r}+\frac{\partial^2 U_Z}{\partial z^2}\right)+\frac{G}{1-2\upsilon}\frac{\partial}{\partial z}\left(\frac{\partial U_r}{\partial r}+\frac{U_r}{r}+\frac{\partial U_Z}{\partial z}\right)-\alpha\rho_f g\frac{\partial h}{\partial z}=0 \qquad (13)$$

$$\begin{aligned}\kappa_{rr}\left(\frac{\partial^2 h}{\partial r^2}+\frac{1}{r}\frac{\partial h}{\partial r}\right)+\kappa_{rz}\left(2\frac{\partial^2 h}{\partial r\partial z}+\frac{1}{r}\frac{\partial h}{\partial z}\right)+\kappa_{zz}\frac{\partial^2 h}{\partial z^2}\\ -\alpha\frac{\partial}{\partial t}\left(\frac{\partial U_r}{\partial r}+\frac{U_r}{r}+\frac{\partial U_Z}{\partial z}\right)-\rho_f g\left[n\left(\frac{1}{K_f}-\frac{1}{K_s}\right)+\frac{\alpha}{K_s}\right]\frac{\partial h}{\partial t}=0\end{aligned} \qquad (14)$$

where

U_r is the displacement in the r direction (positive away from z axis)(L)

U_r is the displacement in the z direction (positive downward)(L)

h is the hydraulic head (L)

G is the shear modulus of the bulk porous medium (N/L^2)

υ is the drained Poisson's ratio of the bulk porous medium (dimensionless)

n is the porosity of the bulk porous medium (dimensionless)

K_S is the bulk modulus of the solid grains (N/L^2)

κ_{rr}, κ_{rz} and κ_{zz} are components of hydraulic conductivity tensor in the r-z axis system (L/T).

$\rho_f g$ is the specific weight of fluid (N/L^3)

K_f is the bulk modulus (inverse compressibility) of the fluid (N/L^2)

$\alpha = 1 - \frac{K}{K_s} = 1 - \left(\frac{2(1+\upsilon)G}{3(1-2\upsilon)K_s} \right)$ where K is the bulk modulus of the porous medium

The displacement in the z and r directions (axisymmetric) and the drawdown are calculated at every node in the finite element mesh, while the stresses and strains are calculated at the center of each element. A direct solution method outlined in Smith and Griffiths (1988) solves the governing equations. The possible boundary conditions in the model are a prescribed (constant) head boundary, a prescribed flux boundary or a prescribed traction boundary. Complete details of the BIOT4 code are obtained from the version 2.0 documentation (Smith et. al 1996).

7.2.2 Calibrated Aquifer Parameters of BIOT model

The aquifer test was simulated as previously described using three different model layers with different parameters for each layer. Sixty-two variably spaced elements were used, with the boundaries of the elements at the same distances from the pumping well as the GPS stations in the field. The first element nearest the well was 0.15 meters wide. Each element was increased in size away from the well by 1.5 times the width. The simulation was calculated out to 35,000 meters from the well. The bottom alluvial Muddy Creek aquifer (layer 3) was divided into four units having the same transmissivity and storage characteristics. The aquifer was divided into different units to simulate possible differences in strain and displacement with depth. The actual storage values, shear modulus, and conductivity values of all model layers were not known and had to be estimated. Table 5 summarizes the initial conditions in each layer. The only parameter listed that was known was the unit thicknesses (b) and the flux (q) across the pumping well boundary. A constant value of 0.2 was used for Poisson’s ratio and porosity. The specific weight of water was 9800 N/m^3. Throughout the entire simulation, the ratio of horizontal to vertical K was 1 to 10. The flux across the pumping boundary was calculated using the following equation:

$$q = \frac{-Q}{2\pi r_W (b_2 - b_1)} \tag{15}$$

where $-Q$ is the pumping rate, r_W is the radius of the well, and $(b_2 - b_1)$ is the thickness of the model layer.

Layer	Hydrogeologic Unit	Initial value of horizontal conductivity (K)(m/s)	Initial value of shear modulus,G (Newton/m^2)	Flux across pumping boundary, q (m/s)	Specific Storage (Ss) (1/m)	Thick-ness, b (m)
1	Upper Muddy Creek alluvial aquifer	5.4578e-^{5}	1.04701e^7	0	0.00117	94
2	Semi-confining layer	5.4578e-^{6}	1.04701e^8	0	0.000117	27
3,4,5,6	Lower Muddy Creek Alluvial Aquifer	5.4578e-^{5}	1.04701e^7	-4.4299e^{-3}	0.00117	271

Table 5: Initial Values used in BIOT model

The total time of the aquifer test was divided up into stress periods. Each stress period represented the amount of time the pump was on or off. There were a total of 333 stress periods in the aquifer test that ranged from one to 10 hours in length.

Initially, only the first 100 (out of 333) stress periods were used to calibrate the model. This was done to decrease the execution time of the model. Of the parameters listed in Table 4, the values that were changed to fit the model to the observation data were the K and G in each layer. The final Ss was calculated from the final value of G using the equation:

$$S_S = \frac{3\rho_W g}{2G(3\upsilon + (1 - 2\upsilon))} \tag{16}$$

Each value of K and G was increased and decreased by an order of magnitude and the root mean square error was examined for the drawdown data in well 31, the VTex well, and for the vertical and radial displacement data at each vault monitoring station. The RMS error was calculated using the following formula:

$$RMS = \sqrt{\frac{(h_m - h_c)^2}{n}} \qquad (17)$$

Where h_m is the head measured (or displacement), h_c is the head calculated (or displacement) and n is the number of measurements. Once the sensitivity of each parameter was calculated, the parameters were adjusted until the simulated drawdown and displacement fit the measured data. Once the parameters were calibrated, all 333 stress periods were simulated and a final RMS value was calculated. Table 6 summarizes the final RMS values for each head measurement location and displacement location. For comparison, the standard deviations of the measured values are included. The RMS of the simulated values should be of the same order as the standard deviation of the measured values. The final simulated RMS for calculated drawdown at well 31 is less than the standard deviation in the measured drawdown values. The model parameters do not adequately represent the drawdown in the VTex well because the calculated RMS is an order of magnitude larger than the standard deviation in the measured data. The drawdown in the VTex well was difficult to adequately represent because the exact thickness and leakance through the semi-confining layer is not known. The calculated displacement RMS values for both horizontal and vertical are approximately two times larger than the standard deviation of the measured values. Because the model was being used to compare strain and displacement at various depths, this model fit was accurate enough to compare relative magnitudes calculated at various depths.

	Well 31	VTex				
Standard deviation of measured drawdown data (m)	4.19	0.032				
FINAL simulated RMS for drawdown (m)	3.127	0.140				
	VT01	**VT02**	**VT03**	**VT04**	**VT06**	**VT10**
Standard deviation of measured vertical displacement (mm)	3.78	3.23	2.79	2.62	2.76	1.43
FINAL vertical simulated RMS (mm)	6.665	6.936	7.340	4.620	5.024	1.899
Standard deviation of measured radial displacement (mm)	1.76	1.78	1.73	1.51	1.17	0.42
FINAL radial simulated RMS (mm)	2.756	2.207	3.939	1.706	2.808	1.231

Table 6: Final RMS values of the calibrated BIOT model and standard deviation of measured values for comparison

Table 7 summarizes each model layer and the final calibrated parameters for the layers. K_H and K_V are the horizontal and vertical components of K respectively, and υ is Poisson's ratio.

		Estimated Parameter					
Model Layer	**Hydro-stratigrahic unit**	**K_H (m/s)**	**K_V (m/s)**	**G (N/m^2)**	**υ**	**S_S (1/m)**	**Layer thickness (m)**
1	**Top aquifer**	5.4578e^{-5}	5.4578e^{-6}	1.0470e^{8}	0.2	1.170e^{-4}	94
2	**Semi-confining layer**	5.4578e^{-8}	5.4578e^{-9}	1.0470e^{9}	0.2	1.170e^{-5}	27
3,4,5,6	**Bottom aquifer**	2.9525e^{-4}	2.9525e^{-5}	1.0470e^{8}	0.2	1.170e^{-4}	271

Table 7: Calibrated parameters and characteristics using the BIOT code

The bottom aquifer (layers 3-6) is simulated to have the highest hydraulic conductivity, while the semi-confining unit (layer 2) has the lowest simulated value. Five orders of magnitude separate the semi-confining layer (layer 2) and bottom aquifer (layers 3-6) hydraulic conductivity values. According to the hydraulic conductivity values, the top aquifer (layer 1) would be composed of silty sand, the semi-confining layer (layer 2) would be composed of silty clay, and the bottom aquifer (layers 3-6) would be composed of clean sand (Charbeneau, 2000).

The head values in both wells were compared every hour for 1,545 hours. The measured displacement values represented an average displacement over a 24 hour or 48 hour period. The model data displacement data were also averaged over a 24 or 48 hour period to make the values comparable to the GPS data measured in the field. The simulated displacement values in the radial and vertical directions were compared relative to the displacement at 2,000 m from the pumping well (e.g. the distance from the well to vault 14), because the measured displacement at each vault represents movement relative to vault 14. Figure 33 shows the relation between simulated and observed head values in both wells. The upper cluster of head values represents the hydraulic head when the pump is off and the lower cluster of head values represents the hydraulic head when the pump is on. The magnitude of the simulated sub-daily drawdown cycles (from the pump turning on and off) in Well 31 are slightly greater than the observed values. In well VTex, all of the simulated values are slightly greater than those observed in the field.

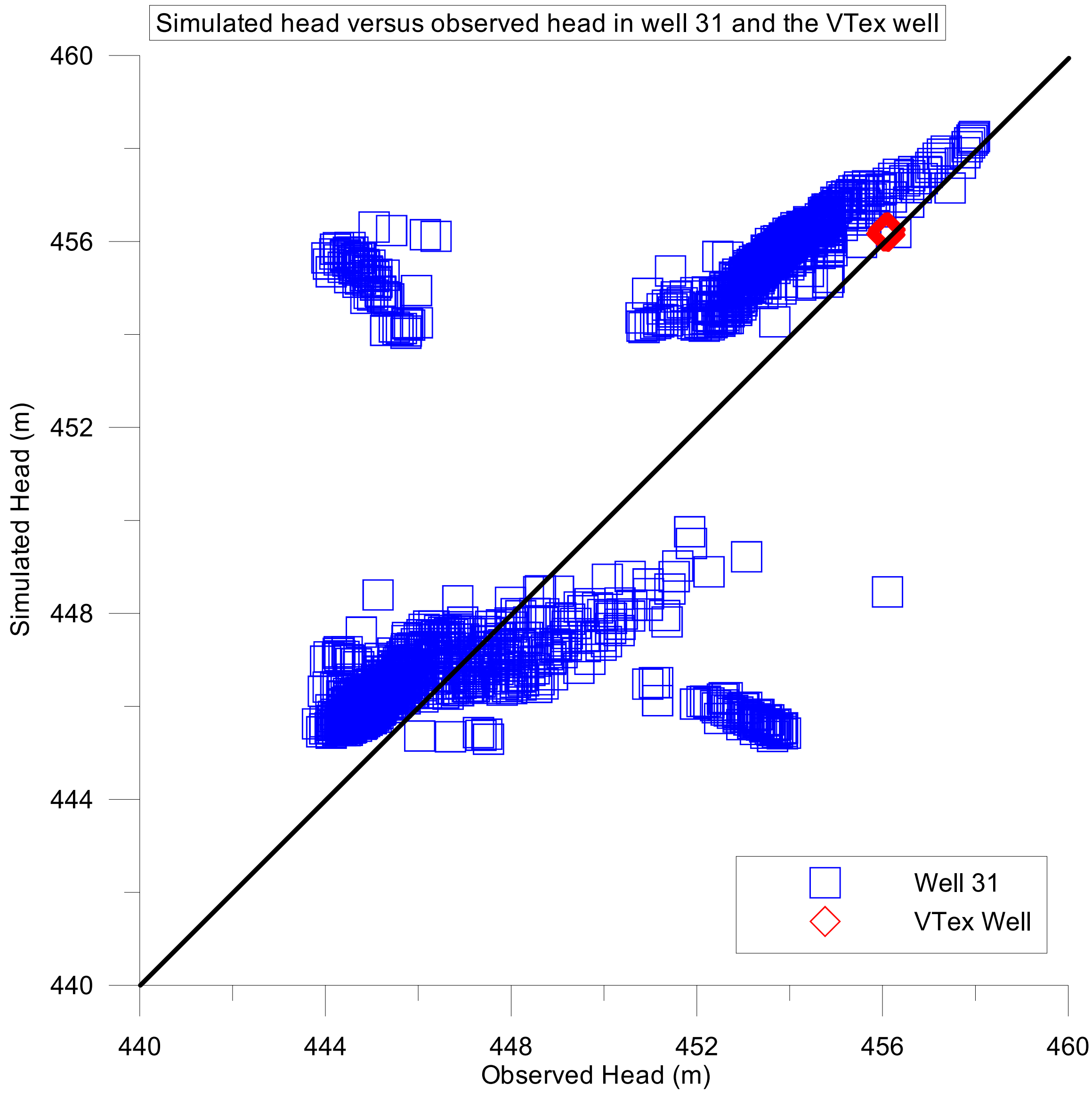


Figure 33: Simulated versus observed head values in well 31 and VTex well.

The simulated displacement in the vertical direction was approximately two times greater than the vertical displacement observed in the field, with the largest differences occurring closest to the pumping well (Figure 34). The simulation does not account for any time delay for the change in pressure to dissipate across clay beds, so head changes are assumed to be instantaneous across the clay units. However, depending on the thickness of the clay bed, the pressure may take hours to days or even years to dissipate. The actual clay beds measured in the well log are usually about 3 m thick, so the time delay for pressure to dissipate is not likely a factor. The simulated vertical displacements are valid to compare to other simulated values (to determine different displacements at different depths), but cannot be directly compared to the measured values since the model over-simulates the compaction by a factor of two.

The differences in the observed values versus simulated radial displacement values were much smaller than the differences in the observed values versus the simulated vertical displacement values.

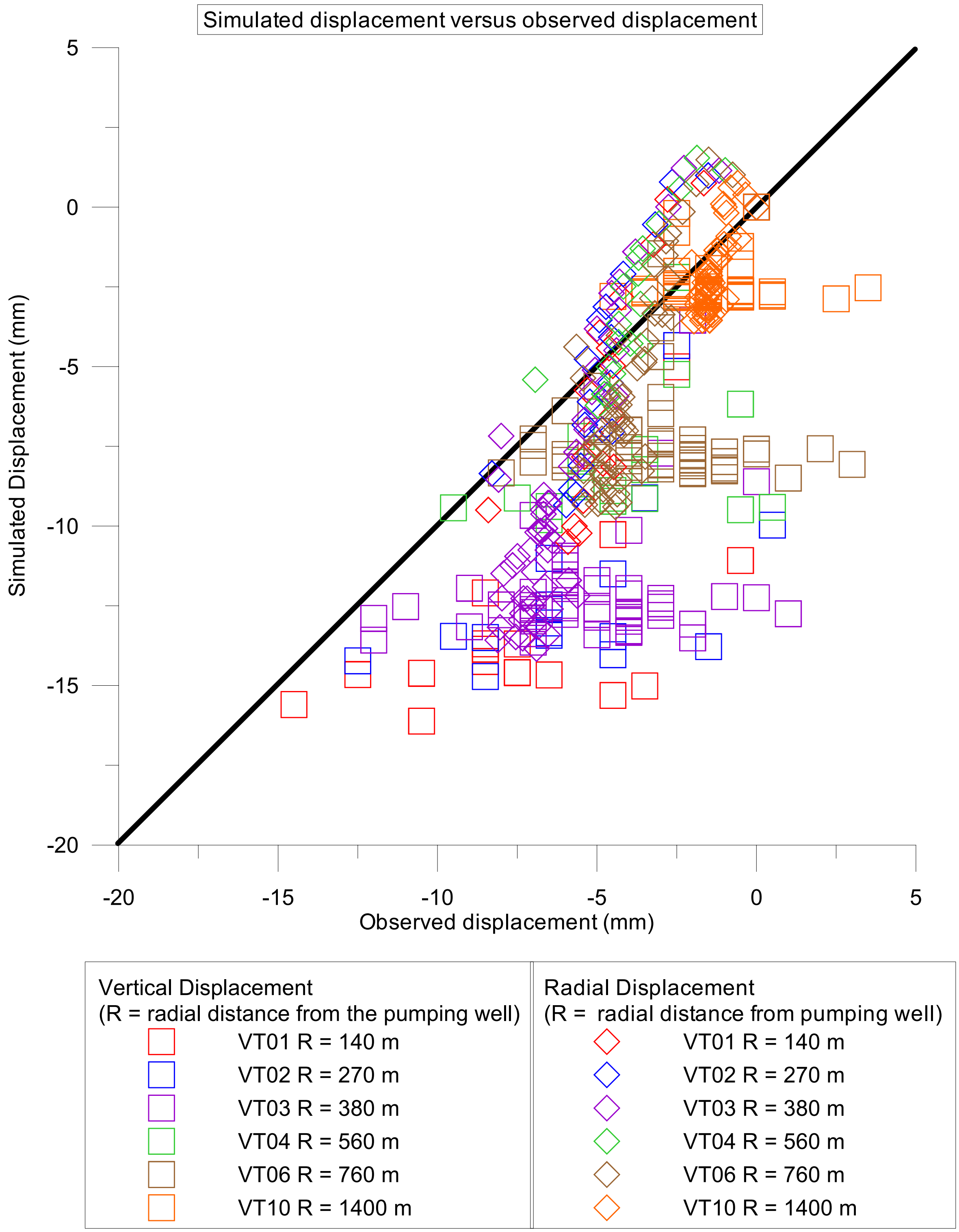


Figure 34: Simulated versus observed vertical and radial displacement values The vertical displacements are shown as boxes and the radial displacements as triangles. The simulated values for vertical displacement are approximately a factor of two larger than the observed values in the field. The difference in simulated versus observed may be to time-delay compaction of clay beds.

7.2.3 Simulated Radial Displacement Profiles

The simulated radial displacement profiles indicate that (1) surface displacements are significantly less than those in the aquifer, and (2) the displacement field is highly heterogeneous because the parameter values are heterogeneous. The assumption was made that the brittle unsaturated zone rides passively on top of the dynamic aquifer, so therefore the top of layer 1 is the equivalent to the horizontal and vertical movement seen on the land surface. In general, the semi-confining bed layer (layer 2) displaces radially the least compared to either of the two aquifer layers. The hydraulic diffusivity of the semi-confining layer (K/Ss) is simulated to be 0.004629 /s which is very low, indicating that the clay lenses may be continuous and act as a barrier to vertical flow. In addition, it may also explain the small simulated magnitudes of radial displacement for layer 2. Figure 35 shows the simulated horizontal displacement after one hour of pumping. At distances of 1,075 and 2,000 m from the well, radial displacement occurs even though no measured drawdown occurs at that distance) . This result is verified by the theory in Burbey (2002). At 29 m from the pumping well, the horizontal movement close to the surface and in layer 2 is small compared to the movement in layers 3-6. This is most likely due to the pumping occurring in layers 3-6 as well as the large hydraulic conductivity difference between the aquifer and the overlying confining. The difference between the displacement in layers 3-6 and layer 1 decreases as the distance from the well increases.

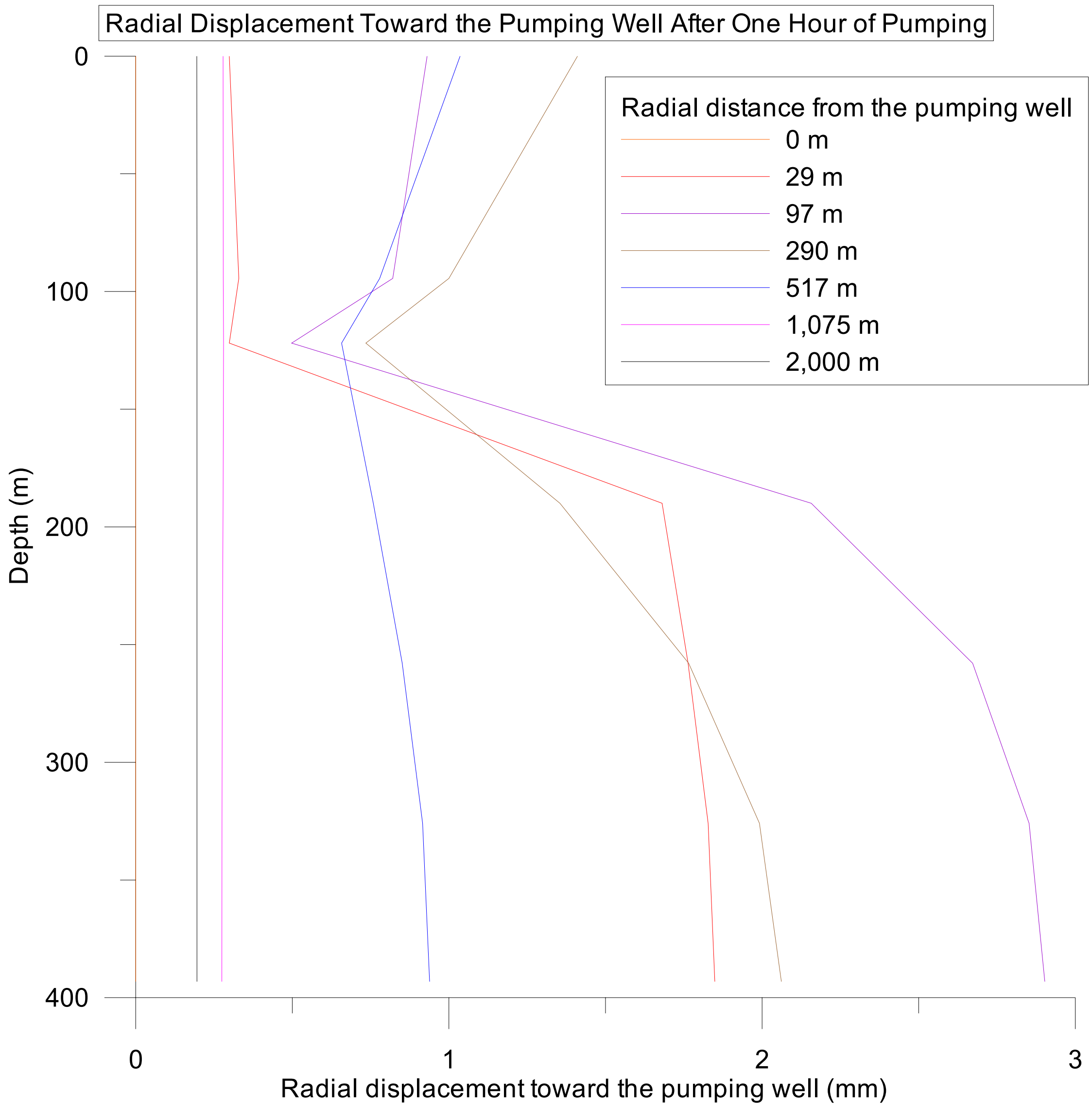


Figure 35: Vertical distribution of radial displacement as a function of distance after an hour of pumping.

After one day of pumping, the radial displacement simulated 29 m and 97 m from the well has not changed more than a fourth of an order of magnitude, and is most likely due to the fact that the well itself is not displacing (Figure 36). However, at distances of 290 m and greater, the displacement has increased by 1.5 orders of magnitude. The differential displacement as a result of layer 2 is just beginning to be expressed at a distance of 1,075 m from the well.

