Kansas Geological Survey

THE SOUTHEAST KANSAS OZARK AQUIFER WATER SUPPLY PROGRAM

PHASE 2 PROJECT RESULTS

By

P. A. Macfarlane

Kansas Geological Survey Open File Report 2007-20

GEOHYDROLOGY

The University of Kansas, Lawrence, KS 66047 (785) 864-3965; www.kgs.ku.edu

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Geohydrology Section
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Executive Summary

Historically, the Ozark Plateaus aquifer system has been the single most important source of water in the Tri-State region of southeast Kansas, southwest Missouri, and northeastern Oklahoma. Recent concerns that the available supply from this source may become inadequate, rendered unusable, or require additional water treatment in the near future stem from: (1) recent and projected population growth that will create increased demand for water by public supplies and some industries; (2) potential upward vertical or eastward migration of saline water into public supply wells due to pumping, if pumping rates or wellfield size are increased to keep up with demand; and (3) possible contamination of ground-water supplies by downward moving leachate derived from mine tailings piles and the mine water contained in the abandoned open shafts. In response to these concerns the Kansas Water Office (KWO) contracted with the Kansas Geological Survey (KGS) to evaluate and redesign the existing ground-water-level monitoring network in southeast Kansas in Phase 1 of the project.

In Phase 2 of the project, the KWO contracted with the KGS to (1) site and construct new wells that would serve as dedicated monitoring wells to track water levels and quality in the Ozark Plateaus aquifer system into the future, (2) continue conducting semi-annual water-level surveys of wells in the monitoring network designed in Phase 1, and (3) provide support to the Ozark aquifer Water Issue Strategic Plan (WISP) group through participation in their meetings, and participation in the technical advisory board (TAC) formed in connection with the USGS project to develop a management model of the Ozark aquifer in the Tri-state region.

Contract specifications were developed and let for bid on (1) Ozark aquifer and a Springfield Plateau aquifer monitoring wells sited within the City of Pittsburg wellfield with the objective of conducting high-frequency water-level monitoring using pressure transducers and well tests to derive estimates of aquifer properties and (2) an Ozark aquifer well near McCune, Kansas, in southwest Crawford County to monitor water level and quality changes near the back edge of the water quality transition zone in the Ozark aquifer. The Ozark aquifer monitoring well in the Pittsburg wellfield site (OW-O) is 900 feet deep and was completed as an open borehole from near the top of the Ozark aquifer at 515 feet below surface down into the lower part of the Roubidoux Formation at 900 feet below surface. The total depth of the Springfield Plateau aquifer well (OW-S) is 375 feet where it ends in the lower part of the aquifer. The well is completed as an open borehole from 200 feet below surface down to total depth. The Ozark

aquifer monitoring well at the site near McCune is 1,206 feet deep and was completed as an open borehole from 830 feet down to total depth. Based on an examination of the drill cuttings it is believed that the well bottoms in the lower part of the Roubidoux Formation.

Two sets of well tests were conducted using Pittsburg wells 8 and 10 to derive aquifer properties data that could be incorporated into the USGS modeling study. Each test set consisted of a pumping (pump on) and recovery (pump off) phase during which water-level data were collected at high frequencies using pressure transducers that had been installed in OW-S and OW-O. The drawdown and recovery data were processed and analyzed using standard procedures to derive estimates of Ozark aquifer transmissivity and storativity. The average of the transmissivity and storativity values from the tests conducted using Pittsburg well 10 as the pumping well are 16,350 ft^2/day and 9.47×10^{-5}, respectively. The average of the transmissivity and storativity values from the tests conducted using Pittsburg well 8 as the pumping well are 13,992 ft^2/day and 9.16×10^{-5}, respectively. Factors that influenced the test results include pumping by other nearby wells and variability in the rate at which water was being withdrawn from the aquifer by the pumping wells in each test.

The water-level data from all of the Phase 1 and Phase 2 semiannual surveys were plotted as hydrographs to assess trends. Hydrograph interpretation is problematic because: (1) the collected survey data are more likely to be representative of pumping conditions than static conditions in the aquifer beyond the cone of depression, (2) the long intervals of time between individual measurements may provide a distorted picture of water-level trends locally within the aquifer depending on when the initial survey measurement was taken and on the spacing between measurements, and (3) human error associated with taking the water-level measurements may be significant even under the best of circumstances. If the goal of these surveys is to assess regional water level change in the aquifer, the interpretation uncertainty can be reduced by investing in additional dedicated observation wells strategically placed in areas of the aquifer outside of the immediate influence of pumping wells. At the moment, only the Ozark aquifer monitoring well near McCune fills this need. Furthermore, some of the future monitoring wells in the transition zone should be completed to the bottom of the Ozark Plateaus aquifer system because the water quality transition within the transition zone is likely three-dimensional and may extend far to the east in the lower part of the Ozark aquifer. If so, pumping stress that lowers the hydraulic head in the upper part of the Ozark aquifer may induce upward flow of poorer quality water from deeper zones to active wells.

Introduction

Water Supply Problem Being Addressed

Historically, the Ozark Plateaus aquifer system has been the single most important source of water in the Tri-State region of southeast Kansas, southwest Missouri, and northeastern Oklahoma. Beginning in the late 19th century pumping from the Ozark Plateaus aquifer system dewatered the lead-zinc mines in the Picher and Joplin fields. Ground water was primarily used for mining and milling activities in the Joplin and Picher fields and the coalfields farther north in Cherokee and Crawford counties. The Ozark aquifer was secondarily used for drinking water by public supplies. With the decline of the mining industry in the mid 20th century the primary use of the Ozark aquifer has been for drinking water and for industries other than mining (Stramel, 1957). Macfarlane and Hathaway (1987) reported that all municipal and most rural water districts in Crawford and Cherokee counties in Kansas and in the adjacent Missouri and Oklahoma counties relied primarily or solely on sources from this regional aquifer system. In 2004 some of the public supplies in western Crawford and Cherokee counties had abandoned the Ozark Plateaus aquifer system as a source of supply because of poor water quality, repairs needed for aging wells, or both.

Concerns have been raised in the Tri-state region that the available supply from the Ozark Plateaus aquifer system may become inadequate, rendered unusable, or require additional water treatment in the near future because of:

1. Recent and projected population growth that will create increased demand for water by public supplies and some industries;
2. Potential upward vertical or eastward migration of saline water into public supply wells due to pumping, if pumping rates or wellfield size are increased to keep up with demand; and
3. Possible contamination of ground-water supplies by downward moving leachate derived from mine tailings piles and the mine water contained in the abandoned open shafts.

Prior to 2004 the existing network of monitoring wells for the Ozark Plateaus aquifer system consisted of actively used water supply wells and a few abandoned or unused wells. Because of their antiquity, very little if any information existed on the construction of wells included in monitoring network in most cases. Many of the wells used were not situated in areas currently experiencing water supply problems. Other issues made interpretation of the collected data from the network problematic at best:

1. The overall long-term stability of the network;
2. The frequency of depth to water measurements;
3. The timing of measurements in relation to (a) when the well was last pumped or (b) other nearby pumping wells; and
4. The experience of the individual or individuals taking the depth to water measurement.

Purpose and Objectives of Phase I of the Ozark Aquifer Monitoring Project

In response to the 3 concerns listed above, recent water supply problems that have occurred in southeast Cherokee County, and the need for a reevaluation and redesign of the monitoring network, the Kansas Water Office (KWO) contracted with the Kansas Geological Survey (KGS) to accomplish these goals. The project was to be conducted in 2 phases.

The Phase 1 objectives were to:

1. Determine how water levels have changed in wells tapping the Ozark Plateaus Aquifer System in Crawford and Cherokee counties, southeast Kansas, since the 1980 KGS survey and determine seasonal water-level changes;
2. Determine if the wells in the existing monitoring network adequately characterize water-level changes since 1980 and are located in the areas of the aquifer experiencing the greatest changes; and
3. During the study conduct high-frequency water-level data collection in 2 unused wells to assess in detail water-level fluctuations caused by turning the pumps in nearby wells on and off, and from seasonal water use near the Kansas-Missouri border.

Results of the Phase I Study

Macfarlane et al. (2005) showed significant water-level declines in the Pittsburg-Frontenac area and significant water-level rises in one of the Galena and two of the Baxter Springs wells. The depth to water remained relatively unchanged in the other wells of eastern Cherokee and Crawford counties. Analysis of the hydrographs from Crawford and Cherokee county wells and from wells in adjacent southwest Missouri reveals long-term trends consistent with the water-level changes determined from a comparison of the 1979-81 and 2004 surveys. Changes in water use and in population from 1981-2003 and projected changes in county population suggested that water demand might increase in eastern Crawford County into the future.

Macfarlane et al. (2005) also included recommendations to be followed up in Phase II. The following recommendations were based on (1) the water-level declines in wells tapping the Ozark aquifer, (2) the past and projected water-use and population trends for Crawford and Cherokee counties, (3) the location of pumping centers in southwest Missouri near the border with Kansas, and (4) the effect of aquifer properties and local pumping on the long- and short-term water-level trends:

1. Semi-annual water-level surveys are needed for Cherokee and Crawford counties to monitor short- and long-term water level changes in wells and should include most of the wells visited in the 2004 water-level surveys;
2. Targeted, high-frequency data collection needs to be on-going in the Pittsburg area where a regional scale coalesced cone of depression has been forming for more than a century and in the Galena-Baxter Springs area where water-supply problems have more recently developed; and
3. Observation wells need to be installed for dedicated long-term monitoring of water levels in the Springfield Plateau and the Ozark aquifers in Crawford County and in the Springfield Plateau aquifer in southern Cherokee County. In Crawford County, one site should be located east of Pittsburg on the Kansas-Missouri border and

another should be located west of Kansas Highway 7. In Cherokee County, a new monitoring well should be installed to monitor water levels in the Springfield Plateau aquifer between Riverton and Galena, Kansas. If the Eagle Picher Agricultural Chemical Division monitoring well has not been plugged, it should be reactivated to monitor water levels near the Kansas-Missouri border in southeastern Cherokee County.

Phase II Study Purpose and Objectives

The primary goal of the work undertaken by the KGS in Phase II was to site and install two dedicated monitoring sites in the Ozark Plateaus aquifer system. Other subsidiary objectives were to be developed in consultation with the Water Issue Strategic Plan (WISP) Ozark-aquifer working group at the beginning of Phase II.

The following is a complete list of the objectives for the KGS Phase II work:

1. In consultation with the WISP Ozark-aquifer working group KGS will develop a scope of work for Phase II of the Ozark Aquifer Monitoring Network project for the remainder of FY05, FY06, and FY07;

2. Site and oversee installation of monitoring wells in the Springfield Plateau aquifer and in the Ozark Plateau aquifer in Crawford and Cherokee counties. Candidate sites include: (1) the intersection of the Crawford-Cherokee County line with the Kansas-Missouri border (Site 1), (2) a site located west of highway K-7 along the Cherokee-Crawford county line (Site 2), and (3) one of the Galena municipal wells (Site 3). Proposed target aquifers to be monitored are the Ozark aquifer and potentially the Springfield Plateau aquifer at Sites 1 and 2, and the Ozark aquifer at Site 3. Monitoring wells in the Springfield aquifer will be completed, if sufficient funds are available.;

   By agreement, all monitoring wells will be owned by the Kansas Department of Agriculture (KDA). The KGS will act as an agent for the KDA and will be responsible for making arrangements with landowners or the county or municipal governments to acquire sites for the monitoring wells. Wells will be located on County or municipal easements. KGS will also be responsible for generating contract specifications for contractors interested in bidding on monitoring well installation and will develop land-use agreements only with counties/municipalities for the well sites.

   KGS will also be on-site during all drilling and construction to gather geologic data on the formations penetrated during drilling and to oversee well construction and installation. KGS will produce a log for the well based on an examination of the cuttings produced during drilling and a sketch of the well construction showing the formations penetrated by the well bore and the particulars with respect to well casing, grouting, or cementing. On completion, this information will be provided to the Division of Water Resources, KDA (DWR);

3. KGS will install continuous monitoring equipment in the monitoring and other wells to collect water-level data in support of Phase II. Transducers with on-board data loggers

will be installed in the new and old deep aquifer supply wells at the degussa/Jayhawk Fine Chemicals Inc. plant site, a Galena municipal well, and all new dedicated Ozark aquifer monitoring wells. KGS will also acquire a transducer and cable for monitoring in the Galena well, if that well is available and the city agrees not to use it for pumping during the life of the project.

Each monitoring well will be outfitted with a pressure transducer and an on-board data collection system to perform high-frequency collection of water-level data. Water-level data will be downloaded periodically for use in estimating aquifer hydraulic properties and for the calibration of the ground-water flow model being developed by the US Geological Survey (USGS). Data collection frequency will be set at according to the goals of the particular monitoring situation. In the new monitoring wells it may be more appropriate to set the frequency of measurement at 1-hour or 30-minute intervals, whereas a much shorter interval (5-minute or 1-minute) may be more appropriate for the Jayhawk plant site monitoring. KGS will be responsible for downloading water-level data from all of the monitoring sites periodically and will prepare and maintain hydrographs showing time vs. depth to water.

KGS will analyze the aquifer testing data from the degussa/Jayhawk Fine Chemicals wells to estimate aquifer hydraulic parameters;

4. KGS will coordinate and provide advisory support for the development and implementation of a ground-water flow model of the Tri-State region Ozark Plateaus aquifer system being developed by the US Geological Survey. KGS will provide technical support to review, collect, and evaluate subsurface and hydrologic model input data from southeast Kansas as a member of technical advisory group. As appropriate, review procedures and techniques used to develop the model, including model calibration. Review model results and interpretation and project reports submitted to the Kansas Water Office (KWO);

5. KGS will conduct semi-annual surveys in FY06-07 to collect depth-to-water data from the wells assigned to the redesigned monitoring network. These surveys will be scheduled for the mid to late summer and early to mid-winter seasons. Division of Water Resources, Dept. of Agriculture (DWR) staff from the field office will be responsible for conducting the fall and spring water-level surveys.

Subsequent Modifications Made to the List of Phase II Objectives

By the end of Phase II some of the tasks in the objectives (scope of work) were modified or not completed either due to lack of funds or time and some additional tasks were added. For Objective 2, the monitoring site location proposed in the Phase I report for the vicinity of the Kansas-Missouri state line and near the Crawford-Cherokee County line was shifted to the City of Pittsburg wellfield. The relocation was partially in response to the need for additional aquifer properties data to support the USGS modeling effort. As a consequence of this change in planning, the KGS was charged with conducting pumping tests using newly installed monitoring wells and other production wells in the wellfield.

KGS was also charged with providing geophysical logging for the deep monitoring wells at each site in addition to the sample log and well-construction schematics for each monitoring well called for in the original objectives.

Actual drilling costs exceeded estimates made in formulating the budget for Phase II, which precluded installation of a monitoring well in Galena-Baxter Springs area of Cherokee County.

Under Objective 3, monitoring equipment was purchased with KGS funds in support of the project and monitoring was conducted throughout Phase II. At the degussa/Jayhawk Fine Chemicals Inc. plant site, the transducer could not be successfully placed at depth in the production well PW-2. Because of this difficulty, a pumping test was not conducted.

Summary of Activities Conducted in Phase II

The KGS completed the following items in Phase II:

1. A mutually agreed upon scope of work for the contract;
2. Two mutually acceptable sites for the installation of monitoring wells in southeast and southwest Crawford County on public rights-of way;
3. Contract specifications, and oversight of the bidding on the monitoring well installation;
4. Oversight of monitoring-well installation in the field;
5. Sample logs from the cuttings produced while drilling the boreholes for the Pittsburg and McCune monitoring wells;
6. Gamma-ray borehole geophysical logs of the Ozark aquifer monitoring wells;
7. Pumping tests in the City of Pittsburg wellfield to determine aquifer properties;
8. Depth to water data from semiannual 2005 and 2006 surveys in the monitoring network established under Phase I of this project; and
9. Liaison activities in support of the USGS work in the Tri-state region, including:
    - Participation and attendance by the KGS at face-to-face technical advisory committee meetings and conference calls; and
    - Participation by the KGS in a public meeting forum at Pittsburg State University.

Other Activities Not Covered Under the Phase II Objectives

In addition to the activities listed above, the KGS provided support for the synoptic water sampling and shared water-quality data developed under a Kansas Water Resources Research Institute grant to assist the USGS in its work on the Ozark Plateaus aquifer system in the Tri-state region.

Monitoring Well Siting, Contracting, Installation, Description and Testing

Monitoring Well Siting, Contracting, and Installation

Siting

The WISP Ozark aquifer working group indicated that the monitoring wells needed to be sited on public rights-of-way to avoid issues related to siting on privately owned land. The KGS and the DWR field office staff worked with the City of Pittsburg and the Kansas Department of Transportation to secure sites. Two monitoring well sites were secured in Phase II with one located within the City of Pittsburg wellfield and one at the Kansas Department of Transportation Materials Storage facility along U.S. Highway 400, approximately one-third of a mile east of the Kansas Highway 126 intersection. The City of Pittsburg wellfield and McCune sites are located in NE NE SE Section 28, T. 30 S., R. 25 W. and SE SE SW Section 16, T. 31 S., R. 22 E. (Figure 1). Once the sites were agreed upon and formally secured by written agreements, installation proceeded as planned.

Contracting

KGS developed monitoring well site specifications and submitted them for bid to Kansas water well contractors. Specifications were developed based on accepted industry standards for drilling, monitoring well construction and installation, and site cleanup and restoration (Attachment 1). The KGS accepted a bid from and contracted with Evans Energy Development, Inc., Paola, Kansas, to complete installation of both monitoring sites.

Drilling

At the beginning of construction, a pit was excavated to contain the cuttings and water produced by drilling. All monitoring wells were drilled using an air hammer to penetrate Pennsylvanian and Mississippian rocks and the air rotary method to complete drilling through Ordovician rocks down to total depth. On completion of well installation and development, the pits were backfilled and the contour of the land was restored.