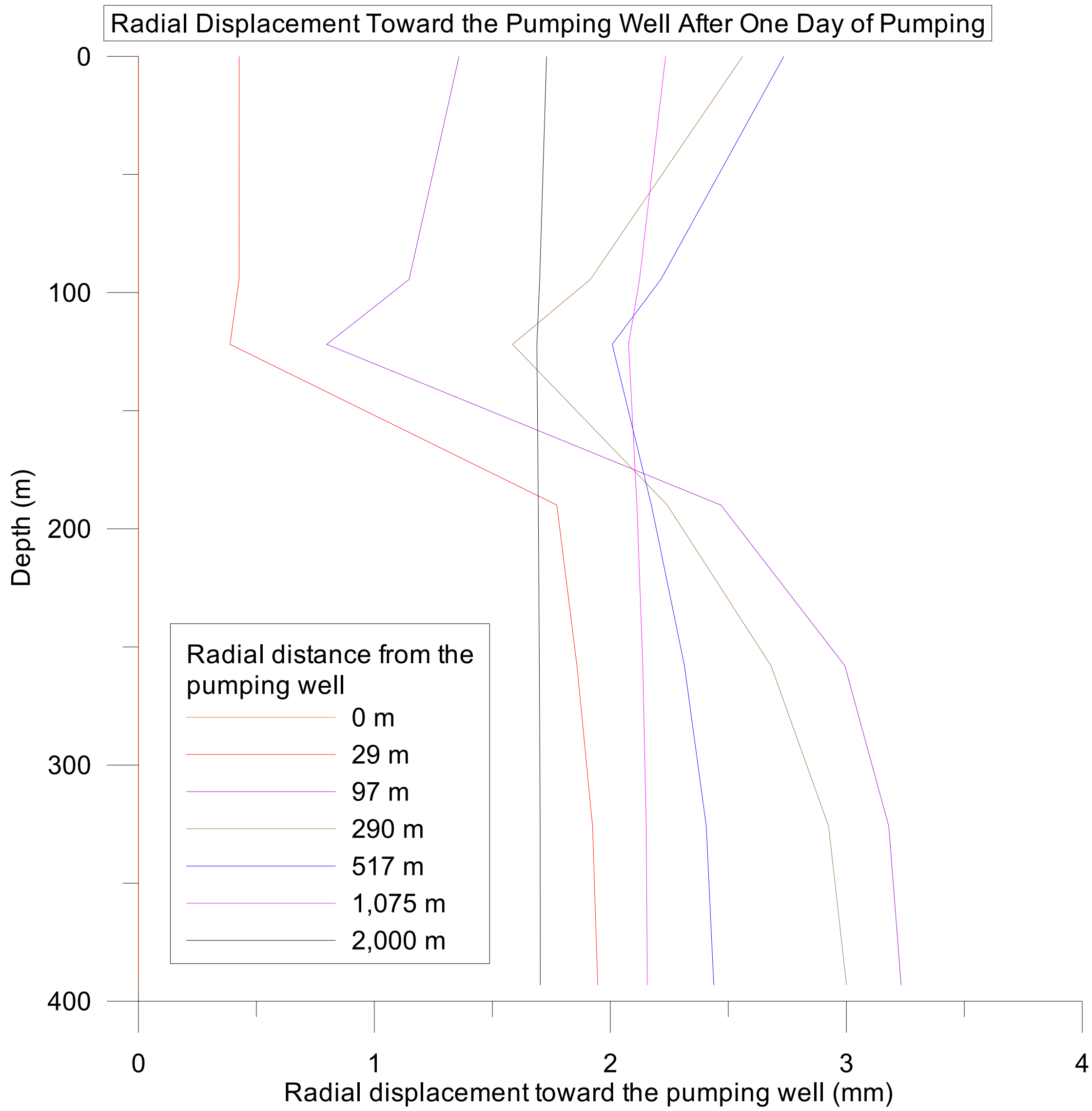


Figure 36: Vertical distribution of radial displacement as a function of distance after one day of pumping.

After four days of pumping, the greatest simulated radial displacements occur in layers 3-6, at distances of 1,075 m and 2,000 m (Figure 37) because the aquifer matrix and water in the pore spaces are displacing at the same rate (Helm, 1994). Largest magnitude displacements also occur further away from the well as time increases because of the zero-displacement boundary of the well screen. Between the distances 290 m and 2,000 m from the well, the displacement magnitudes are similar in layers 3-6, but decrease in layers 1 and 2 due to the pumping occurring in layers 3-6.

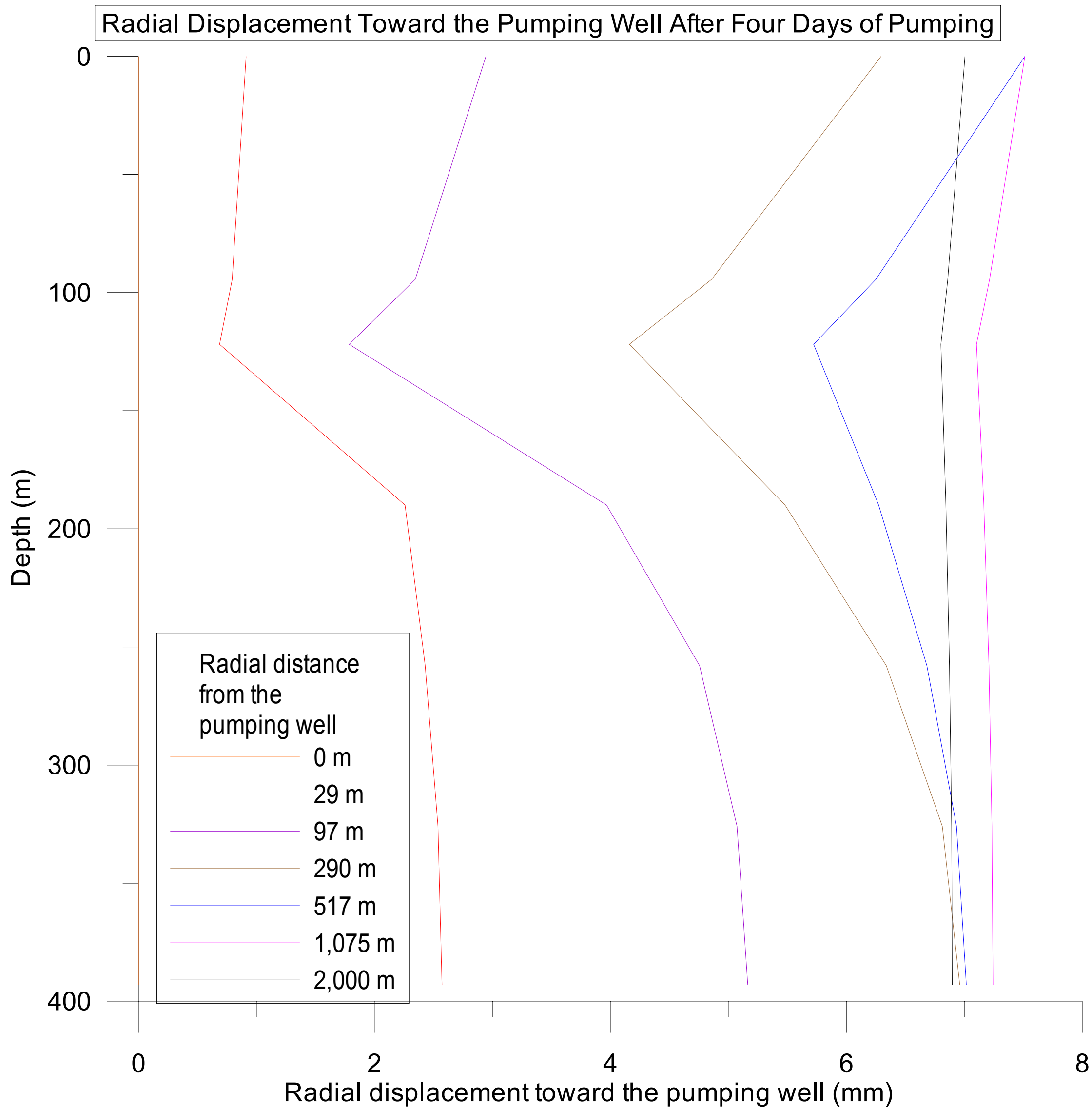


Figure 37: Vertical distribution of radial displacement as a function of distance after 4 days of pumping.

After ten days of pumping, the difference in magnitude of radial displacement as a function of distance from the pumping well becomes more apparent (Figure 38) due to the zero-displacement boundary of the pumping well. The vertical distribution of differential radial displacement with depth is muted except for closer distances to the well (such as 29 and 97 m from the well). At 517 m from the well, layer 1 actually has more displacement occurring than layer 3, possibly due to the different hydraulic diffusivities of the layers. When time increases, the sensitivity of the pumping rate on the magnitude of displacement decreases.

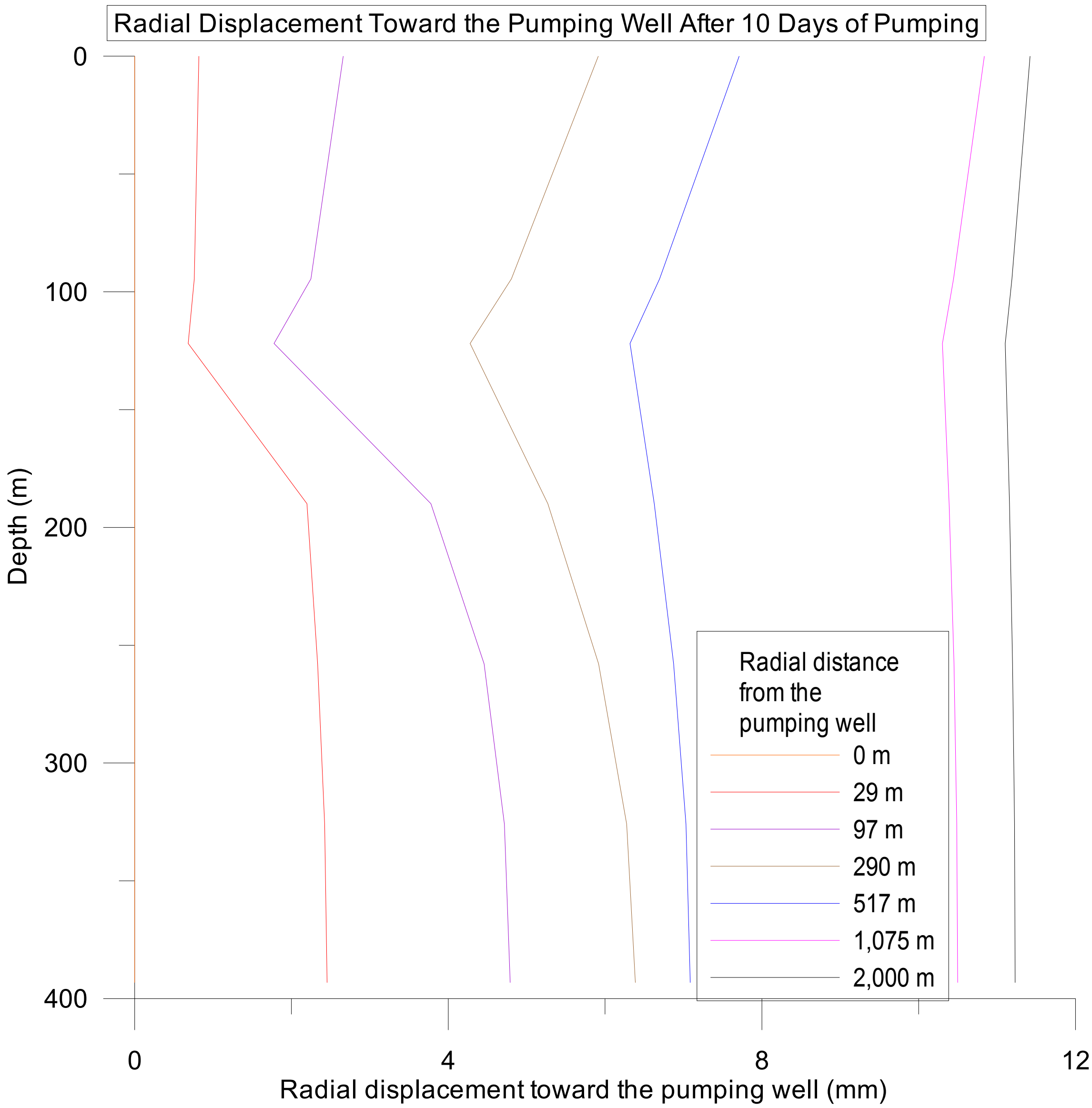


Figure 38: Vertical distribution of radial displacement as a function of distance after 10 days of pumping.

The magnitude of differential displacement as a function of depth due to heterogeneities in the aquifer system depends primarily on distance from the well and time. As distance from the well increases, the displacement across the heterogeneities is uniform suggesting the hydraulic diffusivity and thickness of the layers becomes less significant in determining the magnitude of radial displacement. As time increases the displacement depths also become more uniform. The pumping rate seems to be the most significant factor in determining radial displacement at the onset of pumping. When considering the effects of radial displacement to buildings and structures on the land surface, the greatest magnitude displacement will occur further away from the well where there is negligible drawdown and after a period of time (as opposed to when the well is first turned on), provided the aquifer system is similar to the one simulated.

7.3 Subsidence modeling using IBS1 code

The Interbed Storage (IBS) package (Leake and Prudic, 1991) is one of the most commonly used subsidence modeling codes, because it is incorporated as a package in MODFLOW (Harbough and McDonald, 1988). Subsidence modeling of a particular layer can be accomplished by adding four additional interbed storage parameters: preconsolidation head, elastic storage coefficient, inelastic coefficient, and initial subsidence. The code assumes that all strain in the aquifer is in the vertical direction. For the purpose of this investigation, IBS was used to determine the effect of using an inelastic and elastic storage coefficient instead of assuming all deformation is elastic. This is especially important for pulsed pumping schemes.

7.3.1 Introduction to IBS1 Code

The IBS1 code (Leake and Prudic, 1991) uses the traditional Jacob storage's coefficient, which assumes that deformation is vertical and that the total load (total stress) does not vary (Burbey, 1999). The code allows for an inelastic and elastic storage coefficient, but does not calculate the time delay for the release of water from storage in confining beds without first discretizing the confining layer into may smaller units.

Elastic compaction (Δb) is calculated through the following equation (Leake and Prudic, 1991):

$$\Delta b = \frac{\Delta p'}{\rho_W g} S_{SKE} b_O \tag{18}$$

where Δb is elastic compaction, $\Delta p'$ is the change in pressure across the confining bed, S_{SKE} is the elastic storage coefficient, and b_O is the original thickness of the clay layer.

Inelastic compaction ($\Delta b*$) is approximately equal to (Leake and Prudic, 1991):

$$\Delta b* = \frac{\Delta p}{\rho_W g} S_{SKV} b_O \tag{19}$$

where $\Delta b*$ is the elastic compaction and S_{SKV} is the inelastic storage coefficient. However, according to laboratory tests, the inelastic compaction is more nearly proportional to increase in log of effective stress (Helm, 1975). The IBS code cannot account for non-linear inelastic compaction.

The basic groundwater governing equation for MODFLOW and IBS is:

$$\frac{\partial}{\partial x}\left(K_{XX}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{YY}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{ZZ}\frac{\partial h}{\partial z}\right)-W=S_S\frac{\partial h}{\partial t} \tag{20}$$

where K is conductivity (L/t) and W is a source/sink term. IBS adds the following terms to equations to the right side of the equation:

$$q_i = S'_{SK}\frac{\partial h}{\partial t} \tag{21}$$

where q_i is the specific discharge from storage contained in clay interbeds and S'_{SK} is the storage coefficient of the clay interbed.

If the drawdown is greater than the preconsolidation stress, then inelastic compaction occurs. If the stresses stay within the stress history of the aquifer unit, then elastic deformation occurs. IBS determines whether to use elastic (SKE) or inelastic (SKV) deformation by the following equation:

$$\begin{aligned} q_i^m &= \frac{S_{SK}^m}{\Delta t}\left(h^m - H^{m-1}\right)+\frac{S_{SKE}}{\Delta t}\left(H^{m-1}-h^{m-1}\right) \\ S_{SK}^m &= \begin{cases} S_{SKE}, h^m \rangle H^{m-1} \\ S_{SKV}, h^m \le H^{m-1} \end{cases} \end{aligned} \tag{22}$$

where h is the head being calculated at a particular time step m and H is the preconsolidation head.

Argus One open environment software was used as an interface for running MODFLOW with the IBS package. The pumping well was placed in the center of a 30 km by 30 km grid. The initial grid cell size was 1 km by 1 km. For three kilometers on in all directions from the well, the grid cell size was refined to 100 m by 100 m. The grid cell size was refined two more times at one kilometer from the well and 50 meters from the well to 50 m by 50 m and 10 m by 10 m, respectively.

The same parameters used in the BIOT code were used in the IBS code. The storage value from the BIOT code was used as the inelastic storage value and the elastic storage value was estimated to be one half the magnitude of the inelastic value. Because the Muddy Creek aquifer is composed of predominately highly transmissive sands, the inelastic and elastic storage values are not likely to differ by more than an a factor of five.

7.3 The Effects of Pulsed Pumping vs. Constant Pumping on Subsidence, Strain and Drawdown

The effects of the pumping cycle (approximately eight hours on and eight hours off) on the measured surface movements must be examined. From groundwater models, pulsed pumping usually causes a greater magnitude of subsidence and drawdown than constant pumping, but concentrates the subsidence to a smaller area closer to the well (Wilson and Gorelick, 1996). The effect of pulsed pumping on horizontal strain has not been previously documented.

Each of the models was run with the pulsed pumping that occurred in the field, and then again with an average pumping rate of 376.18 m^3/hr. In the BIOT code, all deformation is assumed to be elastic. When the pump is on, the vertical displacement is simulated to be greater in magnitude than for constant pumping. However, when the water levels recover, the magnitude of displacement in the pulsed pumping simulation becomes less than the constant pumping situation. The higher and lower displacement phenomenon of the pulsed pumping decreases as distance from the well increases. When the displacements are averaged over a 24 or 48 hour periods (as when the simulated values are compared with the observed values in model calibration), no difference is detected in the radial displacement values between the pulsed pumping and the constant pumping. The vertical displacement values in pulsed pumping, on the contrary, are either a factor greater or smaller than the constant values. The difference in vertical displacement for the pulsed pumping and constant pumping scenarios is probably caused by the total amount of time the pumping was on (not exactly 8 hours on and off) rather than by differences in the pumping schemes.

The IBS code simulates both elastic and inelastic deformation so the differences in vertical deformation for pulsed and constant pumping schemes should be apparent. The aquifer test is simulated once with the pulsed pumping rate and once with an average pumping rate for the same duration of time. The compaction results for the constant pumping scenario are subtracted from the simulated vertical displacement for the pulsed pumping rate at the same times step. The pulsed pumping caused more subsidence to occur within a radius of 1,000 m from the pumping well. Figure 39 shows the area of greater pulsed pumping subsidence in red and greater constant subsidence in green. The magnitude of deformation is much smaller than the vertical displacement measured in the field, due to poor model fit. However, for the purpose of comparing the pulsed and constant pumping schemes a pattern of concentrated subsidence near the pumping well can be seen.

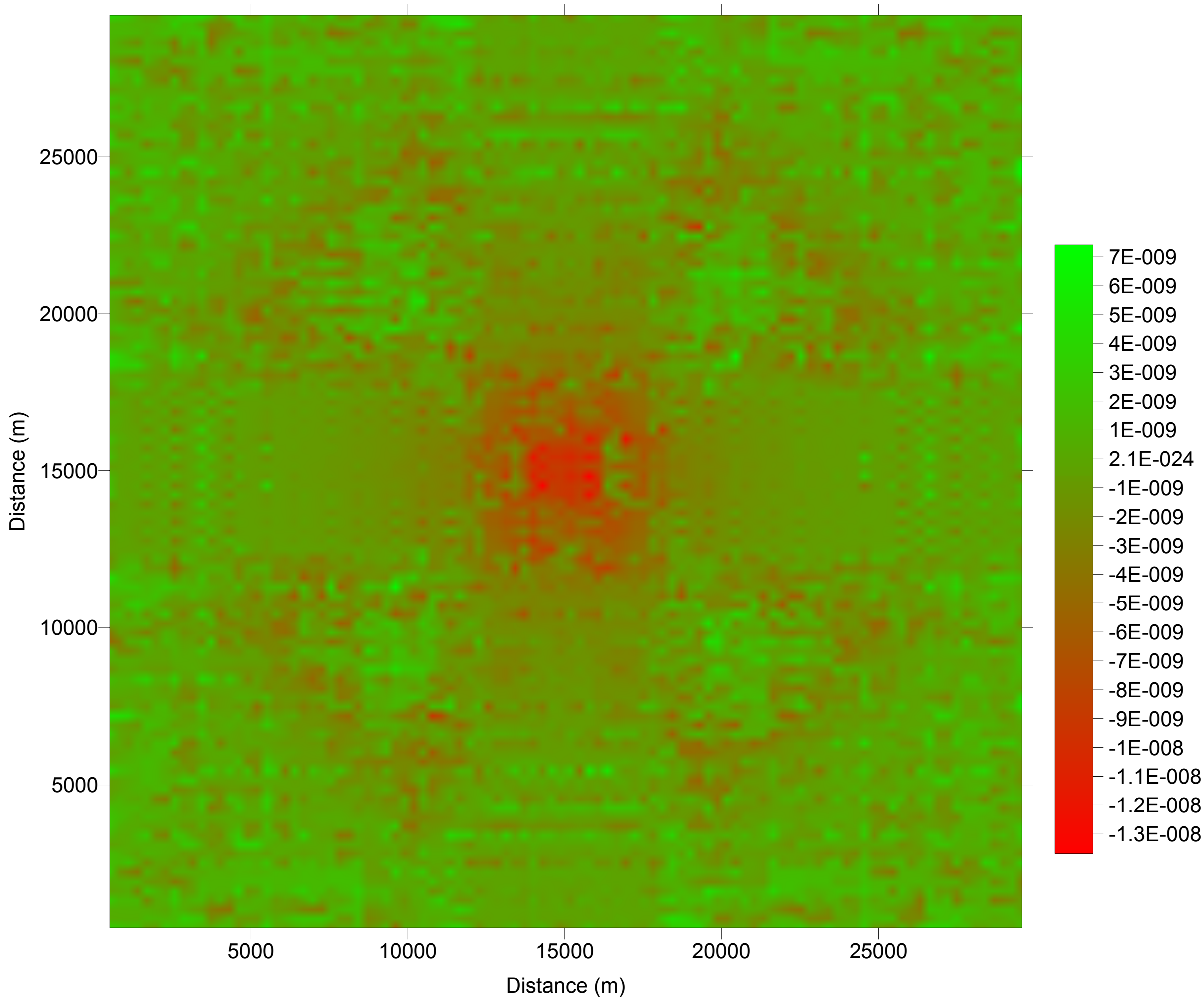


Figure 39: The difference in vertical displacement between a constant pumping scheme and a pulsed pumping scheme.
The pulsed pumping resulted in a higher order magnitude of subsidence but concentrated it closer to the well.

8.0 CALCULATING A STORAGE COEFFICIENT FOR THE AQUIFER

According to Burbey and Helm (1999), the groundwater flow equations related to the volume strain can be expressed as:

$$S_{SK} \frac{\partial h}{\partial t} = K\nabla^2 h \qquad (23)$$

and

$$\frac{\partial \varepsilon_V}{\partial t} = K\nabla^2 h \qquad (24)$$

These equations inherently assume that water compressibility is negligible relative to matrix compressibility.

If these two equations can be combined, the following equation results:

$$S_{SK}\frac{\partial h}{\partial t}=\frac{\partial \varepsilon_V}{\partial t} \qquad (25)$$

Therefore, if $\partial\varepsilon_V$ and ∂h are measured in the field, then S_{SK} can be calculated for each snapshot in time and space. The difficulty in using the data collected in this investigation to solve equation 25 is that drawdown is only definitively known in two locations, while $\partial\varepsilon_V$ surface is defined with a few more locations. However, the $\partial\varepsilon_V$ evaluated at the locations of known drawdown is not yet well constrained because the data from the permanent station has not yet been processed. The drawdown at each GPS station would need to be known to use this method.

9.0 CALCULATING VOLUME OF WATER RELEASED FROM STORAGE BY HORIZONTAL & VERTICAL STRAIN

Compressional strain causes a slight reduction in porosity which results in water being released from storage to the pumping well. The change in porosity resulting from compressional strain can be calculated by the equation:

$$\Delta n=(1-n_O)\varepsilon_V \qquad (26)\text{(Burbey 2001B)}$$

where n_O represents the initial porosity prior to any strain.

From the change in porosity, the volume of water released can be calculated by multiplying the change in porosity by the volume of the aquifer. Very small changes in porosity can result in large amounts of water being released from storage. Table 8 demonstrates that horizontal strain represents a significant component of the porosity change and hence the volume of water released from storage at a distance of 17.5 meters from the pumping well (Burbey 2001B).