City of Pittsburg Monitoring Site Construction

City of Pittsburg monitoring site construction began 3/13/2006 and ended 3/17/2006. Two monitoring wells approximately 25 feet apart were completed, one in the Ozark aquifer and one in the Springfield Plateau aquifer (Figure 2). Total depths of the Ozark (OW-O) and Springfield Plateau (OW-S) aquifer monitoring wells are 900 feet and 375 feet, respectively (Figures 3 and 4). OW-O is cased with 5-inch diameter steel pipe from the surface down to 515 feet below surface and has 22 feet of 8-inch steel surface casing. The 8-inch surface and 5-inch steel pipe were cemented in with neat cement and in the case of the 5-inch casing, cemented in using

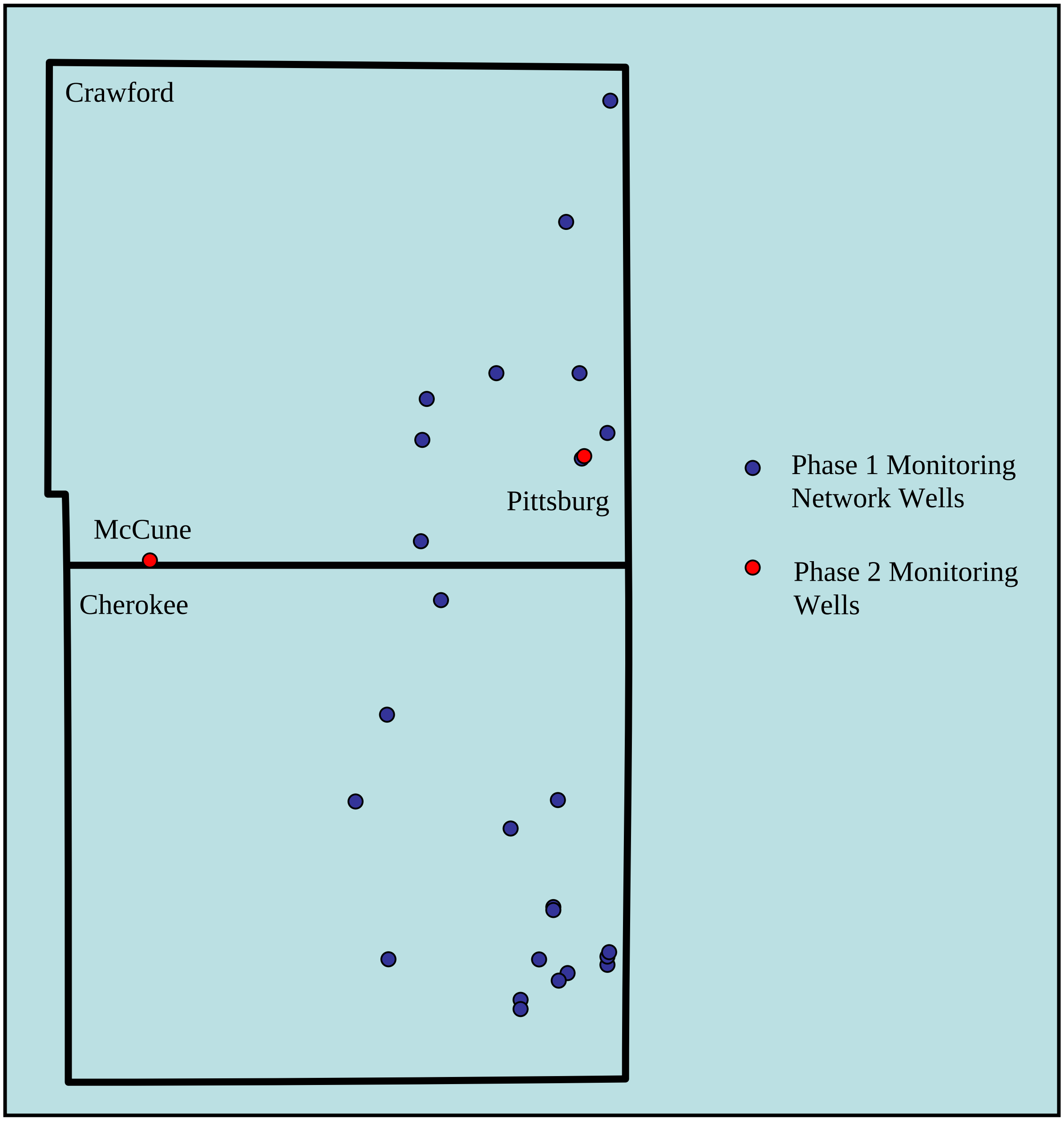

Figure 1. Location of the McCune and Pittsburg monitoring sites constructed in Phase 2 with respect to wells in the Phase 1 monitoring network in eastern Crawford and Cherokee counties, Kansas.

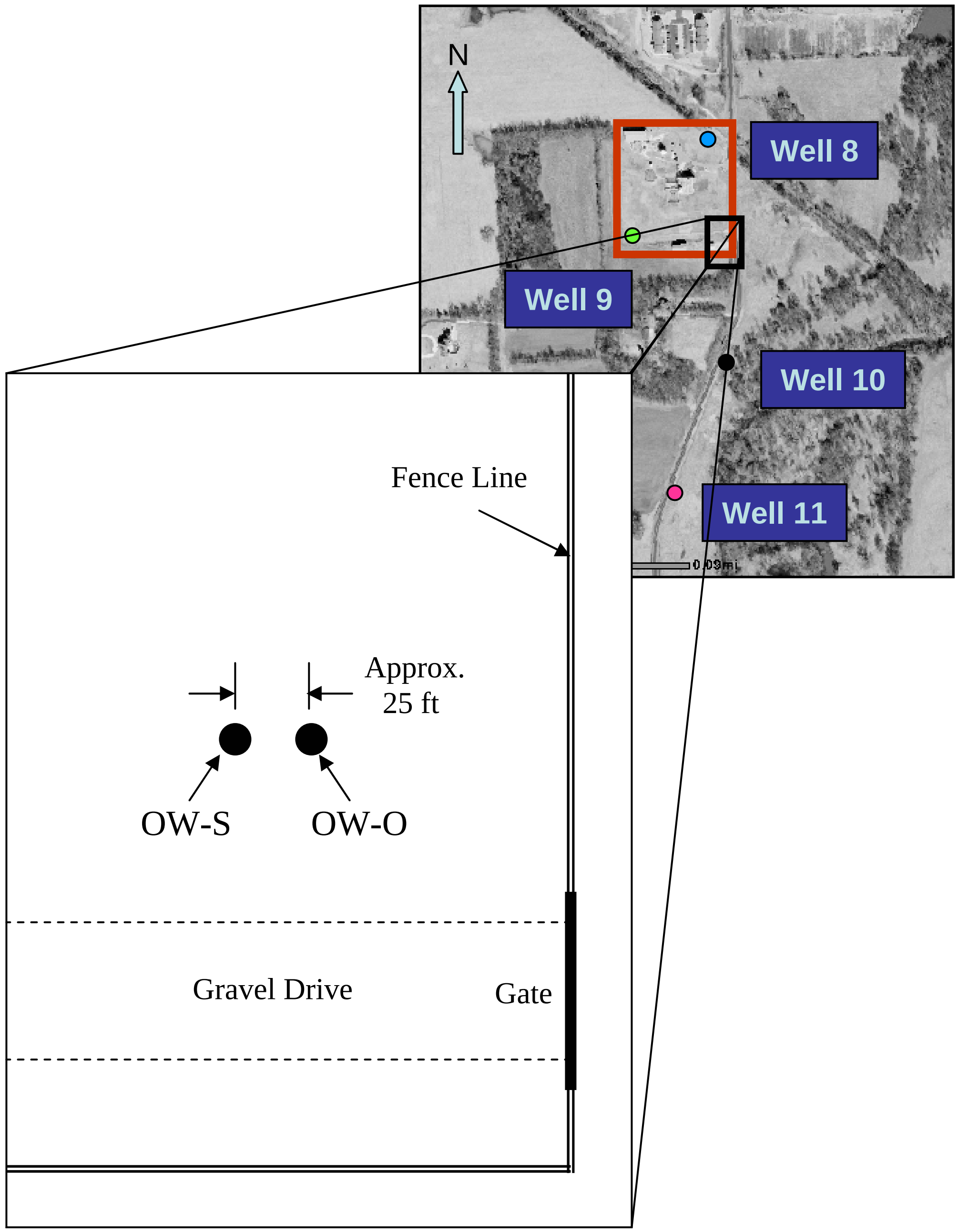

Figure 2. Location of the monitoring site on the city of Pittsburg water treatment plant site outlined in red on the air photo at the top of the figure. Also shown for reference are the supply wells that make up the city's wellfield.