	% change in porosity		
Time	**IBS Model**	**BIOT Model: Vertical**	**BIOT Model: Horizontal**
1 day	0.0039	0.0009	0.0016
20 days	0.0052	0.0018	0.0032
1 year	0.0069	0.0024	0.0034

Table 8: The percent change in porosity as result of horizontal and vertical strain The IBS model is a one dimensional model, so the assumption is that all strain is vertical. The change in porosity increases with time and the horizontal strain is larger than the vertical strain in the BIOT model. From Burbey, 2001B.

The strain data measured at the surface indicate that water is actually entering storage and porosity is increasing in the radial direction. At 205 meters from the well, the measured vertical strain makes up 99% of the volume strain. At 2000 meters from the well the vertical strain makes up an average of 85% of the volume strain but this percentage will decrease as time increases.

The simulated strain data using the BIOT code show that radial and hoop strain in the bottom aquifer results in a higher change in porosity than in the top aquifer (Figure 40). After 3 hours, the greatest increase in porosity is caused by the radial and hoop components of strain in layer 3. The simulation calculated a slight rebound in layer 3, so the vertical displacement actually caused in increase in porosity in layer 3. The calculated value may reflect the influence of the zero vertical-displacement boundary on the bottom of the aquifer. The data are displayed as a function of the log distance from the well because most of the differences in strain magnitude fall within the first 100 m from the pumping well.

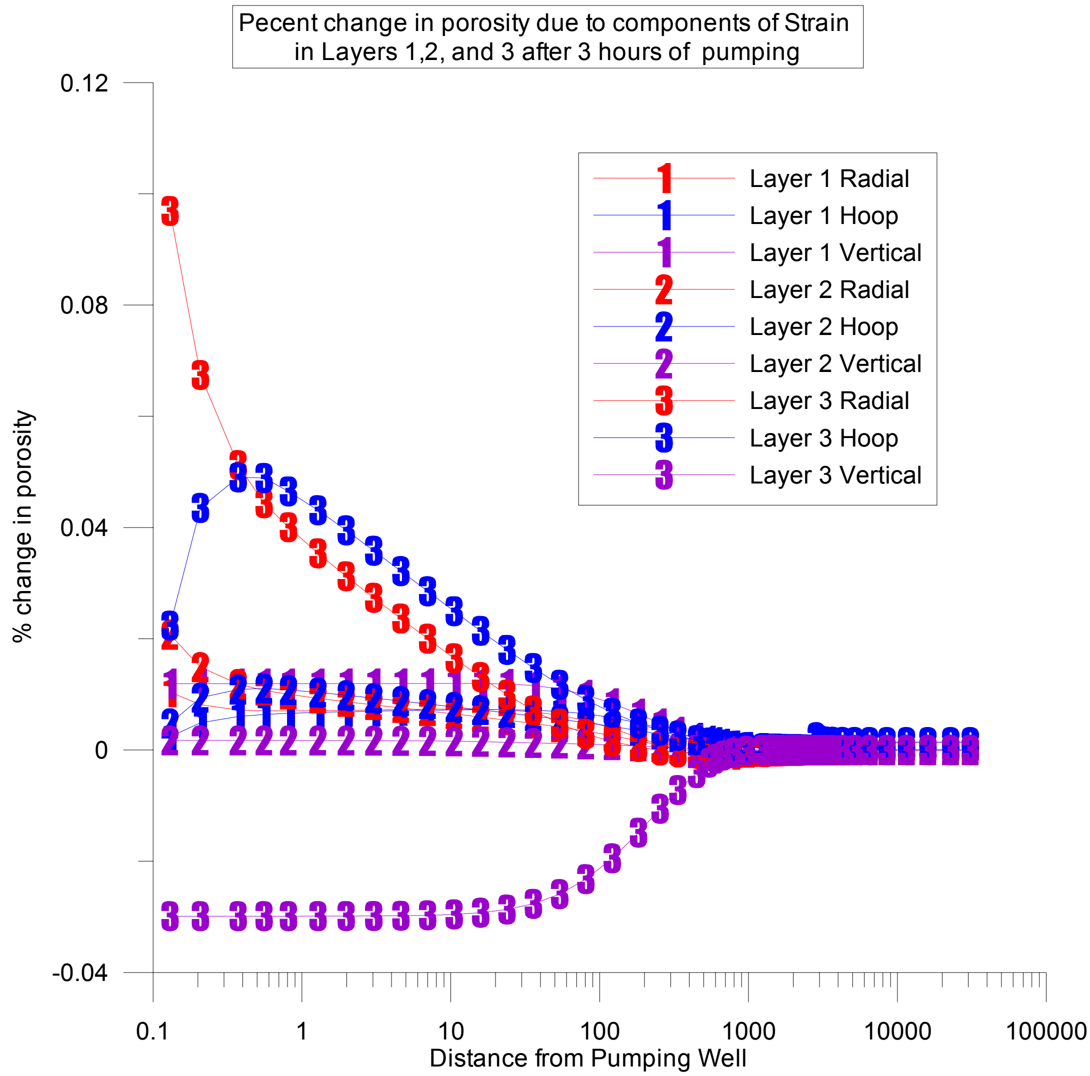


Figure 40: The percent change in porosity as a function of distance from the pumping well resulting from radial, hoop and vertical strain in the three model layers using the BIOT code after 3 hours of pumping.

After 3 days of pumping, the difference in magnitude of radial and hoop strain between layers has almost disappeared (Figure 41). The percent change in porosity is an order of magnitude less than at 3 hours except for the vertical strain in layer 3.

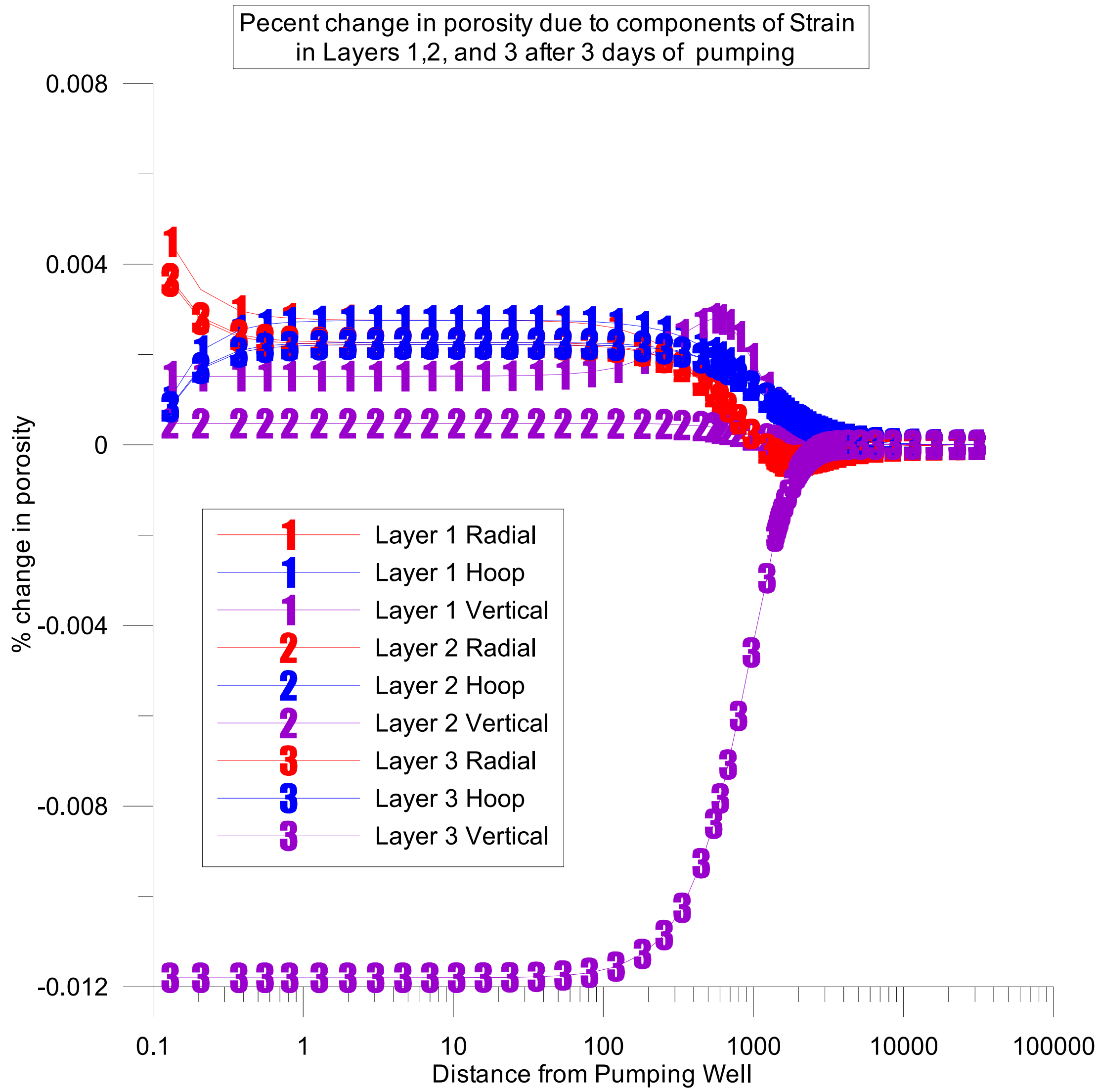


Figure 41: The percent change in porosity as a function of distance from the pumping well resulting from radial, hoop, and vertical strain in the three model layers using the BIOT code after 3 hours of pumping.

When only the strain at the land surface is considered, porosity seems to decrease the most from vertical strain at all measured times and distances from the well. When the strain is simulated at depth, the importance of radial and hoop strain become more apparent in the bottom aquifer (layer 3-6). The radial and hoop strain are especially important when the pump is first turned on and decrease in importance as near equilibrium is reached. After 3 days of pumping, the radial strain in layer 1 is higher than in layer 3, even though the drawdown is lower, supporting the theory that radial strain is not directly dependent on drawdown or hydraulic gradients (Helm, 1994).

10.0 SUMMARY AND CONCLUSIONS

An aquifer test was performed using a new municipal production well in Mesquite, NV. The project's goals were to determine the feasibility of using GPS to monitor small-scale land deformation as a result of aquifer production. The focus was to measure the horizontal deformation that occurs from a pumping well and determine whether horizontal strain represents an important process to consider when determining aquifer parameters such as storage.

Mesquite, NV is located in the basin and range province of the arid southwestern United States. In the study area, the three main geologic formations are (1) the alluvial unit, (2) the Muddy Creek Unit, and (3) the Paleozoic carbonates. In other regions of the south west, the carbonates are the main producing aquifer, but in Mesquite, the carbonates are too deep to practically use as a municipal water source. The main producing aquifer is the Muddy Creek unit, composed of unconsolidated silt, sand, and clay. The alluvial unit on top of the Muddy Creek was unsaturated in the study area, so it was not simulated, and it was assumed it moved passively on top of the Muddy Creek aquifer. The Carbonates were considered too deep to contribute to the aquifer system and were not explicitly modeled. The Muddy Creek aquifer in the study area was composed of several main aquifers separated by semi-confining clay beds.

The land deformation resulting from pumping was measured using 10 GPS stations over a 22 day period, and five stations were monitored for a total of 63 days. The GPS antennas, mounted to a buried cement structure, provide remarkable RMS precision of 0.2 mm in the horizontal direction and 2 mm in the vertical direction. Water levels were measured in a monitoring well approximately 1 m from the pumping well and in another monitoring well 1,480 m from the pumping well. The pumping well was cycled on and off in approximately eight hour intervals at a rate of 0.189 m^3/s throughout the aquifer test.

Drawdown of about 10 m occurred rapidly in monitoring well 1 m at the onset of pumping. In the VTex well, the drawdown responded slowly and the magnitude only reached 5 cm. The drawdown differences between the two monitoring wells can be attributed to the fact that the wells are screened in different units that are separated by semi-confining layers.

During the aquifer test, the aquifer deformed in all three dimensions. At the land surface, radial, tangential, and vertical displacements were measured to be approximately one cm, respectively, at the closest monitoring station located 140 meters from the pumping well. The maximum radial displacement relative to the reference station occurred at the closest GPS station to the well. Radial extension was measured at all of the GPS stations from 205 m to 2000m. However, radial compression must occur between the pumping well and the first GPS station at 205 m because the pumping well represents a zero radial-displacement boundary. Hence, the radial compression to radial extension transition did not move very far from the well, indicating that the aquifer system has a low hydraulic diffusivity.

Using the land deformation data measured at the surface alone is not sufficient to characterize the aquifer deformation or to determine if the horizontal strain represents a significant component of overall storage. Simulating the Muddy Creek Aquifer during an aquifer test revealed that horizontal displacement differs at depth, largely due to the thickness of the semi-confining beds and the differences in aquifer properties. The differential radial displacement with depth diminishes with time and distance from the well as the magnitude of displacement is influenced more by time and less by hydraulic diffusivity and pumping rate.

The assumption that all deformation is vertical during an aquifer test is not a valid assumption if an exact quantitative value for storage is needed. Horizontal displacement occurred even in areas where no drawdown occurred, making it important to monitor aquifer properties at distances farther than the cone of depression from pumping.

Future monitoring at this site should include (1) decreased spacing between GPS stations and (2) installing stations in all directions around the pumping well to better constrain the deformation that occurs during an aquifer test, including the shear deformation. Incorporating InSAR data can allow for far-field deformation measurements resulting from pumping. Completing the processing of the well house GPS station will better constrain the deformation occurring close to the well. All of these actions will help provide a better understanding of the large-scale horizontal deformation that occurs in an aquifer at the basin scale and how the horizontal deformation may affect storage and the distribution of drawdown.

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12.0 APPENDIX I – Well 31 pumping data

simulation #	# of hours	total time	pump	date time(EDT)	
1	580	580	off	4/11/2003	15:00
2	1	581	on	5/5/2003	19:00
3	43	624	off	5/5/2003	20:00
4	3	627	on	5/7/2003	15:00
5	8	635	off		
6	5	640	on		
7	7	647	off		
8	7	654	on		
9	6	660	off		
10	7	667	on		
11	7	674	off		
12	6	680	on		
13	7	687	off		
14	7	694	on		
15	5	699	off		
16	8	707	on		
17	7	714	off		
18	6	720	on		
19	7	727	off		
20	6	733	on		
21	7	740	off		
22	7	747	on		
23	7	754	off		
24	7	761	on		
25	6	767	off		
26	7	774	on		
27	6	780	off		
28	7	787	on		
29	7	794	off		
30	7	801	on		
31	6	807	off		
32	8	815	on		
33	5	820	off		
34	8	828	on		
35	6	834	off		
36	8	842	on		
37	6	848	off		
38	8	856	on		
39	6	862	off		
40	7	869	on		
41	7	876	off		
42	7	883	on		
43	7	890	off		
44	7	897	on		
45	7	904	off		
46	8	912	on		
47	7	919	off		
48	7	926	on		
49	6	932	off		
50	8	940	on		
51	6	946	off		

simulation #	# of hours	total time	pump	date time(EDT)
52	7	953	on	
53	6	959	off	
54	8	967	on	
55	6	973	off	
56	8	981	on	
57	6	987	off	
58	7	994	on	
59	7	1001	off	
60	8	1009	on	
61	6	1015	off	
62	7	1022	on	
63	6	1028	off	
64	8	1036	on	
65	6	1042	off	
66	8	1050	on	
67	6	1056	off	
68	7	1063	on	
69	7	1070	off	
70	8	1078	on	
71	6	1084	off	
72	8	1092	on	
73	6	1098	off	
74	8	1106	on	
75	7	1113	off	
76	7	1120	on	
77	6	1126	off	
78	8	1134	on	
79	6	1140	off	
80	9	1149	on	
81	6	1155	off	
82	8	1163	on	
83	6	1169	off	
84	9	1178	on	
85	6	1184	off	
86	8	1192	on	
87	6	1198	off	
88	8	1206	on	
89	6	1212	off	
90	8	1220	on	
91	7	1227	off	
92	7	1234	on	
93	7	1241	off	
94	5	1246	on	
95	1	1247	off	
96	4	1251	on	
97	6	1257	off	
98	8	1265	on	
99	6	1271	off	
100	7	1278	on	
101	7	1285	off	
102	8	1293	on	
103	6	1299	off	
104	8	1307	on	
105	6	1313	off	

simulation #	# of hours	total time	pump	date time(EDT)
106	9	1322	on	
107	9	1331	off	
108	5	1336	on	
109	5	1341	off	
110	8	1349	on	
111	6	1355	off	
112	8	1363	on	
113	7	1370	off	
114	7	1377	on	
115	7	1384	off	
116	8	1392	on	
117	7	1399	off	
118	8	1407	on	
119	5	1412	off	
120	8	1420	on	
121	7	1427	off	
122	8	1435	on	
123	6	1441	off	
124	7	1448	on	
125	7	1455	off	
126	8	1463	on	
127	6	1469	off	
128	8	1477	on	
129	7	1484	off	
130	7	1491	on	
131	7	1498	off	
132	8	1506	on	
133	6	1512	off	
134	7	1519	on	
135	6	1525	off	
136	9	1534	on	
137	6	1540	off	
138	8	1548	on	
139	8	1556	off	
140	10	1566	on	
141	6	1572	off	
142	9	1581	on	
143	6	1587	off	
144	8	1595	on	
145	6	1601	off	
146	4	1605	on	
147	2	1607	off	
148	6	1613	on	
149	6	1619	off	
150	9	1628	on	
151	6	1634	off	
152	8	1642	on	
153	6	1648	off	
154	9	1657	on	
155	6	1663	off	
156	8	1671	on	
157	6	1677	off	
158	8	1685	on	
159	6	1691	off	

simulation #	# of hours	total time	pump	date time(EDT)
160	9	1700	on	
161	6	1706	off	
162	8	1714	on	
163	7	1721	off	
164	8	1729	on	
165	7	1736	off	
166	8	1744	on	
167	6	1750	off	
168	7	1757	on	
169	7	1764	off	
170	8	1772	on	
171	7	1779	off	
172	8	1787	on	
173	6	1793	off	
174	8	1801	on	
175	7	1808	off	
176	8	1816	on	
177	5	1821	off	
178	8	1829	on	
179	7	1836	off	
180	9	1845	on	
181	6	1851	off	
182	8	1859	on	
183	6	1865	off	
184	9	1874	on	
185	6	1880	off	
186	8	1888	on	
187	6	1894	off	
188	8	1902	on	
189	6	1908	off	
190	9	1917	on	
191	7	1924	off	
192	8	1932	on	
193	6	1938	off	
194	9	1947	on	
195	6	1953	off	
196	8	1961	on	
197	6	1967	off	
198	8	1975	on	
199	6	1981	off	
200	9	1990	on	
201	7	1997	off	
202	8	2005	on	
203	6	2011	off	
204	8	2019	on	
205	7	2026	off	
206	8	2034	on	
207	6	2040	off	
208	7	2047	on	
209	7	2054	off	
210	8	2062	on	
211	7	2069	off	
212	8	2077	on	
213	6	2083	off	

simulation #	# of hours	total time	pump	date time(EDT)
214	9	2092	on	
215	6	2098	off	
216	9	2107	on	
217	6	2113	off	
218	9	2122	on	
219	6	2128	off	
220	9	2137	on	
221	6	2143	off	
222	9	2152	on	
223	5	2157	off	
224	9	2166	on	
225	6	2172	off	
226	9	2181	on	
227	6	2187	off	
228	9	2196	on	
229	6	2202	off	
230	9	2211	on	
231	6	2217	off	
232	9	2226	on	
233	5	2231	off	
234	8	2239	on	
235	7	2246	off	
236	9	2255	on	
237	7	2262	off	
238	8	2270	on	
239	6	2276	off	
240	8	2284	on	
241	7	2291	off	
242	8	2299	on	
243	6	2305	off	
244	9	2314	on	
245	6	2320	off	
246	9	2329	on	
247	6	2335	off	
248	9	2344	on	
249	6	2350	off	
250	8	2358	on	
251	7	2365	off	
252	9	2374	on	
253	6	2380	off	
254	9	2389	on	
255	6	2395	off	
256	8	2403	on	
257	7	2410	off	
258	9	2419	on	
259	6	2425	off	
260	8	2433	on	
261	6	2439	off	
262	9	2448	on	
263	7	2455	off	
264	8	2463	on	
265	7	2470	off	
266	8	2478	on	
267	7	2485	off	

simulation #	# of hours	total time	pump	date time(EDT)
268	8	2493	on	
269	6	2499	off	
270	9	2508	on	
271	7	2515	off	
272	8	2523	on	
273	7	2530	off	
274	9	2539	on	
275	6	2545	off	
276	9	2554	on	
277	6	2560	off	
278	9	2569	on	
279	7	2576	off	
280	8	2584	on	
281	6	2590	off	
282	9	2599	on	
283	6	2605	off	
284	9	2614	on	
285	7	2621	off	
286	8	2629	on	
287	6	2635	off	
288	9	2644	on	
289	6	2650	off	
290	9	2659	on	
291	7	2666	off	
292	8	2674	on	
293	7	2681	off	
294	9	2690	on	
295	7	2697	off	
296	9	2706	on	
297	6	2712	off	
298	8	2720	on	
299	6	2726	off	
300	10	2736	on	
301	6	2742	off	
302	9	2751	on	
303	6	2757	off	
304	8	2765	on	
305	7	2772	off	
306	9	2781	on	
307	6	2787	off	
308	8	2795	on	
309	7	2802	off	
310	9	2811	on	
311	6	2817	off	
312	9	2826	on	
313	6	2832	off	
314	9	2841	on	
315	6	2847	off	
316	9	2856	on	
317	7	2863	off	
318	9	2872	on	
319	6	2878	off	
320	8	2886	on	
321	6	2892	off	

simulation #	# of hours	total time	pump	date time(EDT)	
322	10	2902	on		
323	6	2908	off		
324	9	2917	on		
325	6	2923	off		
326	9	2932	on		
327	6	2938	off		
328	9	2947	on		
329	6	2953	off		
330	9	2962	on		
331	6	2968	off		
332	9	2977	on		
333	7	2984	off		
334	8	2992	on		
335	6	2998	off		
336	3	3001	on	8/14/2003	13:00
average pump cycle					
	8.9315476				
total hours on	total hours off				
1335	1042				
ave pump rate (gpm	1684.8969				