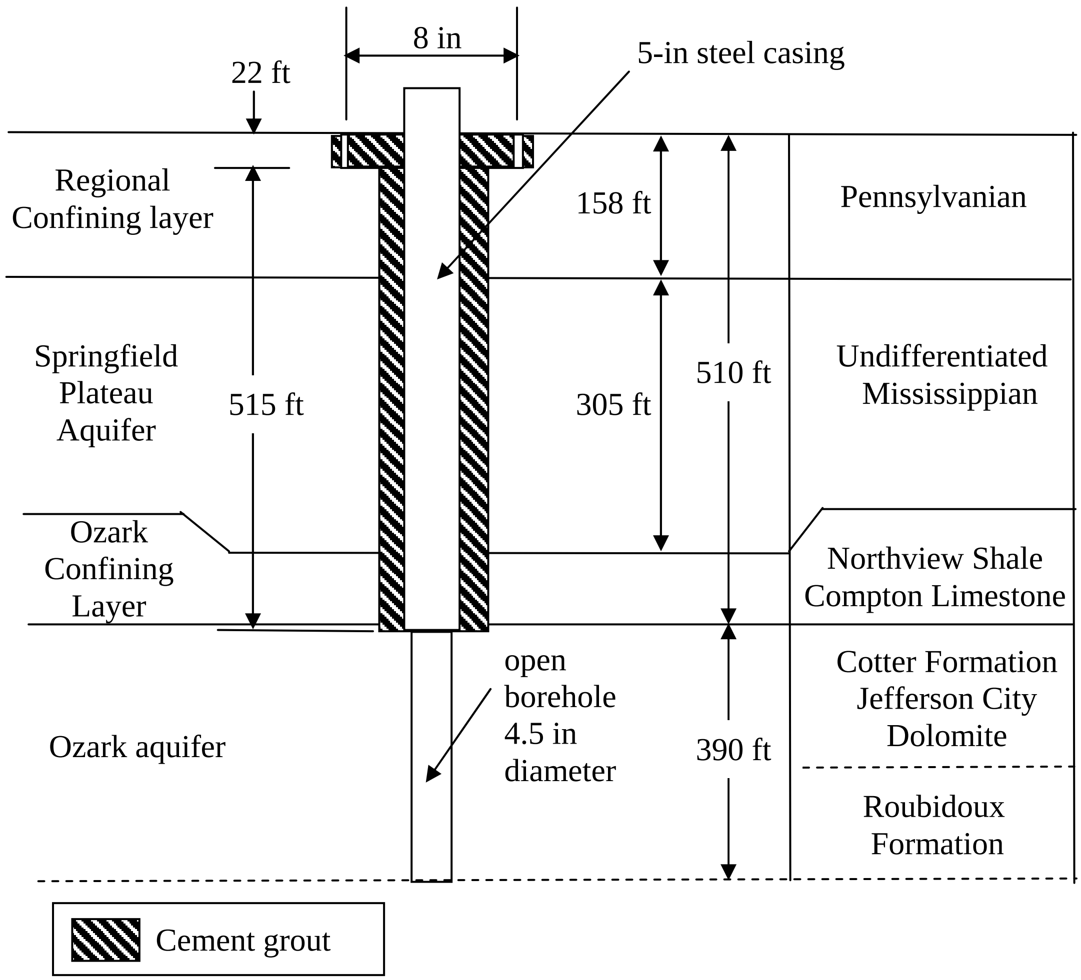

Figure 3. Schematic showing the construction of OW-O as built at the Pittsburg wellfeld monitoring site with reference to the stratigraphic and hydrostratigraphic units penetrated by the well.

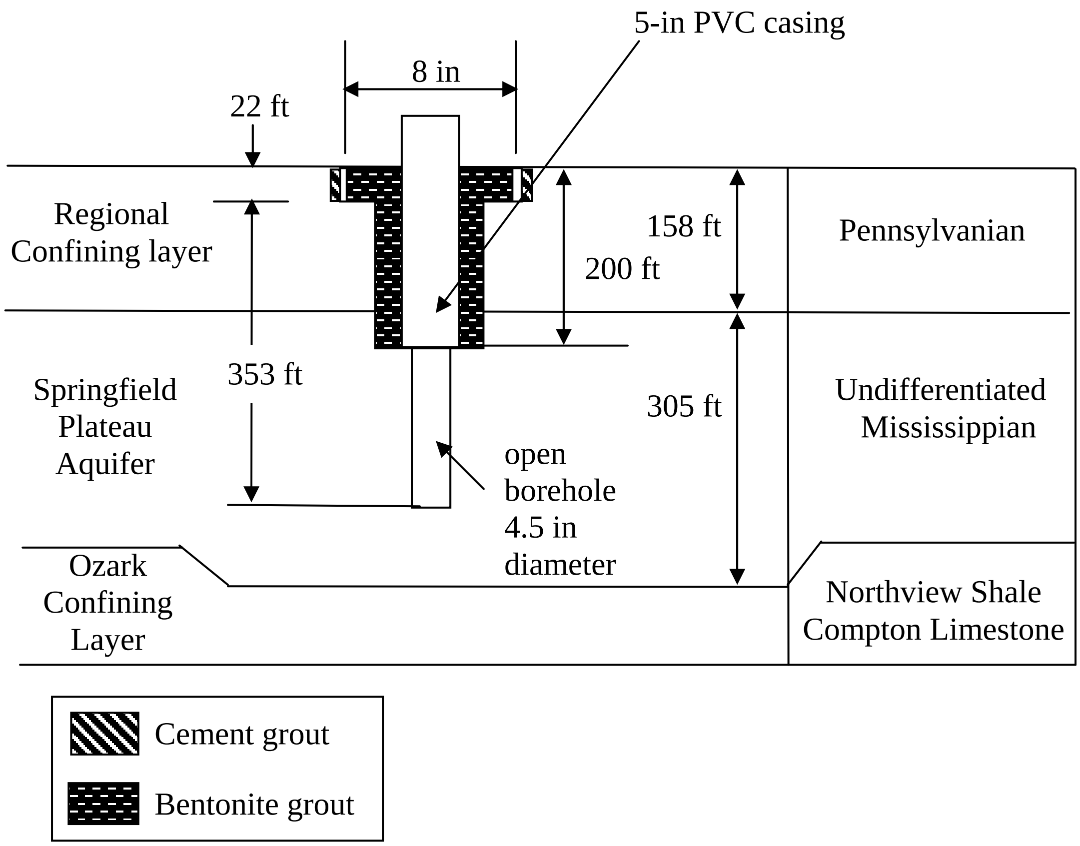

Figure 4. Schematic showing the construction of OW-S as built at the Pittsburg wellfeld monitoring site with reference to the stratigraphic and hydrostratigraphic units penetrated by the well.

the Halliburton method. From 515 feet to total depth the well was completed as an open borehole 4.5 inches in diameter. OW-S has a total depth of 375 feet and is cased with 5-inch PVC pipe from surface down to 200 feet and has 22 feet of 8-inch steel surface casing. The 8-inch steel surface casing was cemented in with neat cement, but bentonite pellets were used to seal the annular space between the borehole and the 5-inch casing for this well. From 200 feet down to total depth the well was completed as an open borehole 4.5 inches in diameter. The submitted WWC-5 forms are attached to this report as Attachment 2.

Upon completion of construction, each well was developed using compressed air pumped downhole through the drill string for approximately 20 minutes to remove cuttings and ground water impacted by construction. No direct measurement was made of flow rate or duration to determine the volume of fluid and solids removed from the wells. Both wells were then fitted with locking caps but not padlocked.

McCune Monitoring Site Construction

At the McCune monitoring site only an Ozark monitoring well was planned (Figure 5). The contractor began construction on 10/24/2006 and halted progress on 10/25/2006 because the pump on the drilling rig that supplies air to the bit could not generate enough pressure to remove the drill cuttings from the bottom of the hole. At this point, surface casing and the inner steel casing for the well had been set below the top of the Ordovician section. The contractor eventually subcontracted with Well Refined Drilling, Thayer, Kansas, to complete the hole at no cost to the project. Drilling began again on 11/07/2006 and ended 11/08/2006. The target depth of 1,230 feet was not reached because of problems related to pump capacity and the volume of fluids and drill cuttings to be removed from the hole.

Total depth of the Ozark monitoring well is 1,206 feet (Figure 6). The well is constructed with 22 feet of 8-inch steel surface casing and cased with 5-inch diameter steel pipe from the surface to 830 feet below surface. The 8-inch surface and 5-inch steel pipe were cemented with neat cement, the latter using the Halliburton method. From 830 feet to total depth the well was completed as an open borehole. The submitted WWC-5 form is attached to this report as Attachment 3.

Upon completion of construction, the well was developed using air for approximately 20 minutes to remove cuttings and ground water impacted by construction. No direct measurement was made of flow rate. The well was then fitted with a locking cap and padlocked.

Figure 5. Location of the McCune monitoring site (black dot) at the Kansas Department of Transportation materials storage yard along US Highway 400 in southwestern Crawford County.

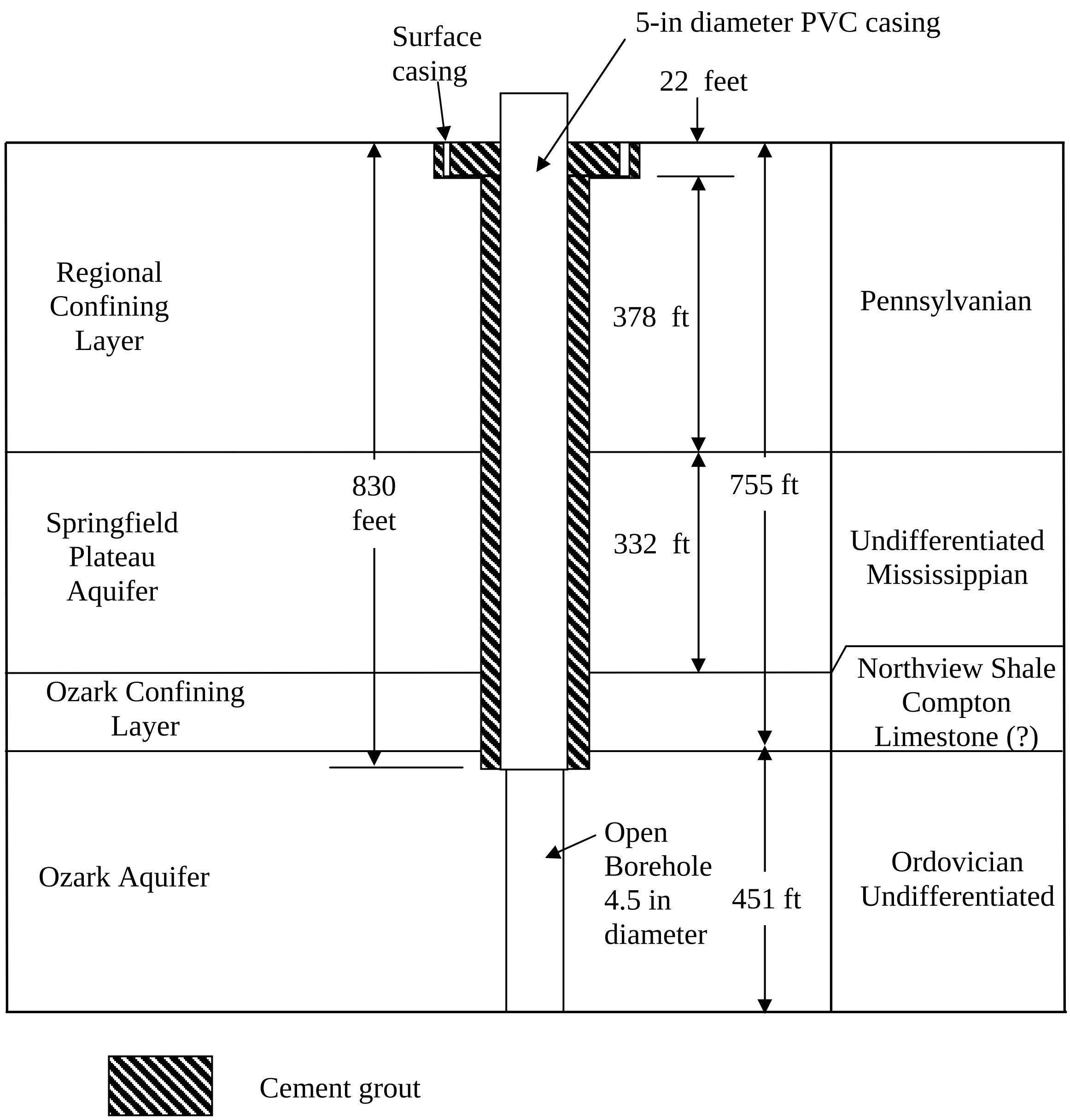

Figure 6. Schematic showing the construction of the Ozark aquifer monitoring well as built at the McCune monitoring site with reference to the stratigraphic and hydrostratigraphic units penetrated by the well.

Subsurface Stratigraphy/Hydrostratigraphy

Regional stratigraphy/hydrostratigraphy

The Ozark Plateaus aquifer system in southeast Kansas and western Missouri consists of karstic and fractured carbonate rock units of Upper Cambrian, Lower Ordovician, and Mississippian age and has been subdivided into the Springfield Plateau, Ozark, and St. Francois regional aquifers (Jorgensen et al., 1993; Macfarlane, 2000; Table 1). Ozark Plateaus aquifer system thickness ranges from 1,735 feet in the Joplin, Missouri, area to 1,390 feet at Parsons, Kansas (Macfarlane and Hathaway, 1987). The Ozark Plateaus aquifer system is confined above by a sequence of Pennsylvanian shales and limestones and below by rocks of Precambrian age. The strata that form the Ozark Plateaus aquifer system are at the surface or at shallow depths in southwest Missouri and progressively increase in depth in the direction of southeast Kansas (Figure 7). In southeast Cherokee County, the strata that form the Springfield Plateau aquifer are at the surface and the top of the Ozark aquifer is within 300 feet of the surface. At Pittsburg the top of Springfield Plateau aquifer is within 200 feet of the surface and the depth to the top of the Ozark aquifer from the surface is on the order of 450 feet. One or more low-permeability stratigraphic units separate these regional aquifers and act as confining layers above the Ozark aquifer (Figure 8).

Table 1. Rock units and aquifer and confining units that form the Ozark Plateaus aquifer system in the Tri-state region of southeast Kansas, southwest Missouri, and northeast Oklahoma.

<table>
<tr><th>Era</th><th>System</th><th>Rock Stratigraphic Unit</th><th colspan="2">Aquifer/Confining Unit</th></tr>
<tr><td rowspan="14">Paleozoic</td><td>Pennsylvanian</td><td></td><td>Confining unit</td><td>Confining unit</td></tr>
<tr><td rowspan="2">Mississippian</td><td></td><td>Springfield Plateau aquifer</td><td rowspan="13">Ozark Plateaus aquifer system</td></tr>
<tr><td>Northview Shale
Compton Limestone</td><td rowspan="2">Confining unit</td></tr>
<tr><td>Mississippian-Devonian</td><td>Chattanooga Shale</td></tr>
<tr><td rowspan="5">Ordovician</td><td>Powell Dolomite</td><td rowspan="7">Ozark aquifer</td></tr>
<tr><td>Cotter Dolomite</td></tr>
<tr><td>Jefferson City Dolomite</td></tr>
<tr><td>Roubidoux Formation</td></tr>
<tr><td>Gasconade Dolomite</td></tr>
<tr><td rowspan="5">Cambrian</td><td>Eminence Dolomite</td></tr>
<tr><td>Potosi Dolomite</td></tr>
<tr><td>Derby-Doe Run Dolomoite</td><td rowspan="2">Confining unit</td></tr>
<tr><td>Davis Formation</td></tr>
<tr><td>Reagan Sandstone</td><td>St. Francois aquifer</td></tr>
<tr><td>Precambrian</td><td></td><td></td><td>Confining unit</td><td>Confining unit</td></tr>
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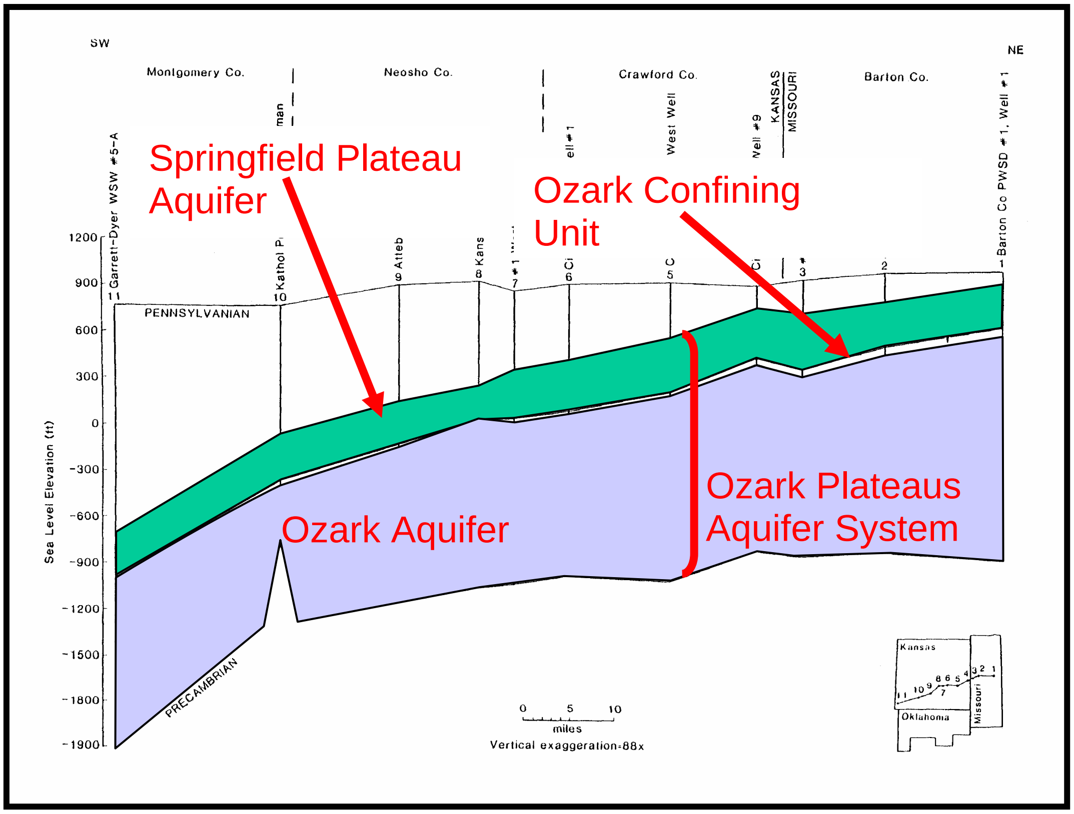

Figure 7. Hydrogeologic vertical section from southwest Missouri across southeast Kansas showing the increasing depth to the top of the Ozark Plateaus aquifer system.

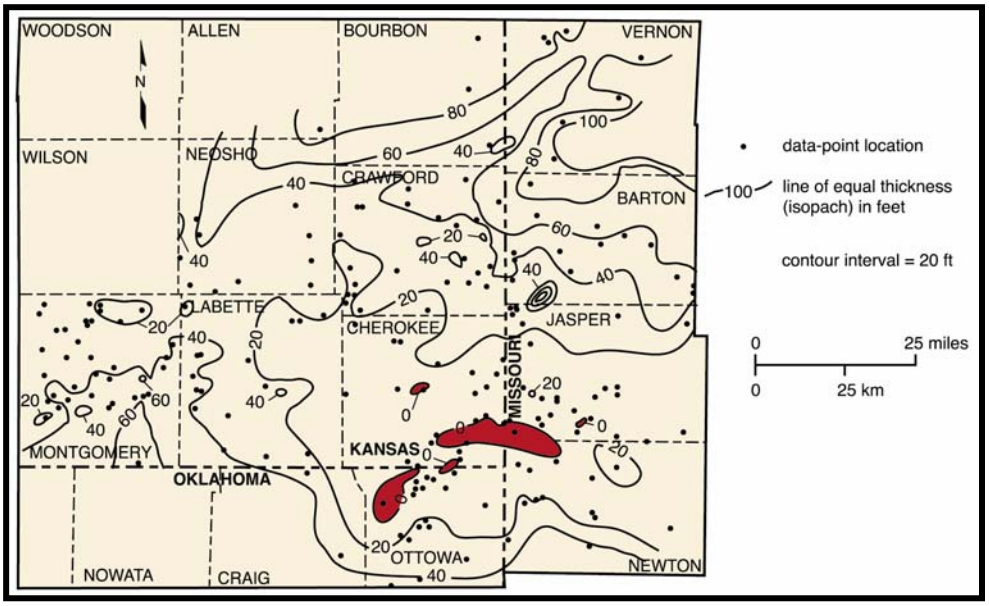

Figure 8. Thickness of the confining layer separating the Springfield Plateau aquifer from the underlying Ozark aquifer in the Tri-state region of southeast Kansas, southwest Missouri, and northeast Oklahoma. Taken from Macfarlane and Hathaway (1987).