13.0 APPENDIX II – Well 31 and Well VX drawdown data

date	time	well 31 head meters AMSL	vetex
4/11/2003	15:00:00	458.548	
4/11/2003	16:00:00	458.57	456.113
4/11/2003	17:00:00	458.561	456.114
4/11/2003	18:00:00	458.589	456.132
4/11/2003	19:00:00	458.589	456.142
4/11/2003	20:00:00	458.587	456.15
4/11/2003	21:00:00	458.591	456.144
4/11/2003	22:00:00	458.582	456.145
4/11/2003	23:00:00	458.58	456.133
4/12/2003	0:00:00	458.578	456.141
4/12/2003	1:00:00	458.577	456.13
4/12/2003	2:00:00	458.589	456.142
4/12/2003	3:00:00	458.576	456.139
4/12/2003	4:00:00	458.574	456.137
4/12/2003	5:00:00	458.577	456.14
4/12/2003	6:00:00	458.576	456.139
4/12/2003	7:00:00	458.574	456.137
4/12/2003	8:00:00	458.575	456.138
4/12/2003	9:00:00	458.574	456.137

date	time	well 31 head meters AMSL	vetex
4/13/2003	17:00:00	458.567	456.13
4/13/2003	18:00:00	458.574	456.147
4/13/2003	19:00:00	458.574	456.137
4/13/2003	20:00:00	458.567	456.15
4/13/2003	21:00:00	458.575	456.148
4/13/2003	22:00:00	458.585	456.148
4/13/2003	23:00:00	458.572	456.135
4/14/2003	0:00:00	458.556	456.129
4/14/2003	1:00:00	458.553	456.116
4/14/2003	2:00:00	458.557	456.13
4/14/2003	3:00:00	458.557	456.12
4/14/2003	4:00:00	458.552	456.115
4/14/2003	5:00:00	458.554	456.117
4/14/2003	6:00:00	458.556	456.109
4/14/2003	7:00:00	458.559	456.122
4/14/2003	8:00:00	458.555	456.108
4/14/2003	9:00:00	458.552	456.115
4/14/2003	10:00:00	458.541	456.124
4/14/2003	11:00:00	458.548	456.121

date	time	well 31 head meters AMSL	vetex	date	time	well 31 head meters AMSL	vetex
4/12/2003	10:00:00	458.567	456.12	4/14/2003	12:00:00	458.555	456.128
4/12/2003	11:00:00	458.573	456.116	4/14/2003	13:00:00	458.554	456.127
4/12/2003	12:00:00	458.567	456.12	4/14/2003	14:00:00	458.559	456.132
4/12/2003	13:00:00	458.557	456.11	4/14/2003	15:00:00	458.564	456.127
4/12/2003	14:00:00	458.559	456.122	4/14/2003	16:00:00	458.588	456.161
4/12/2003	15:00:00	458.58	456.133	4/14/2003	17:00:00	458.585	456.158
4/12/2003	16:00:00	458.588	456.141	4/14/2003	18:00:00	458.597	456.19
4/12/2003	17:00:00	458.583	456.136	4/14/2003	19:00:00	458.622	456.185
4/12/2003	18:00:00	458.588	456.151	4/14/2003	20:00:00	458.633	456.206
4/12/2003	19:00:00	458.609	456.152	4/14/2003	21:00:00	458.638	456.201
4/12/2003	20:00:00	458.595	456.158	4/14/2003	22:00:00	458.644	456.207
4/12/2003	21:00:00	458.593	456.156	4/14/2003	23:00:00	458.624	456.197
4/12/2003	22:00:00	458.599	456.152	4/15/2003	0:00:00	458.627	456.19
4/12/2003	23:00:00	458.592	456.145	4/15/2003	1:00:00	458.635	456.188
4/13/2003	0:00:00	458.574	456.137	4/15/2003	2:00:00	458.626	456.179
4/13/2003	1:00:00	458.568	456.131	4/15/2003	3:00:00	458.624	456.167
4/13/2003	2:00:00	458.563	456.116	4/15/2003	4:00:00	458.609	456.172
4/13/2003	3:00:00	458.562	456.125	4/15/2003	5:00:00	458.604	456.147
4/13/2003	4:00:00	458.562	456.115	4/15/2003	6:00:00	458.596	456.159
4/13/2003	5:00:00	458.567	456.12	4/15/2003	7:00:00	458.619	456.172
4/13/2003	6:00:00	458.552	456.135	4/15/2003	8:00:00	458.593	456.146
4/13/2003	7:00:00	458.564	456.127	4/15/2003	9:00:00	458.599	456.162
4/13/2003	8:00:00	458.561	456.134	4/15/2003	10:00:00	458.585	456.128
4/13/2003	9:00:00	458.566	456.109	4/15/2003	11:00:00	458.569	456.132
4/13/2003	10:00:00	458.548	456.101	4/15/2003	12:00:00	458.561	456.104
4/13/2003	11:00:00	458.551	456.124	4/15/2003	13:00:00	458.554	456.087
4/13/2003	12:00:00	458.545	456.118	4/15/2003	14:00:00	458.535	456.088
4/13/2003	13:00:00	458.544	456.107	4/15/2003	15:00:00	458.514	456.077
4/13/2003	14:00:00	458.546	456.119	4/15/2003	16:00:00	458.527	456.08
4/13/2003	15:00:00	458.553	456.116	4/15/2003	17:00:00	458.52	456.073
4/13/2003	16:00:00	458.564	456.127	4/15/2003	18:00:00	458.521	456.084
4/15/2003	19:00:00	458.517	456.08	4/17/2003	21:00:00	458.601	456.154
4/15/2003	20:00:00	458.508	456.091	4/17/2003	22:00:00	458.583	456.156
4/15/2003	21:00:00	458.51	456.093	4/17/2003	23:00:00	458.565	456.138
4/15/2003	22:00:00	458.505	456.068	4/18/2003	0:00:00	458.56	456.123
4/15/2003	23:00:00	458.485	456.078	4/18/2003	1:00:00	458.574	456.127
4/16/2003	0:00:00	458.493	456.076	4/18/2003	2:00:00	458.56	456.123
4/16/2003	1:00:00	458.487	456.07	4/18/2003	3:00:00	458.55	456.113
4/16/2003	2:00:00	458.497	456.07	4/18/2003	4:00:00	458.555	456.128
4/16/2003	3:00:00	458.484	456.067	4/18/2003	5:00:00	458.554	456.127
4/16/2003	4:00:00	458.484	456.067	4/18/2003	6:00:00	458.561	456.124
4/16/2003	5:00:00	458.472	456.065	4/18/2003	7:00:00	458.548	456.121
4/16/2003	6:00:00	458.471	456.074	4/18/2003	8:00:00	458.566	456.119
4/16/2003	7:00:00	458.484	456.077	4/18/2003	9:00:00	458.548	456.121
4/16/2003	8:00:00	458.486	456.079	4/18/2003	10:00:00	458.54	456.113
4/16/2003	9:00:00	458.47	456.073	4/18/2003	11:00:00	458.548	456.111
4/16/2003	10:00:00	458.462	456.065	4/18/2003	12:00:00	458.539	456.112
4/16/2003	11:00:00	458.454	456.067	4/18/2003	13:00:00	458.56	456.133
4/16/2003	12:00:00	458.467	456.07	4/18/2003	14:00:00	458.549	456.132
4/16/2003	13:00:00	458.47	456.063	4/18/2003	15:00:00	458.559	456.132
4/16/2003	14:00:00	458.464	456.077	4/18/2003	16:00:00	458.568	456.141
4/16/2003	15:00:00	458.475	456.078	4/18/2003	17:00:00	458.572	456.145

date	time	well 31 head meters AMSL	vetex	date	time	well 31 head meters AMSL	vetex
4/16/2003	16:00:00	458.487	456.1	4/18/2003	18:00:00	458.574	456.137
4/16/2003	17:00:00	458.519	456.112	4/18/2003	19:00:00	458.56	456.123
4/16/2003	18:00:00	458.52	456.123	4/18/2003	20:00:00	458.552	456.125
4/16/2003	19:00:00	458.522	456.135	4/18/2003	21:00:00	458.562	456.125
4/16/2003	20:00:00	458.532	456.145	4/18/2003	22:00:00	458.537	456.1
4/16/2003	21:00:00	458.546	456.149	4/18/2003	23:00:00	458.555	456.118
4/16/2003	22:00:00	458.543	456.146	4/19/2003	0:00:00	458.536	456.109
4/16/2003	23:00:00	458.53	456.143	4/19/2003	1:00:00	458.533	456.096
4/17/2003	0:00:00	458.541	456.144	4/19/2003	2:00:00	458.533	456.106
4/17/2003	1:00:00	458.562	456.155	4/19/2003	3:00:00	458.516	456.089
4/17/2003	2:00:00	458.544	456.137	4/19/2003	4:00:00	458.516	456.089
4/17/2003	3:00:00	458.554	456.137	4/19/2003	5:00:00	458.513	456.096
4/17/2003	4:00:00	458.547	456.14	4/19/2003	6:00:00	458.501	456.094
4/17/2003	5:00:00	458.552	456.145	4/19/2003	7:00:00	458.506	456.079
4/17/2003	6:00:00	458.557	456.15	4/19/2003	8:00:00	458.507	456.08
4/17/2003	7:00:00	458.561	456.154	4/19/2003	9:00:00	458.499	456.082
4/17/2003	8:00:00	458.562	456.145	4/19/2003	10:00:00	458.501	456.084
4/17/2003	9:00:00	458.564	456.147	4/19/2003	11:00:00	458.485	456.078
4/17/2003	10:00:00	458.569	456.152	4/19/2003	12:00:00	458.477	456.07
4/17/2003	11:00:00	458.568	456.141	4/19/2003	13:00:00	458.471	456.074
4/17/2003	12:00:00	458.557	456.14	4/19/2003	14:00:00	458.49	456.063
4/17/2003	13:00:00	458.57	456.133	4/19/2003	15:00:00	458.484	456.077
4/17/2003	14:00:00	458.567	456.14	4/19/2003	16:00:00	458.471	456.074
4/17/2003	15:00:00	458.575	456.148	4/19/2003	17:00:00	458.481	456.084
4/17/2003	16:00:00	458.582	456.155	4/19/2003	18:00:00	458.474	456.077
4/17/2003	17:00:00	458.567	456.16	4/19/2003	19:00:00	458.493	456.086
4/17/2003	18:00:00	458.589	456.162	4/19/2003	20:00:00	458.49	456.093
4/17/2003	19:00:00	458.595	456.168	4/19/2003	21:00:00	458.493	456.096
4/17/2003	20:00:00	458.599	456.162	4/19/2003	22:00:00	458.504	456.107
4/19/2003	23:00:00	458.495	456.088	4/22/2003	1:00:00	458.618	456.161
4/20/2003	0:00:00	458.483	456.076	4/22/2003	2:00:00	458.622	456.175
4/20/2003	1:00:00	458.48	456.093	4/22/2003	3:00:00	458.624	456.167
4/20/2003	2:00:00	458.485	456.078	4/22/2003	4:00:00	458.619	456.162
4/20/2003	3:00:00	458.485	456.078	4/22/2003	5:00:00	458.623	456.156
4/20/2003	4:00:00	458.475	456.068	4/22/2003	6:00:00	458.632	456.175
4/20/2003	5:00:00	458.472	456.075	4/22/2003	7:00:00	458.629	456.162
4/20/2003	6:00:00	458.465	456.088	4/22/2003	8:00:00	458.639	456.162
4/20/2003	7:00:00	458.473	456.086	4/22/2003	9:00:00	458.617	456.16
4/20/2003	8:00:00	458.486	456.089	4/22/2003	10:00:00	458.609	456.152
4/20/2003	9:00:00	458.471	456.074	4/22/2003	11:00:00	458.621	456.154
4/20/2003	10:00:00	458.47	456.083	4/22/2003	12:00:00	458.601	456.144
4/20/2003	11:00:00	458.483	456.086	4/22/2003	13:00:00	458.583	456.136
4/20/2003	12:00:00	458.461	456.084	4/22/2003	14:00:00	458.579	456.122
4/20/2003	13:00:00	458.474	456.087	4/22/2003	15:00:00	458.585	456.138
4/20/2003	14:00:00	458.482	456.095	4/22/2003	16:00:00	458.59	456.143
4/20/2003	15:00:00	458.477	456.11	4/22/2003	17:00:00	458.563	456.126
4/20/2003	16:00:00	458.504	456.117	4/22/2003	18:00:00	458.577	456.12
4/20/2003	17:00:00	458.507	456.13	4/22/2003	19:00:00	458.584	456.137
4/20/2003	18:00:00	458.519	456.142	4/22/2003	20:00:00	458.578	456.131
4/20/2003	19:00:00	458.548	456.151	4/22/2003	21:00:00	458.586	456.129
4/20/2003	20:00:00	458.552	456.145	4/22/2003	22:00:00	458.572	456.115
4/20/2003	21:00:00	458.557	456.17	4/22/2003	23:00:00	458.566	456.119

date	time	well 31 head meters AMSL	vetex
4/20/2003	22:00:00	458.55	456.163
4/20/2003	23:00:00	458.562	456.155
4/21/2003	0:00:00	458.562	456.155
4/21/2003	1:00:00	458.561	456.154
4/21/2003	2:00:00	458.557	456.16
4/21/2003	3:00:00	458.568	456.161
4/21/2003	4:00:00	458.57	456.153
4/21/2003	5:00:00	458.578	456.171
4/21/2003	6:00:00	458.577	456.15
4/21/2003	7:00:00	458.577	456.15
4/21/2003	8:00:00	458.587	456.15
4/21/2003	9:00:00	458.577	456.15
4/21/2003	10:00:00	458.586	456.139
4/21/2003	11:00:00	458.586	456.129
4/21/2003	12:00:00	458.571	456.124
4/21/2003	13:00:00	458.572	456.135
4/21/2003	14:00:00	458.574	456.137
4/21/2003	15:00:00	458.584	456.157
4/21/2003	16:00:00	458.588	456.151
4/21/2003	17:00:00	458.594	456.157
4/21/2003	18:00:00	458.577	456.15
4/21/2003	19:00:00	458.605	456.168
4/21/2003	20:00:00	458.609	456.162
4/21/2003	21:00:00	458.614	456.177
4/21/2003	22:00:00	458.612	456.175
4/21/2003	23:00:00	458.617	456.17
4/22/2003	0:00:00	458.62	456.173
4/24/2003	3:00:00	458.535	456.108
4/24/2003	4:00:00	458.527	456.1
4/24/2003	5:00:00	458.537	456.11
4/24/2003	6:00:00	458.541	456.094
4/24/2003	7:00:00	458.54	456.093
4/24/2003	8:00:00	458.53	456.103
4/24/2003	9:00:00	458.527	456.1
4/24/2003	10:00:00	458.525	456.098
4/24/2003	11:00:00	458.521	456.094
4/24/2003	12:00:00	458.52	456.093
4/24/2003	13:00:00	458.521	456.094
4/24/2003	14:00:00	458.535	456.098
4/24/2003	15:00:00	458.535	456.118
4/24/2003	16:00:00	458.541	456.114
4/24/2003	17:00:00	458.551	456.124
4/24/2003	18:00:00	458.561	456.124
4/24/2003	19:00:00	458.571	456.134
4/24/2003	20:00:00	458.575	456.148
4/24/2003	21:00:00	458.565	456.148
4/24/2003	22:00:00	458.57	456.153
4/24/2003	23:00:00	458.577	456.15
4/25/2003	0:00:00	458.57	456.143
4/25/2003	1:00:00	458.571	456.144
4/25/2003	2:00:00	458.555	456.128
4/25/2003	3:00:00	458.557	456.13

date	time	well 31 head meters AMSL	vetex
4/23/2003	0:00:00	458.581	456.114
4/23/2003	1:00:00	458.562	456.115
4/23/2003	2:00:00	458.558	456.101
4/23/2003	3:00:00	458.556	456.109
4/23/2003	4:00:00	458.557	456.11
4/23/2003	5:00:00	458.566	456.109
4/23/2003	6:00:00	458.563	456.116
4/23/2003	7:00:00	458.557	456.11
4/23/2003	8:00:00	458.557	456.11
4/23/2003	9:00:00	458.554	456.107
4/23/2003	10:00:00	458.545	456.108
4/23/2003	11:00:00	458.535	456.088
4/23/2003	12:00:00	458.534	456.097
4/23/2003	13:00:00	458.529	456.092
4/23/2003	14:00:00	458.516	456.099
4/23/2003	15:00:00	458.519	456.102
4/23/2003	16:00:00	458.533	456.106
4/23/2003	17:00:00	458.551	456.114
4/23/2003	18:00:00	458.537	456.12
4/23/2003	19:00:00	458.557	456.12
4/23/2003	20:00:00	458.551	456.114
4/23/2003	21:00:00	458.541	456.124
4/23/2003	22:00:00	458.547	456.12
4/23/2003	23:00:00	458.535	456.118
4/24/2003	0:00:00	458.542	456.115
4/24/2003	1:00:00	458.544	456.107
4/24/2003	2:00:00	458.539	456.112
4/26/2003	5:00:00	458.581	456.134
4/26/2003	6:00:00	458.59	456.143
4/26/2003	7:00:00	458.596	456.139
4/26/2003	8:00:00	458.583	456.146
4/26/2003	9:00:00	458.563	456.126
4/26/2003	10:00:00	458.555	456.118
4/26/2003	11:00:00	458.557	456.11
4/26/2003	12:00:00	458.545	456.088
4/26/2003	13:00:00	458.545	456.098
4/26/2003	14:00:00	458.545	456.098
4/26/2003	15:00:00	458.542	456.115
4/26/2003	16:00:00	458.562	456.125
4/26/2003	17:00:00	458.565	456.138
4/26/2003	18:00:00	458.573	456.126
4/26/2003	19:00:00	458.579	456.132
4/26/2003	20:00:00	458.568	456.131
4/26/2003	21:00:00	458.581	456.144
4/26/2003	22:00:00	458.573	456.136
4/26/2003	23:00:00	458.579	456.132
4/27/2003	0:00:00	458.574	456.127
4/27/2003	1:00:00	458.573	456.126
4/27/2003	2:00:00	458.558	456.121
4/27/2003	3:00:00	458.566	456.119
4/27/2003	4:00:00	458.557	456.14
4/27/2003	5:00:00	458.56	456.123

date	time	well 31 head meters AMSL	vetex
4/25/2003	4:00:00	458.554	456.137
4/25/2003	5:00:00	458.568	456.131
4/25/2003	6:00:00	458.559	456.142
4/25/2003	7:00:00	458.564	456.137
4/25/2003	8:00:00	458.553	456.126
4/25/2003	9:00:00	458.556	456.129
4/25/2003	10:00:00	458.556	456.129
4/25/2003	11:00:00	458.547	456.11
4/25/2003	12:00:00	458.548	456.101
4/25/2003	13:00:00	458.551	456.114
4/25/2003	14:00:00	458.541	456.114
4/25/2003	15:00:00	458.559	456.122
4/25/2003	16:00:00	458.56	456.143
4/25/2003	17:00:00	458.568	456.151
4/25/2003	18:00:00	458.582	456.145
4/25/2003	19:00:00	458.587	456.16
4/25/2003	20:00:00	458.58	456.153
4/25/2003	21:00:00	458.589	456.152
4/25/2003	22:00:00	458.591	456.144
4/25/2003	23:00:00	458.582	456.145
4/26/2003	0:00:00	458.566	456.129
4/26/2003	1:00:00	458.565	456.128
4/26/2003	2:00:00	458.582	456.135
4/26/2003	3:00:00	458.575	456.118
4/26/2003	4:00:00	458.579	456.132
4/28/2003	7:00:00	458.579	456.132
4/28/2003	8:00:00	458.558	456.131
4/28/2003	9:00:00	458.554	456.127
4/28/2003	10:00:00	458.563	456.106
4/28/2003	11:00:00	458.537	456.1
4/28/2003	12:00:00	458.548	456.111
4/28/2003	13:00:00	458.544	456.107
4/28/2003	14:00:00	458.547	456.11
4/28/2003	15:00:00	458.56	456.113
4/28/2003	16:00:00	458.556	456.119
4/28/2003	17:00:00	458.56	456.133
4/28/2003	18:00:00	458.566	456.149
4/28/2003	19:00:00	458.56	456.133
4/28/2003	20:00:00	458.574	456.137
4/28/2003	21:00:00	458.564	456.147
4/28/2003	22:00:00	458.586	456.139
4/28/2003	23:00:00	458.572	456.135
4/29/2003	0:00:00	458.567	456.13
4/29/2003	1:00:00	458.555	456.128
4/29/2003	2:00:00	458.565	456.128
4/29/2003	3:00:00	458.575	456.128
4/29/2003	4:00:00	458.563	456.116
4/29/2003	5:00:00	458.566	456.129
4/29/2003	6:00:00	458.566	456.119
4/29/2003	7:00:00	458.565	456.128
4/29/2003	8:00:00	458.57	456.133
4/29/2003	9:00:00	458.569	456.122

date	time	well 31 head meters AMSL	vetex
4/27/2003	6:00:00	458.574	456.127
4/27/2003	7:00:00	458.573	456.126
4/27/2003	8:00:00	458.569	456.122
4/27/2003	9:00:00	458.555	456.118
4/27/2003	10:00:00	458.548	456.111
4/27/2003	11:00:00	458.542	456.105
4/27/2003	12:00:00	458.557	456.11
4/27/2003	13:00:00	458.555	456.118
4/27/2003	14:00:00	458.549	456.112
4/27/2003	15:00:00	458.566	456.129
4/27/2003	16:00:00	458.573	456.136
4/27/2003	17:00:00	458.581	456.134
4/27/2003	18:00:00	458.584	456.127
4/27/2003	19:00:00	458.576	456.149
4/27/2003	20:00:00	458.59	456.153
4/27/2003	21:00:00	458.588	456.151
4/27/2003	22:00:00	458.603	456.156
4/27/2003	23:00:00	458.596	456.149
4/28/2003	0:00:00	458.594	456.147
4/28/2003	1:00:00	458.585	456.138
4/28/2003	2:00:00	458.579	456.142
4/28/2003	3:00:00	458.575	456.138
4/28/2003	4:00:00	458.572	456.125
4/28/2003	5:00:00	458.564	456.137
4/28/2003	6:00:00	458.561	456.144
4/30/2003	9:00:00	458.505	456.101
4/30/2003	10:00:00	458.497	456.083
4/30/2003	11:00:00	458.502	456.088
4/30/2003	12:00:00	458.499	456.085
4/30/2003	13:00:00	458.496	456.092
4/30/2003	14:00:00	458.5	456.096
4/30/2003	15:00:00	458.499	456.095
4/30/2003	16:00:00	458.504	456.11
4/30/2003	17:00:00	458.506	456.102
4/30/2003	18:00:00	458.503	456.119
4/30/2003	19:00:00	458.518	456.134
4/30/2003	20:00:00	458.523	456.129
4/30/2003	21:00:00	458.534	456.13
4/30/2003	22:00:00	458.517	456.133
4/30/2003	23:00:00	458.52	456.126
5/1/2003	0:00:00	458.507	456.123
5/1/2003	1:00:00	458.514	456.11
5/1/2003	2:00:00	458.5	456.116
5/1/2003	3:00:00	458.498	456.114
5/1/2003	4:00:00	458.503	456.109
5/1/2003	5:00:00	458.493	456.109
5/1/2003	6:00:00	458.487	456.103
5/1/2003	7:00:00	458.481	456.097
5/1/2003	8:00:00	458.497	456.093
5/1/2003	9:00:00	458.483	456.089
5/1/2003	10:00:00	458.488	456.084
5/1/2003	11:00:00	458.463	456.079

date	time	well 31 head meters AMSL	vetex
4/29/2003	10:00:00	458.55	456.103
4/29/2003	11:00:00	458.558	456.111
4/29/2003	12:00:00	458.543	456.106
4/29/2003	13:00:00	458.557	456.12
4/29/2003	14:00:00	458.55	456.113
4/29/2003	15:00:00	458.543	456.116
4/29/2003	16:00:00	458.484	456.12
4/29/2003	17:00:00	458.526	456.122
4/29/2003	18:00:00	458.53	456.136
4/29/2003	19:00:00	458.549	456.135
4/29/2003	20:00:00	458.543	456.149
4/29/2003	21:00:00	458.556	456.142
4/29/2003	22:00:00	458.531	456.137
4/29/2003	23:00:00	458.546	456.142
4/30/2003	0:00:00	458.537	456.133
4/30/2003	1:00:00	458.536	456.132
4/30/2003	2:00:00	458.544	456.13
4/30/2003	3:00:00	458.531	456.117
4/30/2003	4:00:00	458.528	456.134
4/30/2003	5:00:00	458.53	456.126
4/30/2003	6:00:00	458.522	456.118
4/30/2003	7:00:00	458.515	456.111
4/30/2003	8:00:00	458.526	456.112
5/2/2003	11:00:00	458.431	456.087
5/2/2003	12:00:00	458.432	456.088
5/2/2003	13:00:00	458.435	456.091
5/2/2003	14:00:00	458.44	456.096
5/2/2003	15:00:00	458.459	456.105
5/2/2003	16:00:00	458.469	456.115
	17:00:00	458.425	456.071
	18:00:00	458.497	456.133
	19:00:00	458.492	456.128
	20:00:00	458.496	456.142
	21:00:00	458.499	456.135
	22:00:00	458.495	456.141
	23:00:00	458.498	456.134
5/3/2003	0:00:00	458.491	456.117
	1:00:00	458.503	456.119
	2:00:00	458.5	456.116
	3:00:00	458.487	456.123
	4:00:00	458.491	456.127
	5:00:00	458.491	456.117
	6:00:00	458.504	456.13
	7:00:00	458.494	456.12
	8:00:00	458.491	456.117
	9:00:00	458.492	456.118
	10:00:00	458.488	456.104
	11:00:00	458.488	456.104
	12:00:00	458.485	456.111
	13:00:00	458.484	456.11
	14:00:00	458.474	456.1
	15:00:00	458.48	456.106