Lower Ordovician and the Cambrian rock units above the Reagan Sandstone are referred to collectively as the Arbuckle Group in southeast Kansas (Zeller, 1968). Westward of the Tri-state region the Ozark Plateaus aquifer system has been referred to as the Western Interior Plains aquifer system and the hydrologic boundary between these aquifer systems has been defined as the 2,500-mg/L isochlor (Jorgensen et al., 1993; Hansen and Jurachek, 1995). In this report, the Western Interior Plains aquifer is not recognized as an aquifer separate from the Ozark Plateaus aquifer system following the aquifer nomenclature established in Macfarlane (2000).

Methodologies for determining local subsurface stratigraphy/hydrostratigraphy at the monitoring sites

Examination of samples of the drill cuttings

Samples of the drill cuttings from the deep boreholes monitoring site were collected every 10 feet as the hole was being drilled and placed in bags labeled according to the collection depth interval. The samples were examined using a binocular microscope or hand lens to determine lithologies and estimate depths to stratigraphic tops penetrated by the borehole. At the Pittsburg site a log on the nearby Pittsburg City Well 9 from the Missouri Division of Geology and Land Survey, Missouri Department of Natural Resources, was used as a guide to the stratigraphy penetrated by the borehole.

Gamma-ray borehole geophysical logging

All earth materials emit natural gamma radiation, which can be attributed to the decay of trace amounts of radioactive elements contained within them (Doveton, 1986). The radioactive elements of interest here are uranium, thorium, and the radioactive isotope potassium-40. The intensity of radiation and energy emitted depend on the total and relative amounts of these isotopes contained in the rocks. In general clay-bearing, fine-grained rocks and those containing minerals containing naturally radioactive elements (such as glauconite) tend to emit higher levels of radiation than those that are relatively free of these lithologies or minerals.

A gamma-ray log is produced by lowering to the bottom of the borehole a detector (a Geiger counter) mounted in a logging tool that is attached by a cable to the end of a winch (Doveton, 1986). The winch slowly draws the tool back to surface. As the tool moves up the borehole it measures and records the gamma-ray intensity emitted by the adjacent rocks. These readings are recorded as counts per second and transmitted electronically back to the surface through the cable and recorded as a graph of radiation intensity vs. depth below the surface or some other datum. The graph is referred to as the gamma-ray log. On the log the shales and shaly-rocks can be distinguished from the shale free limestones, dolomites, and sandstones because the gamma-ray curve moves to the right on the log indicating higher intensities of emitted gamma radiation. Other lithologies not containing radioactive minerals will show low intensities of natural radioactivity and the curve will remain on the left side of the log.

Because the gamma-ray log is useful for discriminating one class of lithologies from another, it can be used to more precisely pinpoint changes in lithology in the subsurface than a log that describes samples of the drill cuttings. This is because the gamma-ray intensity measurements are being made on the rocks in place with reference to a datum rather than the descriptions of cuttings, which, in this case, have been retrieved over an interval of 10 feet. Lithologic changes are often tied to the surfaces that bound stratigraphic units. Thus, by comparing the log of the borehole with the descriptions of the cuttings samples, it is possible to "fine-tune" estimates of the depth to the boundaries that stratigraphically distinguish one unit from another. In addition, the shape of the fluctuations of the gamma-ray log may elucidate details about the nature of the rock that are not obvious from a description of the drill cuttings samples alone.

Subsurface stratigraphy/hydrostratigraphy at the Pittsburg monitoring site

Pennsylvanian shale, fine sandstone (some of it petroliferous), and coal were penetrated by the upper 158 feet of the borehole (Attachment 2, Figure 3). The higher rate of gamma-ray emission is consistent with the dominance of shaly to silty rocks in this interval of the borehole (Figure 9).

The top of the Mississippian section (top of the Springfield Plateau aquifer) was encountered at 158 feet below surface. The dominant lithologies encountered in the Mississippian interval consisted of limestone and chert. Accordingly, the measured gamma-ray emission intensities are low. From 158 feet to 200 feet below surface the cuttings were completely dry. The borehole produced water from 330 feet to 380 feet below surface as it was being drilled. The top of the Mississippian Northview Shale was encountered at 463 feet. The Northview consists predominantly of green, calcareous shale with disseminated pyrite and some glauconite. On the gamma-ray log the higher level of emitted radiation in that section of the borehole indicates the Northview. At 500 feet below surface the Compton Limestone was encountered and has a thickness of approximately 10 feet.

The top of the Ordovician Cotter Dolomite (top of the Ozark aquifer) was penetrated at 510 feet below surface. Dolostone (a rock made up primarily of the mineral dolomite) with minor sandy dolostone and cherty dolostone constituted the bulk of the Cotter and the underlying Ordovician Jefferson City Dolomite in the cuttings along with traces of shale. The gamma-ray log of this part of the section is characterized as spikey, exhibiting a high degree of variation in gamma emission intensity. One possible explanation for this behavior is that the detector is responding to thin zones of shaly material within a karstic section of the dolostone. The shaly material could be a residuum of weathered, fine-grained sediment that washed into and was deposited in solution channels at the top of the Ordovician, prior to deposition of the Compton Limestone. Similar features can be observed in roadcuts along the highways that pass through the Ozarks of southern Missouri. The top of the Ordovician Roubidoux Formation is estimated to be at 765 feet below surface in OW-O. Below this depth, dolostone and sandy dolostone overlie intervals of white, medium to very fine grained, quartz sandstone in the Roubidoux Formation. At this location the total thickness of sandstone at the bottom of the monitoring well is at least 20 feet.

Subsurface stratigraphy/hydrostratigraphy at the McCune monitoring site

As recorded by the driller, Pennsylvanian shale, fine sandstone (some of it petroliferous), and coal were penetrated by the upper 400 feet of the borehole (Attachment 3, Figure 6). As in the log for

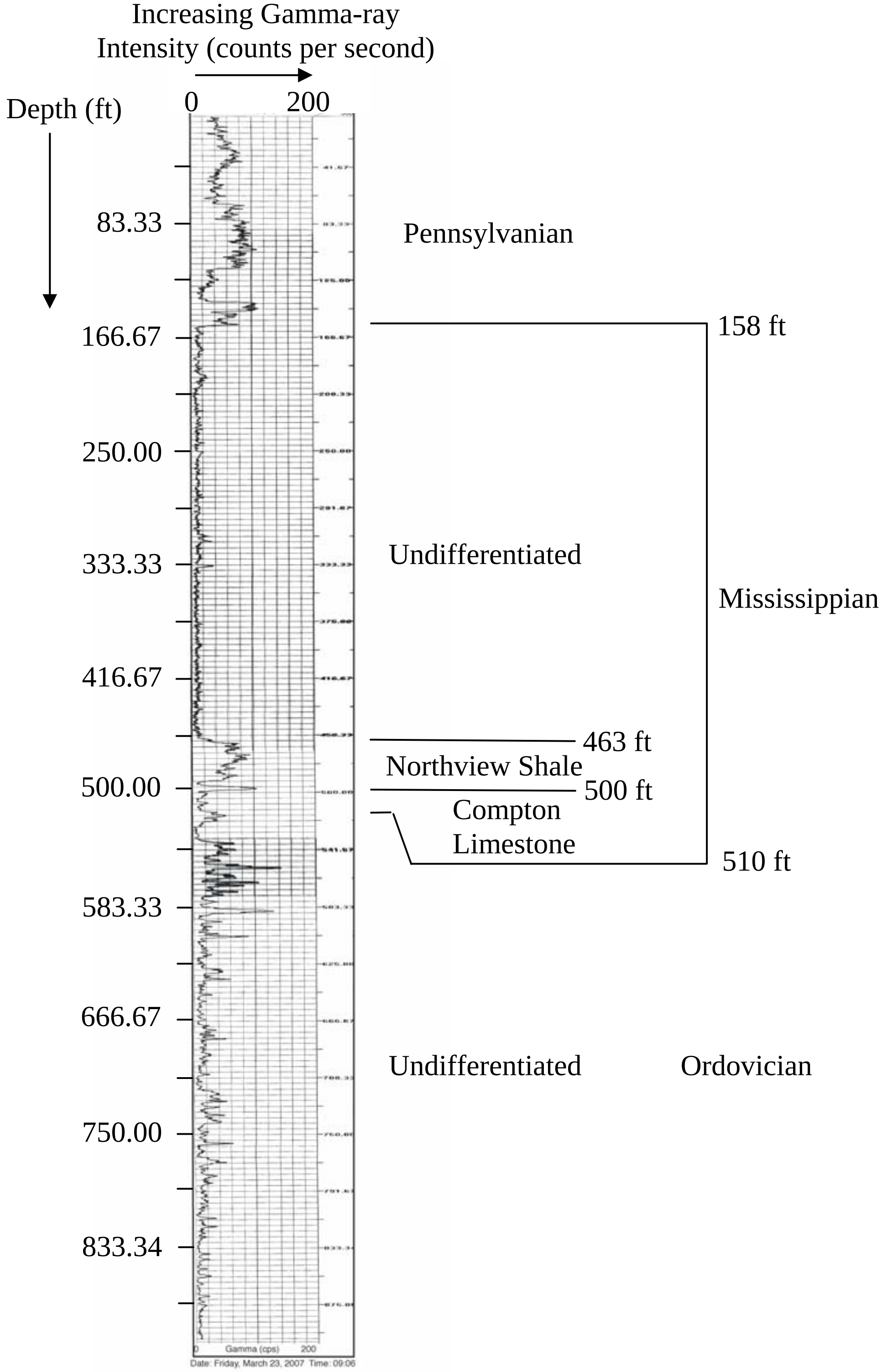

Figure 9. Gamma-ray log of the OW-O monitoring well at the Pittsburg monitoring site.