date	time	well 31 head meters AMSL	vetex
5/1/2003	12:00:00	458.482	456.078
5/1/2003	13:00:00	458.469	456.075
5/1/2003	14:00:00	458.484	456.09
5/1/2003	15:00:00	458.488	456.074
5/1/2003	16:00:00	458.495	456.081
5/1/2003	17:00:00	458.49	456.086
5/1/2003	18:00:00	458.438	456.084
5/1/2003	19:00:00	458.446	456.102
5/1/2003	20:00:00	458.444	456.09
5/1/2003	21:00:00	458.455	456.091
5/1/2003	22:00:00	458.446	456.112
5/1/2003	23:00:00	458.445	456.091
5/2/2003	0:00:00	458.431	456.087
5/2/2003	1:00:00	458.441	456.087
5/2/2003	2:00:00	458.431	456.107
5/2/2003	3:00:00	458.44	456.086
5/2/2003	4:00:00	458.451	456.087
5/2/2003	5:00:00	458.448	456.094
5/2/2003	6:00:00	458.435	456.091
5/2/2003	7:00:00	458.447	456.093
5/2/2003	8:00:00	458.446	456.092
5/2/2003	9:00:00	458.442	456.088
5/2/2003	10:00:00	458.437	456.083
	13:00:00	458.434	456.07
	14:00:00	458.448	456.074
	15:00:00	458.432	456.078
	16:00:00	458.455	456.081
	17:00:00	458.466	456.082
	18:00:00	458.455	456.111
	19:00:00	458.469	456.115
	20:00:00	458.477	456.113
	21:00:00	458.49	456.106
	22:00:00	458.479	456.115
	23:00:00	458.472	456.098
5/5/2003	0:00:00	458.476	456.112
	1:00:00	458.468	456.094
	2:00:00	458.465	456.091
	3:00:00	458.475	456.091
	4:00:00	458.469	456.095
	5:00:00	458.469	456.085
	6:00:00	458.456	456.092
	7:00:00	458.462	456.088
	8:00:00	458.459	456.075
	9:00:00	458.452	456.068
	10:00:00	458.439	456.075
	11:00:00	458.445	456.071
	12:00:00	458.432	456.068
	13:00:00	458.435	456.081
	14:00:00	458.438	456.074
	15:00:00	458.457	456.083
	16:00:00	458.463	456.099
	17:00:00	458.449	456.095

date	time	well 31 head meters AMSL	vetex
	16:00:00	458.488	456.114
	17:00:00	458.493	456.119
	18:00:00	458.508	456.124
	19:00:00	458.512	456.138
	20:00:00	458.478	456.104
	21:00:00	458.484	456.12
	22:00:00	458.485	456.121
	23:00:00	458.493	456.119
5/4/2003	0:00:00	458.49	456.106
	1:00:00	458.475	456.101
	2:00:00	458.487	456.103
	3:00:00	458.465	456.091
	4:00:00	458.476	456.092
	5:00:00	458.474	456.09
	6:00:00	458.472	456.088
	7:00:00	458.468	456.084
	8:00:00	458.467	456.083
	9:00:00	458.462	456.078
	10:00:00	458.437	456.063
	11:00:00	458.434	456.07
	12:00:00	458.443	456.059
	15:00:00	458.209	456.105
	16:00:00	458.22	456.116
	17:00:00	458.228	456.124
	18:00:00	458.235	456.131
	19:00:00	458.254	456.14
	20:00:00	458.263	456.149
	21:00:00	458.286	456.152
	22:00:00	458.299	456.155
	23:00:00	458.299	456.155
5/7/2003	0:00:00	458.297	456.153
	1:00:00	458.293	456.149
	2:00:00	458.302	456.128
	3:00:00	458.312	456.138
	4:00:00	458.31	456.146
	5:00:00	458.321	456.137
	6:00:00	458.32	456.126
	7:00:00	458.33	456.126
	8:00:00	458.337	456.143
	9:00:00	458.338	456.134
	10:00:00	458.336	456.122
	11:00:00	458.352	456.128
	12:00:00	458.335	456.121
	13:00:00	458.337	456.123
	14:00:00	458.34	456.106
	15:00:00	451.848	456.114
	16:00:00	451.59	456.116
	17:00:00	450.951	456.127
	18:00:00	457.457	456.123
	19:00:00	457.678	456.144
	20:00:00	457.775	456.131
	21:00:00	457.825	456.111

date	time	well 31 head meters AMSL	vetex
	18:00:00	458.43	456.106
	19:00:00	452.688	456.124
	20:00:00	453.973	456.119
	21:00:00	457.872	456.108
	22:00:00	457.978	456.114
	23:00:00	458.027	456.113
5/6/2003	0:00:00	458.055	456.121
	1:00:00	458.071	456.107
	2:00:00	458.101	456.107
	3:00:00	458.096	456.112
	4:00:00	458.129	456.115
	5:00:00	458.128	456.114
	6:00:00	458.138	456.124
	7:00:00	458.147	456.103
	8:00:00	458.143	456.099
	9:00:00	458.161	456.097
	10:00:00	458.163	456.089
	11:00:00	458.173	456.089
	12:00:00	458.172	456.088
	13:00:00	458.185	456.091
	14:00:00	458.196	456.092
	17:00:00	450.554	456.14
	18:00:00	450.346	456.152
	19:00:00	450.326	456.162
	20:00:00	449.749	456.145
	21:00:00	456.287	456.143
	22:00:00	456.565	456.141
	23:00:00	456.728	456.124
5/9/2003	0:00:00	456.855	456.121
	1:00:00	456.96	456.116
	2:00:00	457.039	456.115
	3:00:00	452.262	456.118
	4:00:00	450.346	456.102
	5:00:00	450.161	456.107
	6:00:00	450.145	456.101
	7:00:00	449.932	456.108
	8:00:00	450.054	456.11
	9:00:00	449.601	456.097
	10:00:00	455.546	456.082
	11:00:00	455.963	456.079
	12:00:00	456.189	456.085
	13:00:00	456.347	456.073
	14:00:00	456.478	456.064
	15:00:00	456.586	456.062
	16:00:00	456.673	456.069
	17:00:00	450.565	456.091
	18:00:00	449.863	456.089
	19:00:00	449.393	456.089
	20:00:00	449.21	456.086
	21:00:00	449.111	456.087
	22:00:00	448.984	456.07
	23:00:00	453.588	456.074

date	time	well 31 head meters AMSL	vetex
	22:00:00	457.878	456.114
	23:00:00	457.928	456.114
5/8/2003	0:00:00	457.958	456.104
	1:00:00	457.979	456.105
	2:00:00	451.883	456.099
	3:00:00	451.512	456.088
	4:00:00	450.959	456.115
	5:00:00	450.601	456.097
	6:00:00	450.392	456.108
	7:00:00	454.729	456.115
	8:00:00	456.695	456.091
	9:00:00	456.94	456.096
	10:00:00	457.083	456.109
	11:00:00	457.199	456.105
	12:00:00	457.29	456.106
	13:00:00	457.374	456.1
	14:00:00	453.073	456.119
	15:00:00	451.42	456.126
	16:00:00	450.935	456.141
	19:00:00	451.36	456.086
	20:00:00	449.574	456.08
	21:00:00	449.058	456.084
	22:00:00	449.098	456.074
	23:00:00	448.86	456.076
5/11/2003	0:00:00	447.906	456.062
	1:00:00	447.98	456.066
	2:00:00	454.028	456.064
	3:00:00	454.829	456.055
	4:00:00	455.153	456.059
	5:00:00	455.393	456.059
	6:00:00	455.576	456.072
	7:00:00	455.711	456.057
	8:00:00	455.831	456.047
	9:00:00	449.02	456.056
	10:00:00	448.576	456.052
	11:00:00	448.301	456.047
	12:00:00	448.251	456.047
	13:00:00	448.054	456.05
	14:00:00	447.361	456.017
	15:00:00	452.454	456.07
	16:00:00	454.526	456.062
	17:00:00	454.935	456.091
	18:00:00	455.208	456.084
	19:00:00	455.396	456.092
	20:00:00	455.563	456.109
	21:00:00	455.677	456.103
	22:00:00	448.634	456.09
	23:00:00	448.381	456.087
5/12/2003	0:00:00	448.204	456.08
	1:00:00	447.441	456.087
	2:00:00	447.937	456.093
	3:00:00	447.451	456.057

date	time	well 31 head meters AMSL	vetex
5/10/2003	0:00:00	455.461	456.067
	1:00:00	455.756	456.072
	2:00:00	455.964	456.08
	3:00:00	456.123	456.069
	4:00:00	456.239	456.065
	5:00:00	456.344	456.06
	6:00:00	450.073	456.059
	7:00:00	449.548	456.064
	8:00:00	449.21	456.056
	9:00:00	449.176	456.042
	10:00:00	448.946	456.042
	11:00:00	448.761	456.037
	12:00:00	448.782	456.038
	13:00:00	454.912	456.038
	14:00:00	455.384	456.04
	15:00:00	455.647	456.053
	16:00:00	455.832	456.048
	17:00:00	455.976	456.062
	18:00:00	456.106	456.072
	21:00:00	455.006	456.112
	22:00:00	455.193	456.089
	23:00:00	455.336	456.102
5/13/2003	0:00:00	455.477	456.113
	1:00:00	445.135	456.091
	2:00:00	446.335	456.081
	3:00:00	447.473	456.089
	4:00:00	447.242	456.088
	5:00:00	447.614	456.08
	6:00:00	447.008	456.094
	7:00:00	446.894	456.09
	8:00:00	453.981	456.087
	9:00:00	454.437	456.083
	10:00:00	454.659	456.075
	11:00:00	454.847	456.083
	12:00:00	454.992	456.068
	13:00:00	455.122	456.068
	14:00:00	446.851	456.067
	15:00:00	447.033	456.069
	16:00:00	446.129	456.075
	17:00:00	446.24	456.076
	18:00:00	445.769	456.095
	19:00:00	446.114	456.09
	20:00:00	445.56	456.096
	21:00:00	453.687	456.093
	22:00:00	454.302	456.098
	23:00:00	454.623	456.089
5/14/2003	0:00:00	454.832	456.098
	1:00:00	455.022	456.088
	2:00:00	455.17	456.106
	3:00:00	449.698	456.094
	4:00:00	446.746	456.102
	5:00:00	446.231	456.097

date	time	well 31 head meters AMSL	vetex
	4:00:00	452.665	456.071
	5:00:00	454.534	456.07
	6:00:00	454.776	456.072
	7:00:00	455.036	456.082
	8:00:00	455.229	456.075
	9:00:00	455.382	456.068
	10:00:00	455.503	456.069
	11:00:00	448.594	456.05
	12:00:00	447.975	456.061
	13:00:00	447.767	456.053
	14:00:00	447.737	456.053
	15:00:00	447.89	456.066
	16:00:00	447.432	456.068
	17:00:00	447.199	456.085
	18:00:00	453.569	456.085
	19:00:00	454.427	456.093
	20:00:00	454.774	456.1
	23:00:00	446.765	456.161
5/15/2003	0:00:00	454.403	456.159
	1:00:00	454.899	456.155
	2:00:00	455.134	456.14
	3:00:00	455.333	456.139
	4:00:00	455.504	456.13
	5:00:00	455.615	456.141
	6:00:00	449.466	456.132
	7:00:00	448.359	456.115
	8:00:00	448.075	456.111
	9:00:00	447.719	456.085
	10:00:00	447.424	456.09
	11:00:00	447.033	456.069
	12:00:00	447.148	456.064
	13:00:00	447.101	456.077
	14:00:00	454.845	456.075
	15:00:00	454.849	456.069
	16:00:00	454.847	456.087
	17:00:00	454.853	456.093
	18:00:00	454.853	456.083
	19:00:00	451.307	456.087
	20:00:00	449.936	456.086
	21:00:00	449.696	456.086
	22:00:00	449.459	456.099
	23:00:00	448.89	456.1
5/16/2003	0:00:00	448.602	456.072
	1:00:00	448.686	456.076
	2:00:00	448.552	456.062
	3:00:00	454.82	456.06
	4:00:00	454.839	456.069
	5:00:00	454.835	456.075
	6:00:00	454.832	456.062
	7:00:00	454.831	456.071
	8:00:00	454.832	456.072
	9:00:00	449.973	456.053

date	time	well 31 head meters AMSL	vetex
	6:00:00	446.053	456.089
	7:00:00	445.45	456.086
	8:00:00	445.143	456.089
	9:00:00	445.971	456.057
	10:00:00	451.433	456.089
	11:00:00	454.046	456.092
	12:00:00	454.454	456.09
	13:00:00	454.744	456.09
	14:00:00	454.97	456.086
	15:00:00	455.147	456.093
	16:00:00	455.304	456.11
	17:00:00	447.987	456.113
	18:00:00	447.118	456.124
	19:00:00	445.748	456.144
	20:00:00	445.178	456.144
	21:00:00	446.081	456.147
	22:00:00	445.821	456.157
	1:00:00	448.524	456.104
	2:00:00	448.404	456.094
	3:00:00	448.122	456.092
	4:00:00	448.093	456.093
	5:00:00	447.922	456.102
	6:00:00	447.808	456.098
	7:00:00	454.237	456.087
	8:00:00	454.656	456.086
	9:00:00	454.868	456.098
	10:00:00	454.861	456.101
	11:00:00	454.86	456.08
	12:00:00	454.859	456.099
	13:00:00	449.07	456.08
	14:00:00	448.587	456.097
	15:00:00	448.395	456.105
	16:00:00	448.201	456.121
	17:00:00	447.965	456.125
	18:00:00	447.834	456.134
	19:00:00	447.44	456.14
	20:00:00	453.441	456.151
	21:00:00	454.487	456.147
	22:00:00	454.813	456.133
	23:00:00	454.866	456.106
5/18/2003	0:00:00	454.875	456.135
	1:00:00	454.866	456.116
	2:00:00	454.87	456.11
	3:00:00	448.705	456.125
	4:00:00	448.206	456.126
	5:00:00	447.82	456.11
	6:00:00	447.629	456.119
	7:00:00	447.301	456.121
	8:00:00	447.119	456.109
	9:00:00	447.057	456.117
	10:00:00	453.047	456.107
	11:00:00	454.235	456.105

date	time	well 31 head meters AMSL	vetex
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	11:00:00	448.854	456.054
	12:00:00	448.498	456.058
	13:00:00	448.242	456.052
	14:00:00	448.266	456.056
	15:00:00	448.214	456.064
	16:00:00	448.012	456.062
	17:00:00	454.486	456.096
	18:00:00	454.845	456.095
	19:00:00	454.861	456.101
	20:00:00	454.867	456.097
	21:00:00	454.869	456.109
	22:00:00	454.874	456.114
	23:00:00	450.121	456.111
5/17/2003	0:00:00	448.937	456.107
	3:00:00	454.827	456.077
	4:00:00	454.821	456.071
	5:00:00	454.817	456.077
	6:00:00	454.805	456.075
	7:00:00	448.108	456.058
	8:00:00	447.839	456.049
	9:00:00	447.568	456.048
	10:00:00	447.282	456.032
	11:00:00	448.193	456.043
	12:00:00	447.075	456.035
	13:00:00	447.085	456.035
	14:00:00	446.87	456.05
	15:00:00	452.934	456.044
	16:00:00	454.163	456.053
	17:00:00	454.494	456.064
	18:00:00	454.742	456.072
	19:00:00	454.796	456.086
	20:00:00	454.807	456.087
	21:00:00	454.81	456.1
	22:00:00	448.208	456.098
	23:00:00	447.568	456.088
5/20/2003	0:00:00	447.278	456.078
	1:00:00	447.049	456.069
	2:00:00	446.925	456.065
	3:00:00	446.854	456.064
	4:00:00	446.713	456.073
	5:00:00	453.485	456.075
	6:00:00	454.137	456.067
	7:00:00	454.434	456.064
	8:00:00	454.649	456.059
	9:00:00	454.778	456.068
	10:00:00	454.768	456.058
	11:00:00	449.26	456.05
	12:00:00	447.899	456.069
5/20/2003	13:16:24	447.639	456.069
5/20/2003	14:16:24	447.374	456.084
5/20/2003	15:16:24	447.291	456.091
	12:00:00	454.571	456.101
	13:00:00	454.843	456.113
	14:00:00	454.852	456.102
	15:00:00	454.853	456.103
	16:00:00	454.864	456.114
	17:00:00	448.513	456.123
	18:00:00	448.18	456.12
	19:00:00	447.822	456.122
	20:00:00	447.716	456.136
	21:00:00	447.626	456.136
	22:00:00	447.33	456.13
	23:00:00	447.207	456.127
5/19/2003	0:00:00	453.834	456.124
	1:00:00	454.434	456.104
	2:00:00	454.734	456.094
5/21/2003	5:16:24	446.92	456.09
5/21/2003	6:16:24	446.759	456.079
5/21/2003	7:16:24	446.548	456.078
5/21/2003	8:16:24	453.297	456.087
5/21/2003	9:16:24	453.99	456.08
5/21/2003	10:16:24	454.305	456.075
5/21/2003	11:16:24	454.515	456.065
5/21/2003	12:16:24	454.703	456.073
5/21/2003	13:16:24	454.798	456.078
5/21/2003	14:16:24	448.681	456.081
5/21/2003	15:16:24	447.283	456.103
5/21/2003	16:16:24	446.887	456.077
5/21/2003	17:16:24	446.659	456.109
5/21/2003	18:16:24	446.526	456.116
5/21/2003	19:16:24	446.333	456.103
5/21/2003	20:16:24	446.177	456.127
5/21/2003	21:16:24	446.1	456.13
5/21/2003	22:16:24	453.607	456.117
5/21/2003	23:16:24	454.012	456.112
5/22/2003	0:16:24	454.272	456.102
5/22/2003	1:16:24	454.471	456.121
5/22/2003	2:16:24	454.626	456.106
5/22/2003	3:16:24	454.755	456.095
5/22/2003	4:16:24	447.793	456.093
5/22/2003	5:16:24	447.018	456.088
5/22/2003	6:16:24	446.618	456.088
5/22/2003	7:16:24	446.357	456.087
5/22/2003	8:16:24	446.063	456.093
5/22/2003	9:16:24	445.824	456.084
5/22/2003	10:16:24	445.707	456.087
5/22/2003	11:16:24	445.716	456.096
5/22/2003	12:16:24	453.424	456.084
5/22/2003	13:16:24	453.847	456.077
5/22/2003	14:16:24	454.178	456.088
5/22/2003	15:16:24	454.397	456.107
5/22/2003	16:16:24	454.57	456.1
5/22/2003	17:16:24	454.735	456.115

date	time	well 31 head meters AMSL	vetex
5/20/2003	16:16:24	447.14	456.1
5/20/2003	17:16:24	446.853	456.093
5/20/2003	18:16:24	446.645	456.105
5/20/2003	19:16:24	453.813	456.103
5/20/2003	20:16:24	454.217	456.107
5/20/2003	21:16:24	454.464	456.134
5/20/2003	22:16:24	454.666	456.116
5/20/2003	23:16:24	454.805	456.115
5/21/2003	0:16:24	454.823	456.103
5/21/2003	1:16:24	448.43	456.09
5/21/2003	2:16:24	447.547	456.097
5/21/2003	3:16:24	447.423	456.093
5/21/2003	4:16:24	447.221	456.081
5/23/2003	7:16:24	454.727	456.107
5/23/2003	8:16:24	446.958	456.098
5/23/2003	9:16:24	446.4	456.09
5/23/2003	10:16:24	445.995	456.085
5/23/2003	11:16:24	445.724	456.084
5/23/2003	12:16:24	445.594	456.084
5/23/2003	13:16:24	445.453	456.073
5/23/2003	14:16:24	445.329	456.079
5/23/2003	15:16:24	445.227	456.087
5/23/2003	16:16:24	453.215	456.105
5/23/2003	17:16:24	453.735	456.115
5/23/2003	18:16:24	454.021	456.121
5/23/2003	19:16:24	454.244	456.134
5/23/2003	20:16:24	454.402	456.132
5/23/2003	21:16:24	454.551	456.141
5/23/2003	22:16:24	446.854	456.144
5/23/2003	23:16:24	446.241	456.131
5/24/2003	0:16:24	445.894	456.124
5/24/2003	1:16:24	445.566	456.126
5/24/2003	2:16:24	445.293	456.113
5/24/2003	3:16:24	445.236	456.116
5/24/2003	4:16:24	445.298	456.118
5/24/2003	5:16:24	451.979	456.109
5/24/2003	6:16:24	453.452	456.112
5/24/2003	7:16:24	453.83	456.12
5/24/2003	8:16:24	454.089	456.129
5/24/2003	9:16:24	454.266	456.126
5/24/2003	10:16:24	454.44	456.11
5/24/2003	11:16:24	448.01	456.1
5/24/2003	12:16:24	446.411	456.121
5/24/2003	13:16:24	445.935	456.115
5/24/2003	14:16:24	445.696	456.106
5/24/2003	15:16:24	445.397	456.117
5/24/2003	16:16:24	445.055	456.135
5/24/2003	17:16:24	444.945	456.125
5/24/2003	18:16:24	444.925	456.135
5/24/2003	19:16:24	452.975	456.155
5/24/2003	20:16:24	453.536	456.156
5/24/2003	21:16:24	453.858	456.148

date	time	well 31 head meters AMSL	vetex
5/22/2003	18:16:24	447.56	456.11
5/22/2003	19:16:24	446.638	456.128
5/22/2003	20:16:24	446.062	456.122
5/22/2003	21:16:24	445.853	456.133
5/22/2003	22:16:24	445.872	456.122
5/22/2003	23:16:24	445.87	456.12
5/23/2003	0:16:24	445.695	456.115
5/23/2003	1:16:24	452.228	456.108
5/23/2003	2:16:24	453.596	456.106
5/23/2003	3:16:24	454.012	456.102
5/23/2003	4:16:24	454.26	456.1
5/23/2003	5:16:24	454.455	456.105
5/23/2003	6:16:24	454.593	456.103
5/25/2003	9:16:24	452.911	456.121
5/25/2003	10:16:24	453.486	456.116
5/25/2003	11:16:24	453.799	456.109
5/25/2003	12:16:24	454.02	456.1
5/25/2003	13:16:24	454.199	456.109
5/25/2003	14:16:24	454.367	456.107
5/25/2003	15:16:24	446.459	456.119
5/25/2003	16:16:24	445.681	456.131
5/25/2003	17:16:24	445.184	456.124
5/25/2003	18:16:24	444.929	456.139
5/25/2003	19:16:24	444.87	456.14
5/25/2003	20:16:24	444.77	456.14
5/25/2003	21:16:24	444.724	456.134
5/25/2003	22:16:24	451.754	456.134
5/25/2003	23:16:24	453.245	456.135
5/26/2003	0:16:24	453.629	456.129
5/26/2003	1:16:24	453.898	456.128
5/26/2003	2:16:24	454.085	456.115
5/26/2003	3:16:24	454.262	456.102
5/26/2003	4:16:24	454.41	456.11
5/26/2003	5:16:24	446.222	456.102
5/26/2003	6:16:24	445.651	456.101
5/26/2003	7:16:24	445.345	456.095
5/26/2003	8:16:24	445.119	456.089
5/26/2003	9:16:24	444.808	456.078
5/26/2003	10:16:24	444.638	456.078
5/26/2003	11:16:24	444.707	456.077
5/26/2003	12:16:24	444.466	456.046
5/26/2003	13:16:24	452.792	456.062
5/26/2003	14:16:24	453.398	456.068
5/26/2003	15:16:24	453.717	456.077
5/26/2003	16:16:24	453.94	456.08
5/26/2003	17:16:24	454.138	456.078
5/26/2003	18:16:24	454.297	456.097
5/26/2003	19:16:24	446.6	456.09
5/26/2003	20:16:24	445.61	456.11
5/26/2003	21:16:24	445.257	456.107
5/26/2003	22:16:24	444.992	456.102
5/26/2003	23:16:24	444.932	456.092