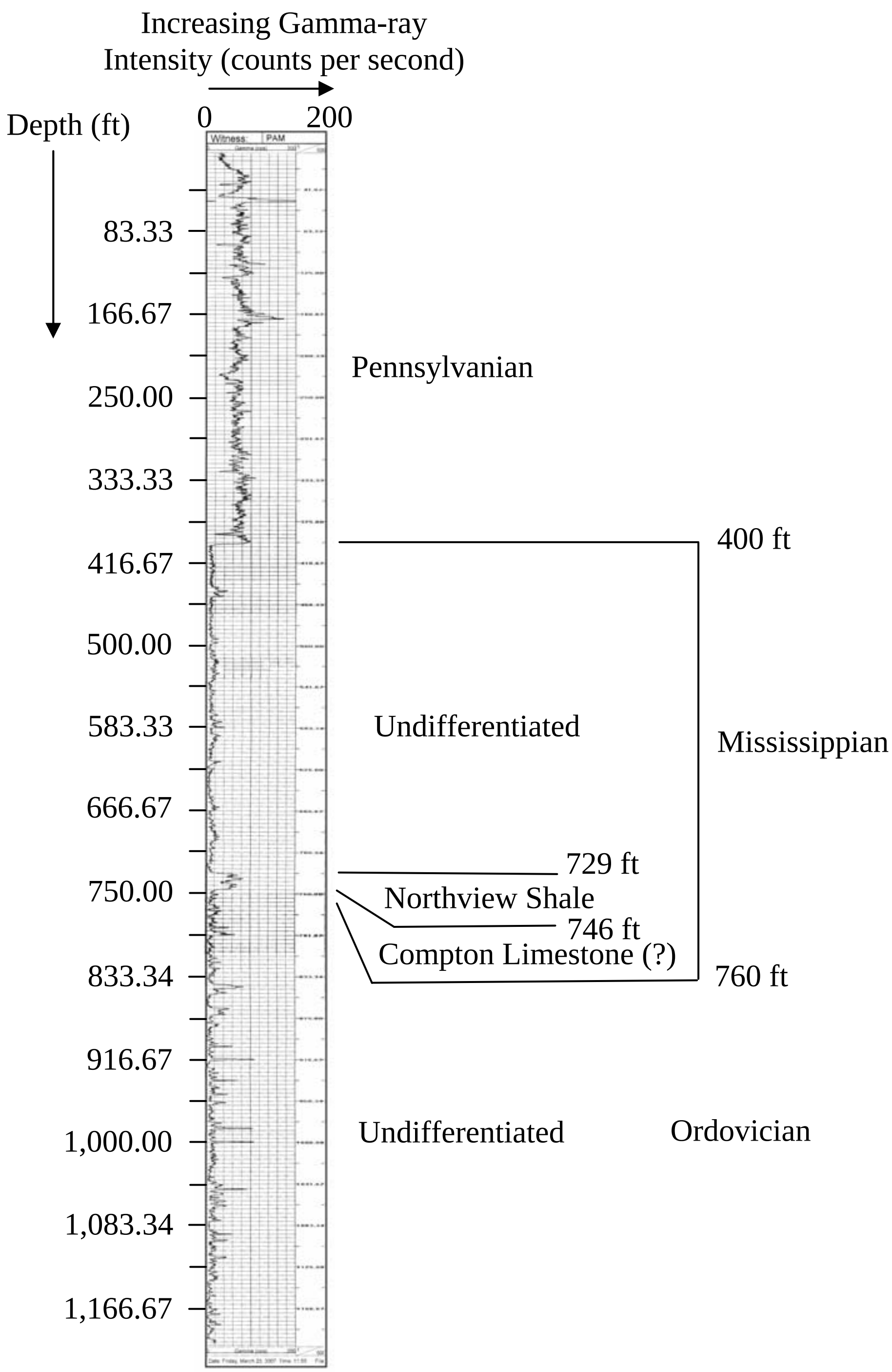

Figure 10. Gamma-ray log of the Ozark monitoring well at the McCune monitoring site.

the deep borehole at the Pittsburg monitoring site, gamma-ray log shows that this part of the section is dominated by finer grained clayey and silty shales (Figure 10).

The top of the Mississippian section (top of the Springfield Plateau aquifer) was encountered at 400 feet below surface. The dominant lithologies encountered were limestone and chert, which is confirmed by the gamma-ray log. The cuttings were dry from 400 feet to 450 feet below surface, damp from 450 feet to 590 feet, and wet below 590 feet. The borehole produced water from 590 feet to total depth as it was being drilled. The top of the Mississippian Northview Shale was encountered at 729 feet. A thin section of Compton Limestone may be present below the Northview from 746 feet to 760 feet below surface. Cuttings of the Compton were not recovered and described in the lithology log, but the gamma-ray log suggests that the Compton is present. The top of the Ordovician (top of the Ozark aquifer) was penetrated at 760 feet below surface. The Ordovician section consists of a thick sequence of dolostone some of it cherty and some with thin, sandy dolostone intervals. Thicker intervals consisting of friable fine to very fine quartz sandstone, some of it glauconitic, were encountered from 1,100 feet to 1,206 feet below surface. The boundaries subdividing the Ordovician section into stratigraphic units could not discerned from examination of the cuttings in the field or in the laboratory at KGS. It is likely that the well penetrates most of the Roubidoux Formation based on the thick intervals of quartz sandstone in the lower part of the well, which is characteristic of the lower part of this stratigraphic unit.

Well Testing

Well Selection for Testing

In early October 2006 a pressure transducer was placed in OW-O at a depth of approximately 290 feet below casing top to:

- Assess seasonal recovery of the potentiometric surface in Ozark aquifer from summer pumping, and
- Select the pumping wells in the City of Pittsburg wellfield to be tested later during the winter months of 2006 and 2007.

Data were collected every 15-minutes, stored on-board in the pressure transducer sonde, and intermittently downloaded onto a laptop computer for analysis to assess the magnitude of variations of the elevation of the potentiometric surface at the monitoring wells under normal wellfield operation (Figure 11). Data were also collected from the city to correlate water-level changes in OW-O with the pumping of individual wells in the field (Figures 12).

Well 10 was selected for testing because of its location near the south end of the wellfield and its proximity to the monitoring site and other production wells that could be monitored (Figure 13). In addition to the monitoring site, reliable water-level data could be obtained from well 11, which is fitted with a water-level access tube. Close examination of the OW-O hydrograph indicated that the maximum drawdown at the monitoring site due to the pumping of well 11 after 36 hours would be less than 15 feet (Figure 14). Well 8 was selected for testing because of its location at the north end of the wellfield. Its pumping rate is lower than either well 10 or 11.

OW-O and OW-S are approximately 20 feet apart and 557 feet south and 845 feet north of Well 8 and Well 10, respectively (Figure 13).

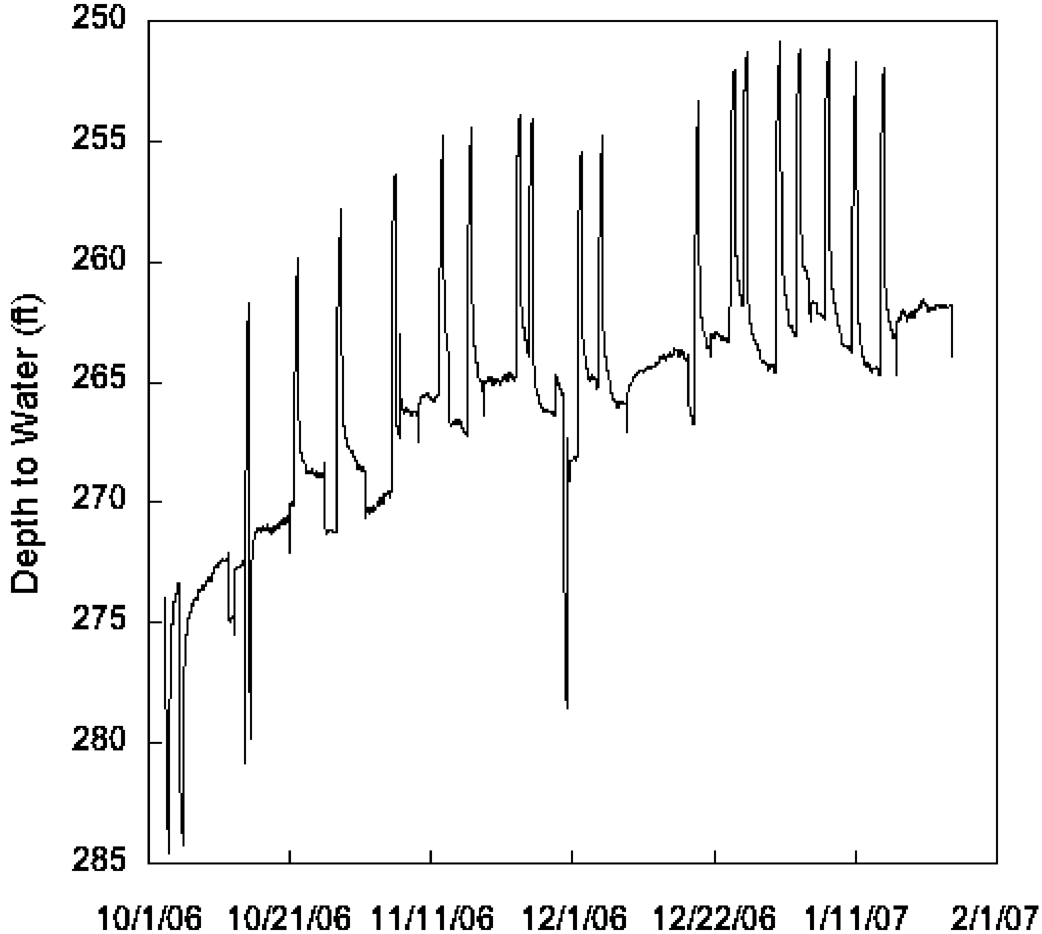

Figure 11. Water depth above the pressure transducer in OW-O in the Pittsburg wellfield for the period 10/2/2006 to 1/25/2007.