date	time	well 31 head meters AMSL	vetex
5/24/2003	22:16:24	454.076	456.156
5/24/2003	23:16:24	454.251	456.141
5/25/2003	0:16:24	454.396	456.146
5/25/2003	1:16:24	446.854	456.134
5/25/2003	2:16:24	445.909	456.129
5/25/2003	3:16:24	445.629	456.139
5/25/2003	4:16:24	445.268	456.118
5/25/2003	5:16:24	445.149	456.129
5/25/2003	6:16:24	444.97	456.12
5/25/2003	7:16:24	444.908	456.138
5/25/2003	8:16:24	444.731	456.091
5/27/2003	11:16:24	445.159	456.029
5/27/2003	12:16:24	444.908	456.048
5/27/2003	13:16:24	444.724	456.054
5/27/2003	14:16:24	444.505	456.055
5/27/2003	15:16:24	444.645	456.055
5/27/2003	16:16:24	444.601	456.071
5/27/2003	17:16:24	452.969	456.079
5/27/2003	18:16:24	453.444	456.084
5/27/2003	19:16:24	453.746	456.096
5/27/2003	20:16:24	453.95	456.1
5/27/2003	21:16:24	454.136	456.106
5/27/2003	22:16:24	454.281	456.101
5/27/2003	23:16:24	454.415	456.095
5/28/2003	0:16:24	446.127	456.097
5/28/2003	1:16:24	445.459	456.089
5/28/2003	2:16:24	445.318	456.068
5/28/2003	3:16:24	445.024	456.074
5/28/2003	4:16:24	445.094	456.084
5/28/2003	5:16:24	444.734	456.074
5/28/2003	6:16:24	444.635	456.085
5/28/2003	7:16:24	451.558	456.078
5/28/2003	8:16:24	453.112	456.082
5/28/2003	9:16:24	453.497	456.077
5/28/2003	10:16:24	453.764	456.074
5/28/2003	11:16:24	453.968	456.068
5/28/2003	12:16:24	454.132	456.062
5/28/2003	13:16:24	447.44	456.07
5/28/2003	14:16:24	445.473	456.063
5/28/2003	15:16:24	445.158	456.078
5/28/2003	16:16:24	444.955	456.085
5/28/2003	17:16:24	444.838	456.088
5/28/2003	18:16:24	444.595	456.095
5/28/2003	19:16:24	444.645	456.115
5/28/2003	20:16:24	444.495	456.125
5/28/2003	21:16:24	452.433	456.113
5/28/2003	22:16:24	453.23	456.12
5/28/2003	23:16:24	453.569	456.109
5/29/2003	0:16:24	453.825	456.105
5/29/2003	1:16:24	454.018	456.098
5/29/2003	2:16:24	454.174	456.084
5/29/2003	3:16:24	447.526	456.096

date	time	well 31 head meters AMSL	vetex
5/27/2003	0:16:24	444.502	456.072
5/27/2003	1:16:24	444.517	456.077
5/27/2003	2:16:24	444.479	456.059
5/27/2003	3:16:24	452.807	456.067
5/27/2003	4:16:24	453.395	456.055
5/27/2003	5:16:24	453.712	456.062
5/27/2003	6:16:24	453.944	456.074
5/27/2003	7:16:24	454.109	456.059
5/27/2003	8:16:24	454.262	456.052
5/27/2003	9:16:24	446.546	456.046
5/27/2003	10:16:24	445.572	456.032
5/29/2003	13:16:24	453.425	456.055
5/29/2003	14:16:24	453.715	456.075
5/29/2003	15:16:24	453.928	456.088
5/29/2003	16:16:24	454.109	456.099
5/29/2003	17:16:24	454.277	456.117
5/29/2003	18:16:24	446.383	456.123
5/29/2003	19:16:24	445.825	456.125
5/29/2003	20:16:24	445.425	456.135
5/29/2003	21:16:24	444.929	456.139
5/29/2003	22:16:24	444.785	456.135
5/29/2003	23:16:24	444.639	456.129
5/30/2003	0:16:24	444.581	456.121
5/30/2003	1:16:24	444.46	456.11
5/30/2003	2:16:24	452.794	456.114
5/30/2003	3:16:24	453.385	456.125
5/30/2003	4:16:24	453.68	456.12
5/30/2003	5:16:24	453.918	456.108
5/30/2003	6:16:24	454.088	456.108
5/30/2003	7:16:24	454.252	456.102
5/30/2003	8:16:24	446.651	456.111
5/30/2003	9:16:24	445.733	456.093
5/30/2003	10:16:24	445.127	456.087
5/30/2003	11:16:24	445.015	456.085
5/30/2003	12:16:24	444.957	456.097
5/30/2003	13:16:24	444.788	456.088
5/30/2003	14:16:24	444.623	456.083
5/30/2003	15:16:24	444.609	456.099
5/30/2003	16:16:24	444.589	456.109
5/30/2003	17:16:24	452.858	456.118
5/30/2003	18:16:24	453.358	456.118
5/30/2003	19:16:24	453.656	456.126
5/30/2003	20:16:24	453.888	456.118
5/30/2003	21:16:24	454.073	456.133
5/30/2003	22:16:24	454.213	456.133
5/30/2003	23:16:24	446.656	456.116
5/31/2003	0:16:24	445.808	456.128
5/31/2003	1:16:24	445.482	456.112
5/31/2003	2:16:24	445.205	456.105
5/31/2003	3:16:24	445.125	456.095
5/31/2003	4:16:24	444.776	456.096
5/31/2003	5:16:24	444.747	456.097

date	time	well 31 head meters AMSL	vetex
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5/29/2003	6:16:24	445.172	456.082
5/29/2003	7:16:24	444.891	456.091
5/29/2003	8:16:24	444.814	456.094
5/29/2003	9:16:24	444.899	456.069
5/29/2003	10:16:24	444.893	456.073
5/29/2003	11:16:24	444.761	456.071
5/29/2003	12:16:24	452.951	456.071
5/31/2003	15:16:24	445.395	456.085
5/31/2003	16:16:24	445.177	456.097
5/31/2003	17:16:24	444.949	456.119
5/31/2003	18:16:24	444.985	456.125
5/31/2003	19:16:24	444.867	456.127
5/31/2003	20:16:24	444.857	456.107
5/31/2003	21:16:24	452.756	456.126
5/31/2003	22:16:24	453.314	456.124
5/31/2003	23:16:24	453.62	456.12
6/1/2003	0:16:24	453.864	456.124
6/1/2003	1:16:24	454.057	456.117
6/1/2003	2:16:24	454.192	456.102
6/1/2003	3:16:24	446.976	456.106
6/1/2003	4:16:24	446.035	456.105
6/1/2003	5:16:24	445.769	456.099
6/1/2003	6:16:24	445.428	456.098
6/1/2003	7:16:24	445.199	456.109
6/1/2003	8:16:24	445.098	456.098
6/1/2003	9:16:24	445.042	456.082
6/1/2003	10:16:24	444.994	456.084
6/1/2003	11:16:24	451.623	456.073
6/1/2003	12:16:24	453.163	456.063
6/1/2003	13:16:24	453.568	456.088
6/1/2003	14:16:24	453.818	456.078
6/1/2003	15:16:24	454.014	456.094
6/1/2003	16:16:24	454.18	456.09
6/1/2003	17:16:24	454.337	456.097
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6/1/2003	19:16:24	445.762	456.112
6/1/2003	20:16:24	445.571	456.121
6/1/2003	21:16:24	445.098	456.128
6/1/2003	22:16:24	445.137	456.127
6/1/2003	23:16:24	445.063	456.123
6/2/2003	0:16:24	444.989	456.119
6/2/2003	1:16:24	451.687	456.117
6/2/2003	2:16:24	453.13	456.12
6/2/2003	3:16:24	453.521	456.111
6/2/2003	4:16:24	453.784	456.104
6/2/2003	5:16:24	453.981	456.111
6/2/2003	6:16:24	454.152	456.112
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6/2/2003	8:16:24	446.674	456.104
6/2/2003	9:16:24	445.79	456.1

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5/31/2003	9:16:24	453.419	456.079
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5/31/2003	11:16:24	453.864	456.074
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5/31/2003	13:16:24	446.565	456.075
5/31/2003	14:16:24	445.671	456.091
6/2/2003	17:16:24	444.772	456.132
6/2/2003	18:16:24	452.827	456.127
6/2/2003	19:16:24	453.33	456.13
6/2/2003	20:16:24	453.623	456.143
6/2/2003	21:16:24	453.845	456.135
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6/2/2003	23:16:24	454.174	456.144
6/3/2003	0:16:24	446.471	456.131
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6/3/2003	2:16:24	445.466	456.126
6/3/2003	3:16:24	445.342	456.132
6/3/2003	4:16:24	445.167	456.117
6/3/2003	5:16:24	444.937	456.107
6/3/2003	6:16:24	444.86	456.1
6/3/2003	7:16:24	444.829	456.099
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6/3/2003	9:16:24	453.352	456.082
6/3/2003	10:16:24	453.621	456.091
6/3/2003	11:16:24	453.836	456.096
6/3/2003	12:16:24	454.016	456.076
6/3/2003	13:16:24	454.195	456.085
6/3/2003	14:16:24	446.282	456.082
6/3/2003	15:16:24	445.842	456.092
6/3/2003	16:16:24	445.541	456.111
6/3/2003	17:16:24	445.318	456.118
6/3/2003	18:16:24	445.027	456.137
6/3/2003	19:16:24	444.574	456.124
6/3/2003	20:16:24	444.628	456.138
6/3/2003	21:16:24	451.534	456.134
6/3/2003	22:16:24	453.047	456.137
6/3/2003	23:16:24	453.445	456.135
6/4/2003	0:16:24	453.725	456.125
6/4/2003	1:16:24	453.912	456.142
6/4/2003	2:16:24	454.086	456.126
6/4/2003	3:16:24	454.234	456.124
6/4/2003	4:16:24	446.079	456.119
6/4/2003	5:16:24	445.649	456.119
6/4/2003	6:16:24	445.315	456.115
6/4/2003	7:16:24	445.132	456.122
6/4/2003	8:16:24	444.996	456.116
6/4/2003	9:16:24	444.824	456.094
6/4/2003	10:16:24	444.702	456.102
6/4/2003	11:16:24	444.64	456.08

date	time	well 31 head meters AMSL	vetex
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6/2/2003	12:16:24	444.985	456.085
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6/2/2003	14:16:24	445.158	456.098
6/2/2003	15:16:24	444.942	456.102
6/2/2003	16:16:24	444.814	456.124
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6/4/2003	20:16:24	445.542	456.152
6/4/2003	21:16:24	445.265	456.155
6/4/2003	22:16:24	444.997	456.157
6/4/2003	23:16:24	444.745	456.155
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6/5/2003	1:16:24	444.481	456.131
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6/5/2003	3:16:24	453.115	456.115
6/5/2003	4:16:24	453.463	456.103
6/5/2003	5:16:24	453.719	456.119
6/5/2003	6:16:24	453.907	456.097
6/5/2003	7:16:24	454.062	456.092
6/5/2003	8:16:24	447.534	456.084
6/5/2003	9:16:24	445.663	456.073
6/5/2003	10:16:24	445.124	456.064
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6/5/2003	13:16:24	444.575	456.075
6/5/2003	14:16:24	444.356	456.086
6/5/2003	15:16:24	444.229	456.089
6/5/2003	16:16:24	444.255	456.095
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6/5/2003	18:16:24	453.216	456.096
6/5/2003	19:16:24	453.534	456.114
6/5/2003	20:16:24	453.738	456.108
6/5/2003	21:16:24	453.944	456.114
6/5/2003	22:16:24	454.084	456.114
6/5/2003	23:16:24	446.154	456.114
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6/6/2003	2:16:24	444.773	456.093
6/6/2003	3:16:24	444.669	456.099
6/6/2003	4:16:24	444.567	456.097
6/6/2003	5:16:24	444.446	456.096
6/6/2003	6:16:24	444.395	456.095
6/6/2003	7:16:24	452.683	456.093
6/6/2003	8:16:24	453.192	456.092
6/6/2003	9:16:24	453.495	456.085
6/6/2003	10:16:24	453.707	456.097
6/6/2003	11:16:24	454.846	456.086
6/6/2003	12:16:24	448.043	456.043
6/6/2003	13:16:24	446.376	456.046
6/6/2003	14:16:24	445.603	456.053
6/6/2003	15:16:24	445.287	456.067

date	time	well 31 head meters AMSL	vetex
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6/4/2003	14:16:24	453.569	456.109
6/4/2003	15:16:24	453.793	456.103
6/4/2003	16:16:24	453.981	456.111
6/4/2003	17:16:24	454.16	456.12
6/4/2003	18:16:24	446.822	456.132
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6/6/2003	22:16:24	453.521	456.101
6/6/2003	23:16:24	453.755	456.105
6/7/2003	0:16:24	453.923	456.093
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6/7/2003	2:16:24	446.533	456.083
6/7/2003	3:16:24	445.584	456.084
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6/7/2003	5:16:24	445.021	456.081
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6/7/2003	12:16:24	453.243	456.063
6/7/2003	13:16:24	453.515	456.055
6/7/2003	14:16:24	453.72	456.07
6/7/2003	15:16:24	453.885	456.055
6/7/2003	16:16:24	454.065	456.075
6/7/2003	17:16:24	445.767	456.087
6/7/2003	18:16:24	445.535	456.105
6/7/2003	19:16:24	445.236	456.116
6/7/2003	20:16:24	445.064	456.114
6/7/2003	21:16:24	444.911	456.131
6/7/2003	22:16:24	444.895	456.125
6/7/2003	23:16:24	444.765	456.125
6/8/2003	0:16:24	451.366	456.106
6/8/2003	1:16:24	452.883	456.083
6/8/2003	2:16:24	453.396	456.106
6/8/2003	3:16:24	453.651	456.091
6/8/2003	4:16:24	453.84	456.09
6/8/2003	5:16:24	454.006	456.086
6/8/2003	6:16:24	454.154	456.084
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6/8/2003	8:16:24	446.032	456.082
6/8/2003	9:16:24	445.693	456.083
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6/8/2003	11:16:24	445.29	456.08
6/8/2003	12:16:24	445.149	456.059
6/8/2003	13:16:24	445.095	456.065
6/8/2003	14:16:24	445.033	456.073
6/8/2003	15:16:24	452.323	456.073
6/8/2003	16:16:24	453.096	456.086
6/8/2003	17:16:24	453.441	456.091

date	time	well 31 head meters AMSL	vetex
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6/6/2003	17:16:24	444.889	456.079
6/6/2003	18:16:24	444.696	456.086
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6/9/2003	2:16:24	445.339	456.089
6/9/2003	3:16:24	445.228	456.088
6/9/2003	4:16:24	445.159	456.089
6/9/2003	5:16:24	445.059	456.089
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6/9/2003	7:16:24	453.333	456.073
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6/9/2003	10:16:24	453.957	456.067
6/9/2003	11:16:24	447.743	456.063
6/9/2003	12:16:24	446.032	456.072
6/9/2003	13:16:24	445.612	456.072
6/9/2003	14:16:24	445.414	456.074
6/9/2003	15:16:24	445.409	456.069
6/9/2003	16:16:24	445.173	456.073
6/9/2003	17:16:24	445.085	456.075
6/9/2003	18:16:24	445.093	456.093
6/9/2003	19:16:24	451.5	456.09
6/9/2003	20:16:24	452.942	456.092
6/9/2003	21:16:24	453.345	456.095
6/9/2003	22:16:24	453.603	456.093
6/9/2003	23:16:24	453.802	456.082
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6/10/2003	4:16:24	445.811	456.061
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6/10/2003	6:16:24	445.523	456.053
6/10/2003	7:16:24	445.396	456.056
6/10/2003	8:16:24	445.048	456.038
6/10/2003	9:16:24	445.044	456.054
6/10/2003	10:16:24	452.855	456.045
6/10/2003	11:16:24	453.339	456.039
6/10/2003	12:16:24	453.656	456.046
6/10/2003	13:16:24	453.884	456.054
6/10/2003	14:16:24	454.037	456.037
6/10/2003	15:16:24	454.191	456.061
6/10/2003	16:16:24	446.576	456.066
6/10/2003	17:16:24	446.055	456.075
6/10/2003	18:16:24	445.732	456.082
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6/10/2003	20:16:24	445.357	456.097
6/10/2003	21:16:24	445.179	456.099

date	time	well 31 head meters AMSL	vetex
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6/8/2003	19:16:24	453.893	456.103
6/8/2003	20:16:24	454.041	456.101
6/8/2003	21:16:24	454.181	456.091
6/8/2003	22:16:24	446.597	456.107
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6/11/2003	2:16:24	453.603	456.063
6/11/2003	3:16:24	453.799	456.069
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6/11/2003	5:16:24	454.092	456.072
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6/11/2003	7:16:24	446.072	456.062
6/11/2003	8:16:24	445.754	456.064
6/11/2003	9:16:24	445.461	456.061
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6/11/2003	11:16:24	445.163	456.053
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6/11/2003	21:16:24	445.975	456.105
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6/12/2003	7:16:24	453.684	456.084
6/12/2003	8:16:24	453.826	456.086
6/12/2003	9:16:24	453.993	456.083
6/12/2003	10:16:24	446.383	456.063
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6/12/2003	12:16:24	445.197	456.067
6/12/2003	13:16:24	445.245	456.075
6/12/2003	14:16:24	445.019	456.079
6/12/2003	15:16:24	444.924	456.084
6/12/2003	16:16:24	444.879	456.079
6/12/2003	17:16:24	444.829	456.099
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6/12/2003	19:16:24	453.039	456.099
6/12/2003	20:16:24	453.4	456.11
6/12/2003	21:16:24	453.675	456.105
6/12/2003	22:16:24	453.849	456.089
6/12/2003	23:16:24	453.996	456.106

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6/11/2003	0:16:24	452.937	456.087
6/13/2003	3:16:24	445.258	456.078
6/13/2003	4:16:24	445.122	456.072
6/13/2003	5:16:24	444.948	456.058
6/13/2003	6:16:24	444.851	456.061
6/13/2003	7:16:24	444.637	456.047
6/13/2003	8:16:24	444.598	456.038
6/13/2003	9:16:24	452.526	456.046
6/13/2003	10:16:24	453.107	456.037
6/13/2003	11:16:24	453.413	456.043
6/13/2003	12:16:24	453.635	456.045
6/13/2003	13:16:24	453.806	456.046
6/13/2003	14:16:24	453.974	456.044
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6/13/2003	16:16:24	445.579	456.059
6/13/2003	17:16:24	445.325	456.055
6/13/2003	18:16:24	445.185	456.075
6/13/2003	19:16:24	445.069	456.079
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6/13/2003	21:16:24	444.86	456.08
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6/14/2003	6:16:24	445.521	456.041
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6/14/2003	10:16:24	444.789	456.029
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6/14/2003	12:16:24	444.769	456.029
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6/14/2003	14:16:24	453.08	456.04
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6/14/2003	16:16:24	453.607	456.037
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6/14/2003	18:16:24	453.921	456.071
6/14/2003	19:16:24	446.688	456.078
6/14/2003	20:16:24	445.877	456.077
6/14/2003	21:16:24	445.441	456.081
6/14/2003	22:16:24	445.254	456.074
6/14/2003	23:16:24	445.03	456.07
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6/15/2003	1:16:24	444.942	456.072
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6/15/2003	3:16:24	451.472	456.072

date	time	well 31 head meters AMSL	vetex
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6/13/2003	2:16:24	445.477	456.067
6/15/2003	5:16:24	453.278	456.048
6/15/2003	6:16:24	453.539	456.069
6/15/2003	7:16:24	453.726	456.066
6/15/2003	8:16:24	453.881	456.061
6/15/2003	9:16:24	454.024	456.034
6/15/2003	10:16:24	454.142	456.052
6/15/2003	11:16:24	446.349	456.029
6/15/2003	12:16:24	445.617	456.027
6/15/2003	13:16:24	445.591	456.031
6/15/2003	14:16:24	445.287	456.037
6/15/2003	15:16:24	445.046	456.056
6/15/2003	16:16:24	445.056	456.046
6/15/2003	17:16:24	444.867	456.057
6/15/2003	18:16:24	444.712	456.062
6/15/2003	19:16:24	444.738	456.078
6/15/2003	20:16:24	444.801	456.061
6/15/2003	21:16:24	452.519	456.089
6/15/2003	22:16:24	453.083	456.083
6/15/2003	23:16:24	453.419	456.089
6/16/2003	0:16:24	453.649	456.089
6/16/2003	1:16:24	453.818	456.088
6/16/2003	2:16:24	453.951	456.061
6/16/2003	3:16:24	446.763	456.063
6/16/2003	4:16:24	445.901	456.061
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6/16/2003	6:16:24	445.323	456.063
6/16/2003	7:16:24	445.198	456.058
6/16/2003	8:16:24	444.981	456.061
6/16/2003	9:16:24	444.878	456.058
6/16/2003	10:16:24	444.771	456.041
6/16/2003	11:16:24	444.707	456.057
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6/16/2003	14:16:24	453.405	456.035
6/16/2003	15:16:24	453.596	456.036
6/16/2003	16:16:24	453.778	456.058
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6/16/2003	21:16:24	445.224	456.074
6/16/2003	22:16:24	445.038	456.078
6/16/2003	23:16:24	445.005	456.085
6/17/2003	0:16:24	444.841	456.071
6/17/2003	1:16:24	444.722	456.052
6/17/2003	2:16:24	452.532	456.072
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6/17/2003	4:16:24	453.401	456.061
6/17/2003	5:16:24	453.635	456.065

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6/17/2003	13:16:24	453.301	456.041
6/17/2003	14:16:24	445.458	456.048
6/17/2003	15:16:24	444.765	456.055
6/17/2003	16:16:24	444.374	456.064
6/17/2003	17:16:24	444.369	456.059
6/17/2003	18:16:24	444.173	456.073
6/17/2003	19:16:24	444.147	456.077
6/17/2003	20:16:24	452.247	456.097
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6/17/2003	22:16:24	453.2	456.09
6/17/2003	23:16:24	453.43	456.09
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6/18/2003	3:16:24	445.442	456.072
6/18/2003	4:16:24	444.897	456.077
6/18/2003	5:16:24	444.626	456.076
6/18/2003	6:16:24	444.387	456.067
6/18/2003	7:16:24	444.387	456.077
6/18/2003	8:16:24	444.262	456.072
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6/18/2003	10:16:24	444.154	456.064
6/18/2003	11:16:24	452.466	456.066
6/18/2003	12:16:24	452.936	456.056
6/18/2003	13:16:24	453.247	456.057
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6/18/2003	15:16:24	453.664	456.074
6/18/2003	16:16:24	453.814	456.074
6/18/2003	17:16:24	445.735	456.085
6/18/2003	18:16:24	445.199	456.099
6/18/2003	19:16:24	444.853	456.103
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6/18/2003	21:16:24	444.546	456.116
6/18/2003	22:16:24	444.434	456.114
6/18/2003	23:16:24	444.433	456.123
6/19/2003	0:16:24	443.829	456.089
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6/19/2003	2:16:24	452.803	456.103
6/19/2003	3:16:24	453.156	456.106
6/19/2003	4:16:24	453.378	456.088
6/19/2003	5:16:24	453.583	456.093
6/19/2003	6:16:24	453.716	456.096
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6/19/2003	8:16:24	445.278	456.078
6/21/2003	11:16:24	452.067	456.057

date	time	well 31 head meters AMSL	vetex
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6/19/2003	11:16:24	444.51	456.08
6/19/2003	12:16:24	444.37	456.08
6/19/2003	13:16:24	444.321	456.061
6/19/2003	14:16:24	444.377	456.087
6/19/2003	15:16:24	444.382	456.082
6/19/2003	16:16:24	452.496	456.076
6/19/2003	17:16:24	453.073	456.093
6/19/2003	18:16:24	453.366	456.086
6/19/2003	19:16:24	453.6	456.1
6/19/2003	20:16:24	453.787	456.107
6/19/2003	21:16:24	453.916	456.116
6/19/2003	22:16:24	446.513	456.103
6/19/2003	23:16:24	445.73	456.1
6/20/2003	0:16:24	445.372	456.112
6/20/2003	1:16:24	445.11	456.11
6/20/2003	2:16:24	445.01	456.11
6/20/2003	3:16:24	444.967	456.097
6/20/2003	4:16:24	444.407	456.097
6/20/2003	5:16:24	444.299	456.109
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6/20/2003	8:16:24	453.116	456.096
6/20/2003	9:16:24	453.389	456.079
6/20/2003	10:16:24	453.583	456.083
6/20/2003	11:16:24	453.764	456.074
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6/20/2003	13:16:24	445.421	456.091
6/20/2003	14:16:24	445.187	456.077
6/20/2003	15:16:24	444.755	456.085
6/20/2003	16:16:24	444.677	456.087
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6/20/2003	18:16:24	444.521	456.101
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6/20/2003	21:16:24	452.808	456.108
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6/20/2003	23:16:24	453.44	456.09
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6/21/2003	1:16:24	453.792	456.102
6/21/2003	2:16:24	447.37	456.09
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6/21/2003	4:16:24	445.305	456.085
6/21/2003	5:16:24	445.145	456.095
6/21/2003	6:16:24	444.983	456.093
6/21/2003	7:16:24	444.861	456.091
6/21/2003	8:16:24	444.77	456.08
6/21/2003	9:16:24	444.545	456.065
6/21/2003	10:16:24	444.538	456.068
6/23/2003	13:16:24	446.068	456.088

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6/21/2003	14:16:24	453.461	456.061	6/23/2003	16:16:24	445.102	456.112
6/21/2003	15:16:24	453.646	456.066	6/23/2003	17:16:24	445.028	456.118
6/21/2003	16:16:24	453.817	456.077	6/23/2003	18:16:24	444.932	456.122
6/21/2003	17:16:24	447.413	456.083	6/23/2003	19:16:24	444.843	456.133
6/21/2003	18:16:24	445.85	456.09	6/23/2003	20:16:24	452.304	456.134
6/21/2003	19:16:24	445.355	456.095	6/23/2003	21:16:24	453.023	456.133
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6/21/2003	23:16:24	444.766	456.096	6/24/2003	1:16:24	453.937	456.127
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6/22/2003	3:16:24	453.225	456.085	6/24/2003	5:16:24	445.329	456.099
6/22/2003	4:16:24	453.5	456.09	6/24/2003	6:16:24	445.099	456.089
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6/22/2003	6:16:24	453.833	456.083	6/24/2003	8:16:24	444.844	456.074
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6/22/2003	11:16:24	445.253	456.053	6/24/2003	13:16:24	453.114	456.024
6/22/2003	12:16:24	445.096	456.056	6/24/2003	14:16:24	453.379	456.039
6/22/2003	13:16:24	444.937	456.067	6/24/2003	15:16:24	453.576	456.036
6/22/2003	14:16:24	444.78	456.07	6/24/2003	16:16:24	453.73	456.02
6/22/2003	15:16:24	444.773	456.073	6/24/2003	17:16:24	453.919	456.039
6/22/2003	16:16:24	452.166	456.096	6/24/2003	18:16:24	446.23	456.03
6/22/2003	17:16:24	452.934	456.094	6/24/2003	19:16:24	445.421	456.031
6/22/2003	18:16:24	453.32	456.1	6/24/2003	20:16:24	445.111	456.031
6/22/2003	19:16:24	453.553	456.113	6/24/2003	21:16:24	445.029	456.039
6/22/2003	20:16:24	453.758	456.118	6/24/2003	22:16:24	444.924	456.024
6/22/2003	21:16:24	453.917	456.117	6/24/2003	23:16:24	444.829	456.029
6/22/2003	22:16:24	454.061	456.121	6/25/2003	0:16:24	444.711	456.031
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6/23/2003	1:16:24	445.365	456.105	6/25/2003	3:16:24	453.047	456.007
6/23/2003	2:16:24	445.233	456.103	6/25/2003	4:16:24	453.334	456.004
6/23/2003	3:16:24	445.174	456.104	6/25/2003	5:16:24	453.634	456.004
6/23/2003	4:16:24	444.823	456.103	6/25/2003	6:16:24	453.807	455.997
6/23/2003	5:16:24	444.761	456.111	6/25/2003	7:16:24	453.961	456.001
6/23/2003	6:16:24	444.789	456.099	6/25/2003	8:16:24	446.35	455.99
6/23/2003	7:16:24	452.677	456.097	6/25/2003	9:16:24	445.651	456.001
6/23/2003	8:16:24	453.164	456.094	6/25/2003	10:16:24	445.425	455.995
6/23/2003	9:16:24	453.439	456.089	6/25/2003	11:16:24	445.209	455.979
6/23/2003	10:16:24	453.649	456.089	6/25/2003	12:16:24	445.072	455.992
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6/25/2003	16:16:24	451.175	456.005	6/27/2003	18:16:24	445.872	456.062
6/25/2003	17:16:24	452.602	456.012	6/27/2003	19:16:24	445.301	456.081

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6/25/2003	22:16:24	453.82	456.03
6/25/2003	23:16:24	445.878	456.028
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6/26/2003	1:16:24	445.002	456.022
6/26/2003	2:16:24	444.937	456.007
6/26/2003	3:16:24	444.826	456.006
6/26/2003	4:16:24	444.705	456.005
6/26/2003	5:16:24	444.613	456.013
6/26/2003	6:16:24	444.493	456.003
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6/26/2003	14:16:24	445.23	456.01
6/26/2003	15:16:24	445.022	456.012
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6/26/2003	19:16:24	444.533	456.043
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6/26/2003	23:16:24	453.317	456.057
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6/27/2003	7:16:24	444.376	456.056
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6/27/2003	10:16:24	444.243	456.033
6/27/2003	11:16:24	444.172	456.032
6/27/2003	12:16:24	452.327	456.037
6/27/2003	13:16:24	452.816	456.036
6/27/2003	14:16:24	453.132	456.032
6/27/2003	15:16:24	453.365	456.055
6/27/2003	16:16:24	453.533	456.053
6/29/2003	19:16:24	444.393	456.063
6/29/2003	20:16:24	444.462	456.062
6/29/2003	21:16:24	451.91	456.08
6/29/2003	22:16:24	452.693	456.063
6/29/2003	23:16:24	453.068	456.058

date	time	well 31 head meters AMSL	vetex
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6/27/2003	22:16:24	444.766	456.096
6/27/2003	23:16:24	444.693	456.093
6/28/2003	0:16:24	444.69	456.09
6/28/2003	1:16:24	444.565	456.055
6/28/2003	2:16:24	452.334	456.074
6/28/2003	3:16:24	452.904	456.074
6/28/2003	4:16:24	453.242	456.072
6/28/2003	5:16:24	453.459	456.069
6/28/2003	6:16:24	453.623	456.073
6/28/2003	7:16:24	453.776	456.076
6/28/2003	8:16:24	446.054	456.064
6/28/2003	9:16:24	445.367	456.057
6/28/2003	10:16:24	445.095	456.055
6/28/2003	11:16:24	444.924	456.054
6/28/2003	12:16:24	444.731	456.051
6/28/2003	13:16:24	444.665	456.055
6/28/2003	14:16:24	444.615	456.055
6/28/2003	15:16:24	444.49	456.07
6/28/2003	16:16:24	444.425	456.025
6/28/2003	17:16:24	452.266	456.056
6/28/2003	18:16:24	452.94	456.06
6/28/2003	19:16:24	453.255	456.065
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6/28/2003	22:16:24	453.834	456.084
6/28/2003	23:16:24	446.354	456.084
6/29/2003	0:16:24	445.482	456.092
6/29/2003	1:16:24	445.095	456.065
6/29/2003	2:16:24	444.902	456.082
6/29/2003	3:16:24	444.779	456.069
6/29/2003	4:16:24	444.533	456.063
6/29/2003	5:16:24	444.511	456.081
6/29/2003	6:16:24	444.358	456.068
6/29/2003	7:16:24	451.113	456.053
6/29/2003	8:16:24	452.585	456.045
6/29/2003	9:16:24	453.011	456.041
6/29/2003	10:16:24	453.266	456.046
6/29/2003	11:16:24	453.461	456.041
6/29/2003	12:16:24	453.64	456.03
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6/29/2003	15:16:24	444.984	456.034
6/29/2003	16:16:24	444.864	456.044
6/29/2003	17:16:24	444.72	456.05
6/29/2003	18:16:24	444.605	456.055
7/1/2003	21:16:24	453.366	456.056
7/1/2003	22:16:24	453.535	456.055
7/1/2003	23:16:24	453.689	456.059
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7/2/2003	1:16:24	445.368	456.048

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6/30/2003	3:16:24	447.292	456.052
6/30/2003	4:16:24	445.541	456.051
6/30/2003	5:16:24	445.118	456.038
6/30/2003	6:16:24	444.673	456.033
6/30/2003	7:16:24	444.48	456.03
6/30/2003	8:16:24	444.397	456.037
6/30/2003	9:16:24	444.249	456.029
6/30/2003	10:16:24	443.987	456.017
6/30/2003	11:16:24	443.921	456.011
6/30/2003	12:16:24	450.819	456.019
6/30/2003	13:16:24	452.382	456.022
6/30/2003	14:16:24	452.823	456.023
6/30/2003	15:16:24	453.122	456.042
6/30/2003	16:16:24	453.329	456.029
6/30/2003	17:16:24	453.526	456.056
6/30/2003	18:16:24	453.653	456.053
6/30/2003	19:16:24	445.452	456.052
6/30/2003	20:16:24	444.996	456.066
6/30/2003	21:16:24	444.724	456.064
6/30/2003	22:16:24	444.634	456.054
6/30/2003	23:16:24	444.425	456.065
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7/1/2003	4:16:24	452.783	456.043
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7/1/2003	6:16:24	453.34	456.04
7/1/2003	7:16:24	453.516	456.026
7/1/2003	8:16:24	453.676	456.046
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7/1/2003	12:16:24	444.604	456.024
7/1/2003	13:16:24	444.45	456.03
7/1/2003	14:16:24	444.371	456.021
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7/1/2003	16:16:24	444.166	456.036
7/1/2003	17:16:24	444.121	456.021
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7/1/2003	19:16:24	452.756	456.046
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7/4/2003	2:16:24	444.079	456.049
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7/4/2003	4:16:24	452.114	456.044
7/4/2003	5:16:24	452.7	456.04

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7/2/2003	5:16:24	444.459	456.039
7/2/2003	6:16:24	444.446	456.046
7/2/2003	7:16:24	444.263	456.033
7/2/2003	8:16:24	450.997	456.037
7/2/2003	9:16:24	452.532	456.032
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7/2/2003	13:16:24	453.61	456.03
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7/2/2003	15:16:24	445.166	456.026
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7/2/2003	23:16:24	452.787	456.057
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7/3/2003	12:16:24	444.125	456.025
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7/3/2003	16:16:24	453.163	456.043
7/3/2003	17:16:24	453.378	456.038
7/3/2003	18:16:24	453.559	456.049
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7/3/2003	22:16:24	444.852	456.072
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7/6/2003	2:16:24	453.549	456.079
7/6/2003	3:16:24	453.705	456.075
7/6/2003	4:16:24	453.846	456.066
7/6/2003	5:16:24	445.754	456.074
7/6/2003	6:16:24	445.19	456.07
7/6/2003	7:16:24	444.856	456.076

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7/4/2003	10:16:24	445.814	456.044
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7/4/2003	13:16:24	444.383	456.023
7/4/2003	14:16:24	444.296	456.036
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7/4/2003	17:16:24	444.278	456.048
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7/6/2003	0:16:24	453.076	456.086
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7/6/2003	18:16:24	453.7	456.07
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7/6/2003	20:16:24	445.981	456.091
7/6/2003	21:16:24	445.181	456.081
7/6/2003	22:16:24	444.967	456.087
7/6/2003	23:16:24	444.625	456.095
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7/7/2003	3:16:24	444.361	456.071
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7/7/2003	6:16:24	453.046	456.066
7/7/2003	7:16:24	453.323	456.073
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7/7/2003	14:16:24	444.617	456.037
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7/7/2003	18:16:24	444.273	456.043
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7/7/2003	20:16:24	452.885	456.075
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7/7/2003	22:16:24	453.488	456.078
7/7/2003	23:16:24	453.691	456.071
7/8/2003	0:16:24	453.837	456.077
7/8/2003	1:16:24	447.478	456.068
7/8/2003	2:16:24	445.637	456.067
7/10/2003	5:16:24	444.354	456.044
7/10/2003	6:16:24	444.117	456.027
7/10/2003	7:16:24	452.494	456.024
7/10/2003	8:16:24	452.969	456.029
7/10/2003	9:16:24	453.259	456.029
7/10/2003	10:16:24	453.485	456.025
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7/10/2003	12:16:24	447.514	456.024
7/10/2003	13:16:24	445.733	456.013

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7/8/2003	22:16:24	444.725	456.055
7/8/2003	23:16:24	444.518	456.058
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7/9/2003	8:16:24	445.298	456.018
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7/9/2003	10:16:24	444.703	456.013
7/9/2003	11:16:24	444.125	456.015
7/9/2003	12:16:24	444.066	456.016
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7/9/2003	14:16:24	444.004	456.024
7/9/2003	15:16:24	443.956	456.016
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7/9/2003	17:16:24	452.892	456.022
7/9/2003	18:16:24	453.231	456.051
7/9/2003	19:16:24	453.465	456.035
7/9/2003	20:16:24	453.691	456.041
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7/10/2003	2:16:24	444.914	456.054
7/10/2003	3:16:24	444.828	456.048
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7/12/2003	11:16:24	445.377	455.997
7/12/2003	12:16:24	445.338	456.008
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7/12/2003	14:16:24	445.083	456.003
7/12/2003	15:16:24	444.962	456.012
7/12/2003	16:16:24	444.978	456.028
7/12/2003	17:16:24	444.945	456.035

date	time	well 31 head meters AMSL	vetex
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7/11/2003	0:16:24	453.413	456.053
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7/11/2003	4:16:24	445.629	456.029
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7/14/2003	13:16:24	445.046	456.016
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7/14/2003	15:16:24	452.973	456.023
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7/14/2003	17:16:24	453.571	456.041
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7/14/2003	19:16:24	453.918	456.048

date	time	well 31 head meters AMSL	vetex	date	time	well 31 head meters AMSL	vetex
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7/12/2003	21:16:24	453.848	456.068	7/14/2003	23:16:24	445.848	456.058
7/12/2003	22:16:24	453.996	456.066	7/15/2003	0:16:24	445.682	456.052
7/12/2003	23:16:24	454.179	456.069	7/15/2003	1:16:24	445.58	456.05
7/13/2003	0:16:24	446.651	456.051	7/15/2003	2:16:24	445.389	456.049
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7/13/2003	3:16:24	445.464	456.044	7/15/2003	5:16:24	452.292	456.042
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7/13/2003	5:16:24	445.243	456.053	7/15/2003	7:16:24	453.393	456.043
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7/13/2003	7:16:24	445.046	456.026	7/15/2003	9:16:24	453.815	456.025
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7/14/2003	6:16:24	446.107	456.037	7/16/2003	8:16:24	444.895	456.025
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7/16/2003	15:16:24	453.886	456.016	7/18/2003	17:16:24	445.906	456.026
7/16/2003	16:16:24	447.973	456.023	7/18/2003	18:16:24	445.823	456.033
7/16/2003	17:16:24	446.376	456.036	7/18/2003	19:16:24	445.821	456.031
7/16/2003	18:16:24	446.029	456.039	7/18/2003	20:16:24	445.821	456.051
7/16/2003	19:16:24	445.834	456.014	7/18/2003	21:16:24	451.695	456.055
7/16/2003	20:16:24	445.738	456.028	7/18/2003	22:16:24	453.111	456.041
7/16/2003	21:16:24	445.585	456.035	7/18/2003	23:16:24	453.475	456.025
7/16/2003	22:16:24	445.55	456.04	7/19/2003	0:16:24	453.699	455.999
7/16/2003	23:16:24	445.287	456.037	7/19/2003	1:16:24	453.879	456.009

date	time	well 31 head meters AMSL	vetex
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7/17/2003	3:16:24	453.508	456.018
7/17/2003	4:16:24	453.704	456.014
7/17/2003	5:16:24	453.878	456.008
7/17/2003	6:16:24	454.006	456.016
7/17/2003	7:16:24	446.778	455.998
7/17/2003	8:16:24	446.282	456.002
7/17/2003	9:16:24	446.02	456
7/17/2003	10:16:24	445.725	456.005
7/17/2003	11:16:24	445.468	455.998
7/17/2003	12:16:24	445.495	456.005
7/17/2003	13:16:24	445.401	456.011
7/17/2003	14:16:24	445.404	456.004
7/17/2003	15:16:24	445.484	455.994
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7/17/2003	19:16:24	453.783	456.043
7/17/2003	20:16:24	453.963	456.053
7/17/2003	21:16:24	454.119	456.039
7/17/2003	22:16:24	448.335	456.045
7/17/2003	23:16:24	446.734	456.044
7/18/2003	0:16:24	446.49	456.04
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7/18/2003	3:16:24	445.796	456.016
7/18/2003	4:16:24	445.814	456.024
7/18/2003	5:16:24	445.644	456.024
7/18/2003	6:16:24	445.556	456.026
7/18/2003	7:16:24	452.452	456.022
7/18/2003	8:16:24	453.168	455.998
7/18/2003	9:16:24	453.504	456.014
7/18/2003	10:16:24	453.714	456.004
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7/18/2003	12:16:24	454.041	456.011
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7/20/2003	20:16:24	453.518	456.048
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7/20/2003	23:16:24	454.132	456.052
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7/21/2003	5:16:24	446.197	456.017

date	time	well 31 head meters AMSL	vetex
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7/19/2003	5:16:24	446.33	456.01
7/19/2003	6:16:24	446.157	455.997
7/19/2003	7:16:24	446.098	455.998
7/19/2003	8:16:24	445.821	455.981
7/19/2003	9:16:24	445.714	455.994
7/19/2003	10:16:24	445.592	455.972
7/19/2003	11:16:24	445.668	455.988
7/19/2003	12:16:24	445.522	455.952
7/19/2003	13:16:24	452.725	455.985
7/19/2003	14:16:24	453.295	455.985
7/19/2003	15:16:24	453.578	455.988
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7/19/2003	17:16:24	453.979	455.999
7/19/2003	18:16:24	454.151	456.021
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7/19/2003	21:16:24	446.255	456.035
7/19/2003	22:16:24	445.834	456.044
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7/20/2003	7:16:24	453.798	456.008
7/20/2003	8:16:24	453.944	456.004
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7/20/2003	10:16:24	446.96	456
7/20/2003	11:16:24	446.546	455.986
7/20/2003	12:16:24	446.283	456.003
7/20/2003	13:16:24	446.066	455.996
7/20/2003	14:16:24	445.793	456.003
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7/22/2003	18:16:24	453.912	456.042
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7/22/2003	20:16:24	454.254	456.054
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7/22/2003	22:16:24	447.769	456.049
7/22/2003	23:16:24	447.451	456.031
7/23/2003	0:16:24	447.1	456.03
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7/23/2003	2:16:24	446.947	456.017
7/23/2003	3:16:24	446.832	456.012
7/23/2003	4:16:24	446.819	456.009
7/23/2003	5:16:24	446.754	456.004
7/23/2003	6:16:24	452.863	456.013
7/23/2003	7:16:24	453.51	456

date	time	well 31 head meters AMSL	vetex
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7/21/2003	9:16:24	445.32	456
7/21/2003	10:16:24	452.767	455.997
7/21/2003	11:16:24	453.225	456.005
7/21/2003	12:16:24	453.499	456.009
7/21/2003	13:16:24	453.685	456.005
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7/21/2003	15:16:24	453.996	456.006
7/21/2003	16:16:24	446.926	456.016
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7/21/2003	18:16:24	446.391	456.051
7/21/2003	19:16:24	446.283	456.053
7/21/2003	20:16:24	446.213	456.073
7/21/2003	21:16:24	445.934	456.064
7/21/2003	22:16:24	445.932	456.052
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7/22/2003	2:16:24	453.663	456.023
7/22/2003	3:16:24	453.88	456.03
7/22/2003	4:16:24	454.044	456.034
7/22/2003	5:16:24	454.165	456.035
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7/22/2003	7:16:24	447.046	456.026
7/22/2003	8:16:24	446.83	456.02
7/22/2003	9:16:24	446.66	456.01
7/22/2003	10:16:24	446.54	456.01
7/22/2003	11:16:24	446.487	455.997
7/22/2003	12:16:24	446.418	456.008
7/22/2003	13:16:24	446.38	456.01
7/22/2003	14:16:24	446.3	456.01
7/22/2003	15:16:24	452.716	456.016
7/22/2003	16:16:24	453.383	456.023
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7/24/2003	20:16:24	448.053	456.043
7/24/2003	21:16:24	447.9	456.05
7/24/2003	22:16:24	447.781	456.041
7/24/2003	23:16:24	447.609	456.039
7/25/2003	0:16:24	447.554	456.034
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7/25/2003	2:16:24	447.448	455.998
7/25/2003	3:16:24	453.356	456.026
7/25/2003	4:16:24	453.817	456.027
7/25/2003	5:16:24	454.098	456.038
7/25/2003	6:16:24	454.296	456.016
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7/25/2003	8:16:24	454.629	456.019
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7/25/2003	10:16:24	448.471	456.021
7/25/2003	11:16:24	448.281	456.011

date	time	well 31 head meters AMSL	vetex
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7/23/2003	11:16:24	454.306	455.996
7/23/2003	12:16:24	448.348	455.988
7/23/2003	13:16:24	447.779	455.989
7/23/2003	14:16:24	447.581	455.991
7/23/2003	15:16:24	447.322	456.002
7/23/2003	16:16:24	447.241	456.021
7/23/2003	17:16:24	447.122	456.022
7/23/2003	18:16:24	447.1	456.02
7/23/2003	19:16:24	446.997	456.037
7/23/2003	20:16:24	447.004	456.044
7/23/2003	21:16:24	453.395	456.035
7/23/2003	22:16:24	453.814	456.044
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7/24/2003	3:16:24	448.323	456.023
7/24/2003	4:16:24	447.957	456.027
7/24/2003	5:16:24	447.844	456.024
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7/24/2003	7:16:24	447.552	456.022
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7/24/2003	9:16:24	447.383	456.013
7/24/2003	10:16:24	447.256	456.016
7/24/2003	11:16:24	447.098	456.008
7/24/2003	12:16:24	452.951	456.011
7/24/2003	13:16:24	453.59	456.02
7/24/2003	14:16:24	453.906	456.036
7/24/2003	15:16:24	454.102	456.032
7/24/2003	16:16:24	454.28	456.02
7/24/2003	17:16:24	454.395	456.025
7/24/2003	18:16:24	449.65	456.02
7/26/2003	21:16:24	447.704	456.024
7/26/2003	22:16:24	447.61	456.02
7/26/2003	23:16:24	447.504	456.034
7/27/2003	0:16:24	447.288	456.018
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7/27/2003	2:16:24	453.828	456.018
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7/27/2003	5:16:24	454.376	456.016
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7/27/2003	7:16:24	448.595	456.015
7/27/2003	8:16:24	448.235	456.005
7/27/2003	9:16:24	448.001	456.001
7/27/2003	10:16:24	447.947	455.997
7/27/2003	11:16:24	447.702	455.992
7/27/2003	12:16:24	447.67	456
7/27/2003	13:16:24	447.617	455.997

date	time	well 31 head meters AMSL	vetex
7/25/2003	12:16:24	448.097	456.007
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7/25/2003	14:16:24	447.878	456.008
7/25/2003	15:16:24	447.776	456.016
7/25/2003	16:16:24	447.717	456.017
7/25/2003	17:16:24	447.699	455.999
7/25/2003	18:16:24	452.463	456.013
7/25/2003	19:16:24	453.747	456.007
7/25/2003	20:16:24	454.016	455.996
7/25/2003	21:16:24	454.248	456.018
7/25/2003	22:16:24	454.398	456.008
7/25/2003	23:16:24	454.511	456.021
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7/26/2003	6:16:24	447.698	455.998
7/26/2003	7:16:24	447.586	455.996
7/26/2003	8:16:24	447.563	455.993
7/26/2003	9:16:24	447.492	455.982
7/26/2003	10:16:24	453.072	455.982
7/26/2003	11:16:24	453.652	456.002
7/26/2003	12:16:24	453.922	455.982
7/26/2003	13:16:24	454.108	455.978
7/26/2003	14:16:24	454.266	455.986
7/26/2003	15:16:24	454.433	455.983
7/26/2003	16:16:24	449.659	455.999
7/26/2003	17:16:24	448.354	456.004
7/26/2003	18:16:24	448.015	456.005
7/26/2003	19:16:24	447.872	456.012
7/26/2003	20:16:24	447.719	456.029
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7/29/2003	0:16:24	453.755	456.025
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7/29/2003	3:16:24	454.259	456.019
7/29/2003	4:16:24	447.999	456.009
7/29/2003	5:16:24	447.268	456.018
7/29/2003	6:16:24	446.874	456.004
7/29/2003	7:16:24	446.72	456
7/29/2003	8:16:24	446.624	456.004
7/29/2003	9:16:24	446.571	455.991
7/29/2003	10:16:24	446.533	455.983
7/29/2003	11:16:24	446.409	455.999
7/29/2003	12:16:24	446.389	455.989
7/29/2003	13:16:24	452.735	455.995
7/29/2003	14:16:24	453.408	455.988
7/29/2003	15:16:24	453.723	456.003
7/29/2003	16:16:24	453.925	456.005
7/29/2003	17:16:24	454.133	456.023

date	time	well 31 head meters AMSL	vetex
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7/27/2003	16:16:24	453.068	456.018
7/27/2003	17:16:24	453.699	456.029
7/27/2003	18:16:24	453.974	456.034
7/27/2003	19:16:24	454.192	456.042
7/27/2003	20:16:24	454.364	456.034
7/27/2003	21:16:24	454.498	456.048
7/27/2003	22:16:24	454.597	456.047
7/27/2003	23:16:24	448.545	456.045
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7/28/2003	1:16:24	446.802	456.022
7/28/2003	2:16:24	446.594	456.024
7/28/2003	3:16:24	446.48	456.03
7/28/2003	4:16:24	446.379	456.019
7/28/2003	5:16:24	446.298	456.018
7/28/2003	6:16:24	446.278	456.018
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7/28/2003	8:16:24	453.266	456.016
7/28/2003	9:16:24	453.622	456.022
7/28/2003	10:16:24	453.904	456.004
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7/28/2003	15:16:24	446.887	456.007
7/28/2003	16:16:24	446.692	456.022
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7/28/2003	18:16:24	446.473	456.033
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7/28/2003	20:16:24	446.407	456.047
7/28/2003	21:16:24	446.283	456.053
7/28/2003	22:16:24	453.094	456.064
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7/31/2003	2:16:24	447.557	455.997
7/31/2003	3:16:24	447.303	455.993
7/31/2003	4:16:24	447.077	455.987
7/31/2003	5:16:24	447.013	455.993
7/31/2003	6:16:24	446.919	455.999
7/31/2003	7:16:24	446.815	455.995
7/31/2003	8:16:24	446.763	455.983
7/31/2003	9:16:24	446.641	455.971
7/31/2003	10:16:24	452.034	455.974
7/31/2003	11:16:24	453.38	455.97
7/31/2003	12:16:24	453.708	455.968
7/31/2003	13:16:24	453.961	455.981
7/31/2003	14:16:24	454.153	455.983
7/31/2003	15:16:24	454.301	455.981
7/31/2003	16:16:24	454.413	456.003
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date	time	well 31 head meters AMSL	vetex
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7/29/2003	22:16:24	446.974	456.034
7/29/2003	23:16:24	446.853	456.053
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7/30/2003	1:16:24	446.684	456.024
7/30/2003	2:16:24	446.62	456.03
7/30/2003	3:16:24	446.602	456.032
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7/30/2003	6:16:24	453.713	456.003
7/30/2003	7:16:24	453.945	456.015
7/30/2003	8:16:24	454.106	456.006
7/30/2003	9:16:24	454.24	456
7/30/2003	10:16:24	448.076	456.006
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7/30/2003	15:16:24	446.541	456.001
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7/30/2003	23:16:24	454.108	456.018
7/31/2003	0:16:24	454.255	456.005
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8/2/2003	5:16:24	446.823	456.003
8/2/2003	6:16:24	446.708	456.008
8/2/2003	7:16:24	446.706	455.996
8/2/2003	8:16:24	446.579	455.969
8/2/2003	9:16:24	453.001	455.991
8/2/2003	10:16:24	453.472	455.982
8/2/2003	11:16:24	453.744	455.994
8/2/2003	12:16:24	453.963	455.983
8/2/2003	13:16:24	454.123	455.983
8/2/2003	14:16:24	454.281	455.991
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8/2/2003	18:16:24	447.048	456.018
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8/2/2003	21:16:24	446.733	456.023
8/2/2003	22:16:24	446.654	456.024
8/2/2003	23:16:24	452.848	456.038
7/31/2003	20:16:24	447.202	456.012
7/31/2003	21:16:24	447.049	456.029
7/31/2003	22:16:24	446.992	456.022
7/31/2003	23:16:24	447.025	456.015
8/1/2003	0:16:24	446.898	456.018
8/1/2003	1:16:24	452.056	456.006
8/1/2003	2:16:24	453.419	456.019
8/1/2003	3:16:24	453.746	456.016
8/1/2003	4:16:24	453.958	456.008
8/1/2003	5:16:24	454.143	456.013
8/1/2003	6:16:24	454.284	456.014
8/1/2003	7:16:24	454.401	456.001
8/1/2003	8:16:24	447.901	456.011
8/1/2003	9:16:24	447.551	456.011
8/1/2003	10:16:24	447.274	456.014
8/1/2003	11:16:24	447.248	455.998
8/1/2003	12:16:24	447.135	455.995
8/1/2003	13:16:24	447.083	456.003
8/1/2003	14:16:24	446.819	455.999
8/1/2003	15:16:24	446.712	455.982
8/1/2003	16:16:24	446.696	456.006
8/1/2003	17:16:24	451.901	456.001
8/1/2003	18:16:24	453.327	455.997
8/1/2003	19:16:24	453.694	456.014
8/1/2003	20:16:24	453.887	456.007
8/1/2003	21:16:24	454.077	456.017
8/1/2003	22:16:24	454.211	456.001
8/1/2003	23:16:24	454.346	455.986
8/2/2003	0:16:24	448.011	455.991
8/2/2003	1:16:24	447.46	456
8/2/2003	2:16:24	447.194	455.994
8/4/2003	5:16:24	446.848	455.998
8/4/2003	6:16:24	453.097	456.017
8/4/2003	7:16:24	453.579	456.009
8/4/2003	8:16:24	453.842	456.002
8/4/2003	9:16:24	454.027	456.007
8/4/2003	10:16:24	454.214	456.014
8/4/2003	11:16:24	454.321	455.991
8/4/2003	12:16:24	448.02	456
8/4/2003	13:16:24	447.56	456
8/4/2003	14:16:24	447.323	455.993
8/4/2003	15:16:24	447.191	456.001
8/4/2003	16:16:24	447.124	456.004
8/4/2003	17:16:24	447.042	456.012
8/4/2003	18:16:24	447.013	456.023
8/4/2003	19:16:24	446.986	456.026
8/4/2003	20:16:24	452.024	456.024
8/4/2003	21:16:24	453.417	456.027
8/4/2003	22:16:24	453.754	456.034
8/4/2003	23:16:24	453.981	456.031
8/5/2003	0:16:24	454.162	456.032
8/5/2003	1:16:24	454.297	456.027

date	time	well 31 head meters AMSL	vetex	date	time	well 31 head meters AMSL	vetex
8/3/2003	0:16:24	453.472	456.032	8/5/2003	2:16:24	454.436	456.036
8/3/2003	1:16:24	453.777	456.027	8/5/2003	3:16:24	447.888	456.018
8/3/2003	2:16:24	453.977	456.017	8/5/2003	4:16:24	447.635	456.025
8/3/2003	3:16:24	454.145	456.005	8/5/2003	5:16:24	447.265	456.015
8/3/2003	4:16:24	454.289	456.029	8/5/2003	6:16:24	447.279	456.019
8/3/2003	5:16:24	449.229	456.009	8/5/2003	7:16:24	447.16	456.02
8/3/2003	6:16:24	447.594	456.014	8/5/2003	8:16:24	447.095	456.005
8/3/2003	7:16:24	447.373	456.013	8/5/2003	9:16:24	447.037	456.007
8/3/2003	8:16:24	447.158	456.008	8/5/2003	10:16:24	447	456
8/3/2003	9:16:24	447.041	455.991	8/5/2003	11:16:24	446.884	456.004
8/3/2003	10:16:24	446.917	455.997	8/5/2003	12:16:24	453.318	456.008
8/3/2003	11:16:24	446.816	455.996	8/5/2003	13:16:24	453.689	455.999
8/3/2003	12:16:24	446.814	456.004	8/5/2003	14:16:24	453.934	456.004
8/3/2003	13:16:24	446.744	456.004	8/5/2003	15:16:24	454.116	456.006
8/3/2003	14:16:24	446.736	455.996	8/5/2003	16:16:24	454.283	456.013
8/3/2003	15:16:24	453.294	456.004	8/5/2003	17:16:24	454.414	456.014
8/3/2003	16:16:24	453.694	456.014	8/5/2003	18:16:24	448.492	456.022
8/3/2003	17:16:24	453.938	456.008	8/5/2003	19:16:24	447.888	456.018
8/3/2003	18:16:24	454.159	456.019	8/5/2003	20:16:24	447.754	456.024
8/3/2003	19:16:24	454.34	456.03	8/5/2003	21:16:24	447.676	456.036
8/3/2003	20:16:24	454.46	456.04	8/5/2003	22:16:24	447.454	456.034
8/3/2003	21:16:24	448.535	456.045	8/5/2003	23:16:24	447.41	456.04
8/3/2003	22:16:24	447.692	456.032	8/6/2003	0:16:24	447.306	456.036
8/3/2003	23:16:24	447.418	456.038	8/6/2003	1:16:24	447.311	456.011
8/4/2003	0:16:24	447.291	456.021	8/6/2003	2:16:24	452.111	456.021
8/4/2003	1:16:24	447.227	456.037	8/6/2003	3:16:24	453.478	456.028
8/4/2003	2:16:24	447.087	456.037	8/6/2003	4:16:24	453.828	456.028
8/4/2003	3:16:24	447.016	456.026	8/6/2003	5:16:24	454.038	456.028
8/4/2003	4:16:24	446.942	456.032	8/6/2003	6:16:24	454.214	456.014
8/6/2003	7:16:24	454.351	456.011	8/8/2003	9:16:24	447.541	456.001
8/6/2003	8:16:24	454.459	456.019	8/8/2003	10:16:24	447.287	455.997
8/6/2003	9:16:24	448.288	456.008	8/8/2003	11:16:24	447.235	456.005
8/6/2003	10:16:24	447.832	456.002	8/8/2003	12:16:24	447.114	456.004
8/6/2003	11:16:24	447.669	455.999	8/8/2003	13:16:24	447.082	456.002
8/6/2003	12:16:24	447.576	455.996	8/8/2003	14:16:24	446.998	455.998
8/6/2003	13:16:24	447.538	455.998	8/8/2003	15:16:24	451.99	456.01
8/6/2003	14:16:24	447.413	456.003	8/8/2003	16:16:24	453.428	456.008
8/6/2003	15:16:24	447.37	456.01	8/8/2003	17:16:24	453.769	456.019
8/6/2003	16:16:24	447.261	456.011	8/8/2003	18:16:24	454.004	456.014
8/6/2003	17:16:24	447.255	456.005	8/8/2003	19:16:24	454.179	456.029
8/6/2003	18:16:24	453.375	456.035	8/8/2003	20:16:24	454.351	456.031
8/6/2003	19:16:24	453.749	456.029	8/8/2003	21:16:24	454.476	456.036
8/6/2003	20:16:24	454.003	456.023	8/8/2003	22:16:24	448.46	456.03
8/6/2003	21:16:24	454.191	456.031	8/8/2003	23:16:24	447.975	456.025
8/6/2003	22:16:24	454.35	456.04	8/9/2003	0:16:24	447.558	456.018
8/6/2003	23:16:24	454.474	456.034	8/9/2003	1:16:24	447.467	456.017
8/7/2003	0:16:24	448.878	456.038	8/9/2003	2:16:24	447.37	456.01
8/7/2003	1:16:24	448.135	456.025	8/9/2003	3:16:24	447.276	456.006
8/7/2003	2:16:24	447.891	456.031	8/9/2003	4:16:24	447.095	456.015
8/7/2003	3:16:24	447.648	456.018	8/9/2003	5:16:24	446.998	456.008
8/7/2003	4:16:24	447.487	456.027	8/9/2003	6:16:24	446.813	456.003
8/7/2003	5:16:24	447.39	456.02	8/9/2003	7:16:24	453.04	456.01

date	time	well 31 head meters AMSL	vetex
8/7/2003	6:16:24	447.385	456.015
8/7/2003	7:16:24	447.278	456.008
8/7/2003	8:16:24	447.257	455.997
8/7/2003	9:16:24	452.931	456.001
8/7/2003	10:16:24	453.578	455.998
8/7/2003	11:16:24	453.862	455.992
8/7/2003	12:16:24	454.108	455.998
8/7/2003	13:16:24	454.256	455.996
8/7/2003	14:16:24	454.394	455.994
8/7/2003	15:16:24	448.627	456.007
8/7/2003	16:16:24	447.965	456.005
8/7/2003	17:16:24	447.794	456.024
8/7/2003	18:16:24	447.506	456.026
8/7/2003	19:16:24	447.426	456.036
8/7/2003	20:16:24	447.485	456.035
8/7/2003	21:16:24	447.352	456.052
8/7/2003	22:16:24	447.289	456.039
8/7/2003	23:16:24	447.283	456.033
8/8/2003	0:16:24	453.4	456.03
8/8/2003	1:16:24	453.77	456.01
8/8/2003	2:16:24	454.009	456.019
8/8/2003	3:16:24	454.207	456.017
8/8/2003	4:16:24	454.337	456.017
8/8/2003	5:16:24	454.466	456.016
8/8/2003	6:16:24	448.22	456.01
8/8/2003	7:16:24	447.821	456.011
8/8/2003	8:16:24	447.623	456.003
8/10/2003	11:16:24	446.816	455.976
8/10/2003	12:16:24	446.775	455.975
8/10/2003	13:16:24	453.169	455.989
8/10/2003	14:16:24	453.573	455.973
8/10/2003	15:16:24	453.83	455.99
8/10/2003	16:16:24	454.002	456.002
8/10/2003	17:16:24	454.16	455.99
8/10/2003	18:16:24	454.279	456.009
8/10/2003	19:16:24	448.526	456.016
8/10/2003	20:16:24	447.775	456.025
8/10/2003	21:16:24	447.496	456.036
8/10/2003	22:16:24	447.369	456.049
8/10/2003	23:16:24	447.233	456.033
8/11/2003	0:16:24	447.01	456.03
8/11/2003	1:16:24	446.369	456.029
8/11/2003	2:16:24	446.376	456.026
8/11/2003	3:16:24	446.534	455.994
8/11/2003	4:16:24	453.078	456.018
8/11/2003	5:16:24	453.581	456.011
8/11/2003	6:16:24	453.839	456.009
8/11/2003	7:16:24	454.017	456.007
8/11/2003	8:16:24	454.173	456.013
8/11/2003	9:16:24	454.333	456.003
8/11/2003	10:16:24	448.339	455.999
8/11/2003	11:16:24	447.665	455.995

date	time	well 31 head meters AMSL	vetex
8/9/2003	8:16:24	453.565	456.005
8/9/2003	9:16:24	453.818	455.998
8/9/2003	10:16:24	454.015	455.985
8/9/2003	11:16:24	454.158	455.978
8/9/2003	12:16:24	454.29	455.98
8/9/2003	13:16:24	447.908	455.978
8/9/2003	14:16:24	447.553	455.983
8/9/2003	15:16:24	447.279	455.989
8/9/2003	16:16:24	447.171	456.001
8/9/2003	17:16:24	446.986	456.006
8/9/2003	18:16:24	446.844	456.014
8/9/2003	19:16:24	446.95	456.02
8/9/2003	20:16:24	446.832	456.022
8/9/2003	21:16:24	452.862	456.022
8/9/2003	22:16:24	453.521	456.021
8/9/2003	23:16:24	453.796	456.026
8/10/2003	0:16:24	454.012	456.022
8/10/2003	1:16:24	454.15	456.01
8/10/2003	2:16:24	454.368	456.018
8/10/2003	3:16:24	449.452	456.002
8/10/2003	4:16:24	447.904	455.994
8/10/2003	5:16:24	447.511	455.991
8/10/2003	6:16:24	447.217	455.997
8/10/2003	7:16:24	447.114	455.984
8/10/2003	8:16:24	447.069	455.989
8/10/2003	9:16:24	446.922	455.992
8/10/2003	10:16:24	446.778	455.978
8/12/2003	13:16:24	454.141	456.001
8/12/2003	14:16:24	454.291	456.011
8/12/2003	15:16:24	454.421	456.021
8/12/2003	16:16:24	448.276	456.016
8/12/2003	17:16:24	447.796	456.006
8/12/2003	18:16:24	447.509	456.019
8/12/2003	19:16:24	447.301	456.021
8/12/2003	20:16:24	447.34	456.02
8/12/2003	21:16:24	447.164	456.024
8/12/2003	22:16:24	447.094	456.034
8/12/2003	23:16:24	446.998	456.018
8/13/2003	0:16:24	447.229	456.019
8/13/2003	1:16:24	453.345	456.015
8/13/2003	2:16:24	453.756	456.016
8/13/2003	3:16:24	453.995	456.015
8/13/2003	4:16:24	454.174	456.014
8/13/2003	5:16:24	454.33	456.01
8/13/2003	6:16:24	454.448	456.008
8/13/2003	7:16:24	448.834	456.004
8/13/2003	8:16:24	448.035	455.995
8/13/2003	9:16:24	447.771	456.001
8/13/2003	10:16:24	447.577	455.987
8/13/2003	11:16:24	447.561	455.991
8/13/2003	12:16:24	447.22	455.99
8/13/2003	13:16:24	447.031	455.981

date	time	well 31 head meters AMSL	vetex
8/11/2003	12:16:24	447.486	455.996
8/11/2003	13:16:24	447.566	455.996
8/11/2003	14:16:24	447.315	455.985
8/11/2003	15:16:24	447.227	456.007
8/11/2003	16:16:24	447.125	456.015
8/11/2003	17:16:24	447.056	456.026
8/11/2003	18:16:24	446.946	456.036
8/11/2003	19:16:24	453.315	456.045
8/11/2003	20:16:24	453.702	456.042
8/11/2003	21:16:24	453.915	456.045
8/11/2003	22:16:24	454.116	456.056
8/11/2003	23:16:24	454.266	456.036
8/12/2003	0:16:24	454.383	456.043
8/12/2003	1:16:24	448.308	456.048
8/12/2003	2:16:24	447.898	456.038
8/12/2003	3:16:24	447.495	456.045
8/12/2003	4:16:24	447.474	456.024
8/12/2003	5:16:24	447.474	456.024
8/12/2003	6:16:24	447.285	456.025
8/12/2003	7:16:24	447.156	456.026
8/12/2003	8:16:24	447.246	456.026
8/12/2003	9:16:24	447.043	456.013
8/12/2003	10:16:24	453.378	456.008
8/12/2003	11:16:24	453.754	456.024
8/12/2003	12:16:24	453.992	456.002
8/14/2003	15:16:24	447.141	455.971

date	time	well 31 head meters AMSL	vetex
8/13/2003	14:16:24	447.091	455.991
8/13/2003	15:16:24	447.034	455.984
8/13/2003	16:16:24	452.161	456.001
8/13/2003	17:16:24	453.546	456.006
8/13/2003	18:16:24	453.874	456.004
8/13/2003	19:16:24	454.131	456.021
8/13/2003	20:16:24	454.268	456.018
8/13/2003	21:16:24	454.398	456.018
8/13/2003	22:16:24	454.52	456.03
8/13/2003	23:16:24	448.227	456.027
8/14/2003	0:16:24	447.917	456.017
8/14/2003	1:16:24	447.556	456.026
8/14/2003	2:16:24	447.41	456.01
8/14/2003	3:16:24	447.364	456.014
8/14/2003	4:16:24	447.144	456.014
8/14/2003	5:16:24	447.203	456.003
8/14/2003	6:16:24	447.111	456.001
8/14/2003	7:16:24	452.915	456.005
8/14/2003	8:16:24	453.568	455.998
8/14/2003	9:16:24	453.838	455.988
8/14/2003	10:16:24	454.063	455.983
8/14/2003	11:16:24	454.227	455.977
8/14/2003	12:16:24	454.365	455.975
8/14/2003	13:16:24	448.065	455.985
8/14/2003	14:16:24	447.429	455.969

Complete Vita

Sandra Warner

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Education

Masters of Science in Hydrogeosciences
Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.
Anticipated Graduation: December 2003; current GPA 3.97
ADVISOR:Dr. Thomas Burbey, 231-6696

Bachelor of Science in Geosciences, Minor GIS
Pennsylvania State University, University Park, PA 16802
May 2001 GPA: 3.70

Master's Thesis

"Using GPS and inSAR to Quantify Three Dimensional Storage and Aquifer Deformation in the Virgin River Valley, Nevada"

Project Goals:

1. Develop a field technique to use three dimensional strain measurements and head changes over time to determine the storage coefficient in order to improve aquifer management.
2. Characterize storage properties of an aquifer using one dimensional time subsidence data during an aquifer test.
3. Demonstrate how GPS receivers will be evaluated as a inexpensive yet important tool for measuring land subsidence.

Publications and Presentations

1. AGU Fall Annual Meeting, 2003. "Using GPS to Quantify Three Dimensional Storage and Aquifer Deformation in the Virgin River Valley, NV."

2. Geological Sciences Student Research Symposium 2003: "Quantifying Strain and Storage in Three Dimensions in an Unconsolidated Aquifer."

3. GSA Fall Annual Meeting 2002: Poster Presentation: "USING GPS TO QUANTIFY THREE DIMENSIONAL AQUIFER DEFORMATION AND STORAGE IN THE VIRGIN RIVER VALLEY, NEVADA"

4. Warner, S.M., Bradshaw, D.L., Spencer, C.S., 2002. "Protecting Your Raw Water Intake: A Hydrologic Contamination Transport Model Utilizing Source Water Assessment Data, GIS, and ArcView's Spatial Analyst." VA AWWA/VWEA Water JAM 2002.

5. Geological Sciences Student Research Symposium, 2002:“Evaluating the Effectiveness of inSAR and GPS methods to measure small scale vertical and horizontal deformation due to land subsidence in the Las Vegas Valley Aquifer.”

6. Undergraduate Thesis, 2001:“Using Dye Tracers to Delineate Flow Patterns through Two KarstBasins: Kooken Cave, Huntingdon County, PA and Tytoona Cave, Blair County, PA.”

Job Experience

1) GIS/Geology Technician
   Olver, Incorporated, Blacksburg VA
   Summer 2002, worked 20 hours a week helping with GIS databases and technical reports for the EPA. I helped make a model of surface runoff travel times in order to more effective source water protection and emergency planning incorporating slope, land use and stream data.
   SUPERVISOR: Mr. David Bradshaw (540)-552-5548

2) Teaching Assistant
   Virginia Polytechnic Institute, Blacksburg, VA
   Fall 2001-Spring 2003, worked 20 hours week teaching 3 sections of various introductory geology lab courses. I am in charge of instruction, evaluation, and planning for all students, usually around 28/section.
   SUPERVISOR: Dr. Thomas .J. Burbey (540)-231-6651)

3) Hydrology Department Student Intern
   MD Geological Survey, Baltimore, MD
   June 1999-Aug 1999, worked 40 hours a week as an intern on a research project on groundwater radium concentrations. My duties included searching out wells to test, testing wells, preparing lab samples, cleaning up experiments, data entry, and working with topography maps to spot the wells.
   SUPERVISOR: Mr. David Bolton, Hydrogeologist.(410) 554-5561

Technology Experience

ArcView, ArcInfo, Flash, Surfer, Adobe Illustrator & Photoshop, MS Word, MS Excel, html, Fortran 95.

Field Experience

Geologic mapping: Elk Basin Anticline, Wyoming; Challis Volcanics, Idaho; Alta Pluton and Overthrust Belt, Utah; Glacial Deposits, Rose Bud, Wyoming.

Sequence Stratigraphy: the Book Cliffs (Ferrum Delta), Price, Utah; Wallops Island, VA.

Hydrology: Dye traces near Huntington County, PA, currently working on measuring land subsidence using GPS and inSAR technology near the Las Vegas Valley, Nevada.

Activities & Honors

1) Graduate Student Liaison Committee Fall 2003
2) Geological Sciences Student Research Symposium (GSSRS) Organizational Committee 2001-2003
3) student member of the National Speleological Society, 1998-2002
4) Ronald Landon Honorarium Scholarship Recipient 2000