Methodology

Well tests are used to estimate the aquifer properties, transmissivity and storativity; to locate sources of recharge, impermeable boundaries within an aquifer; and estimate leakage of water across confining units. Transmissivity quantifies the ease with which water is transmitted through the entire thickness of the aquifer and is defined as the product of the aquifer hydraulic conductivity and thickness (Domenico and Schwartz, 1990). The hydraulic conductivity is a derived parameter that incorporates the intrinsic permeability property of the aquifer and the viscosity of the ground water. If the ground water is low in total dissolved solids concentrations and under temperature conditions near 20°C., the hydraulic conductivity is considered an aquifer property relative to fresh water. In aquifers that consist primarily of limestone and dolostone, the

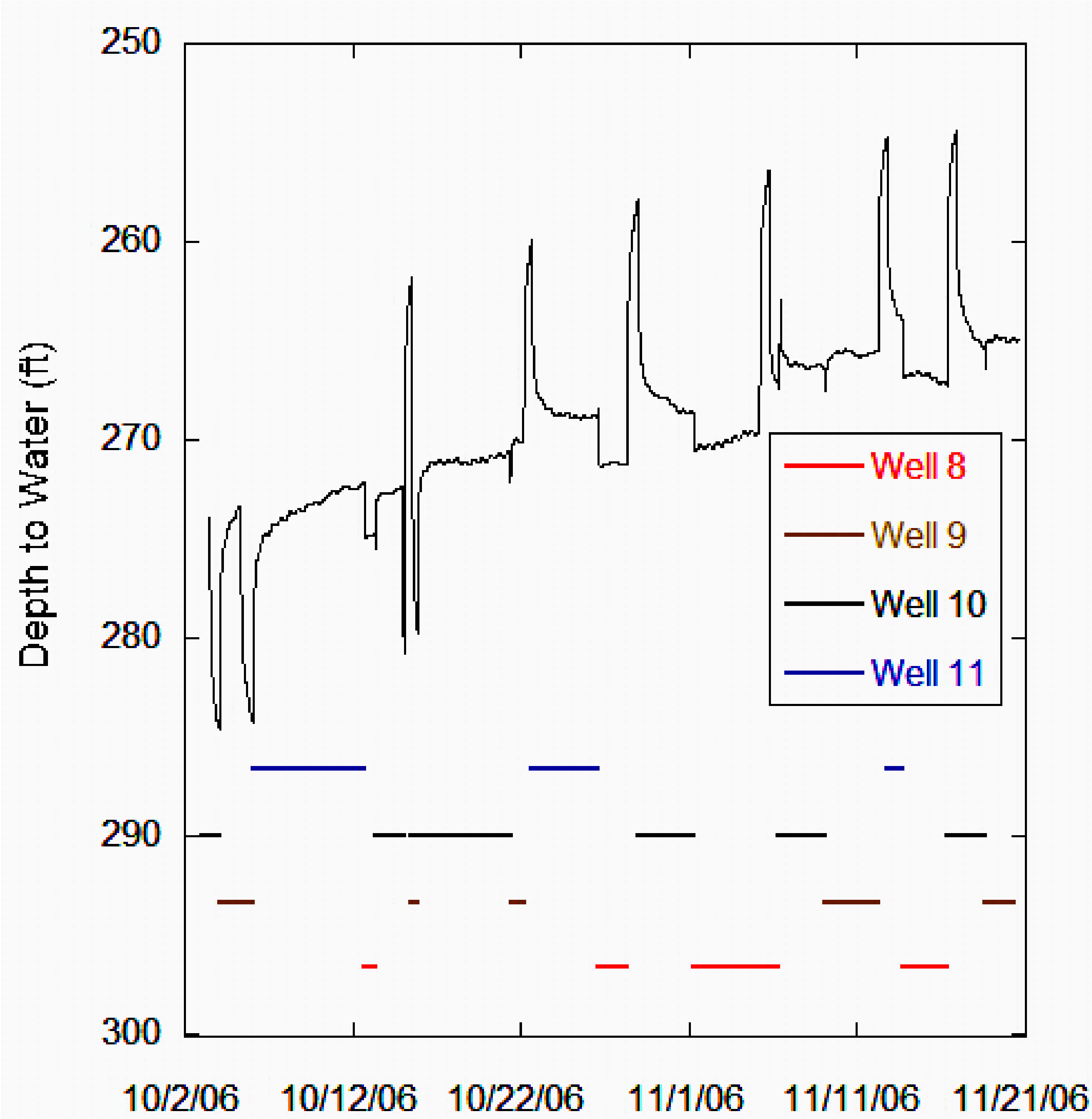

Figure 12. Example of the correlation of water-level fluctuations in OW-O with pumping in the City of Pittsburg wellfield for the period 10/2/06 to 11/21/06.

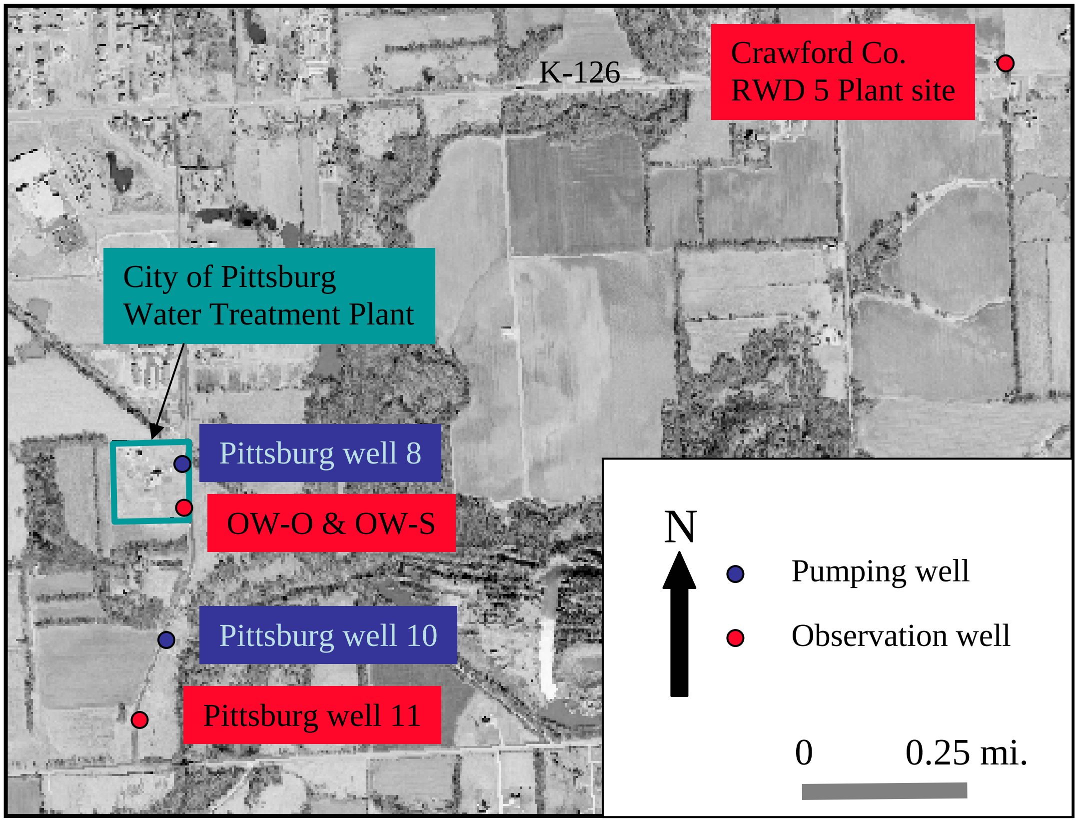

Figure 13. Location of the pumping wells (wells 8 through 11) in the Pittsburg wellfield with respect to the monitoring site where OW-O and OW-S are situated.

hydraulic conductivity of the surrounding solid rock is a measure of (1) the average fracture and solution channel aperture and spacing and (2) the connectedness of the network of open fractures and solution channels within the rock (Domenico and Schwartz, 1990). Storativity is a parameter used to quantify the storage capacity of confined aquifers and is defined as the product of the aquifer specific storage property and thickness (Domenico and Schwartz, 1990). The specific storage depends on the compressibility of the rock and the water and the aquifer porosity. Leakage of water from one aquifer to another across a confining layer depends on the confining layer thickness and vertical hydraulic conductivity in relation to the transmissivity of the underlying aquifer (Domenico and Schwartz, 1990).

Multi-well tests are conducted using a production well to pump water from an aquifer and one or more observation wells to observe water level change as pumping continues and later after the well is turned off as water-levels recover. As the well is pumped, withdrawals lower the hydraulic head within the aquifer and observation wells are used to track changes in hydraulic head over time. The potentiometric surface describes the areal variation in hydraulic head in a confined aquifer. The hydraulic head is equivalent to the elevation of the water level in wells that tap the aquifer. The area around the well where the hydraulic head has been lowered by pumping is typically circular or elliptical in shape and is referred to as the cone of depression. The difference between the altitude of the potentiometric surface prior to pumping and the

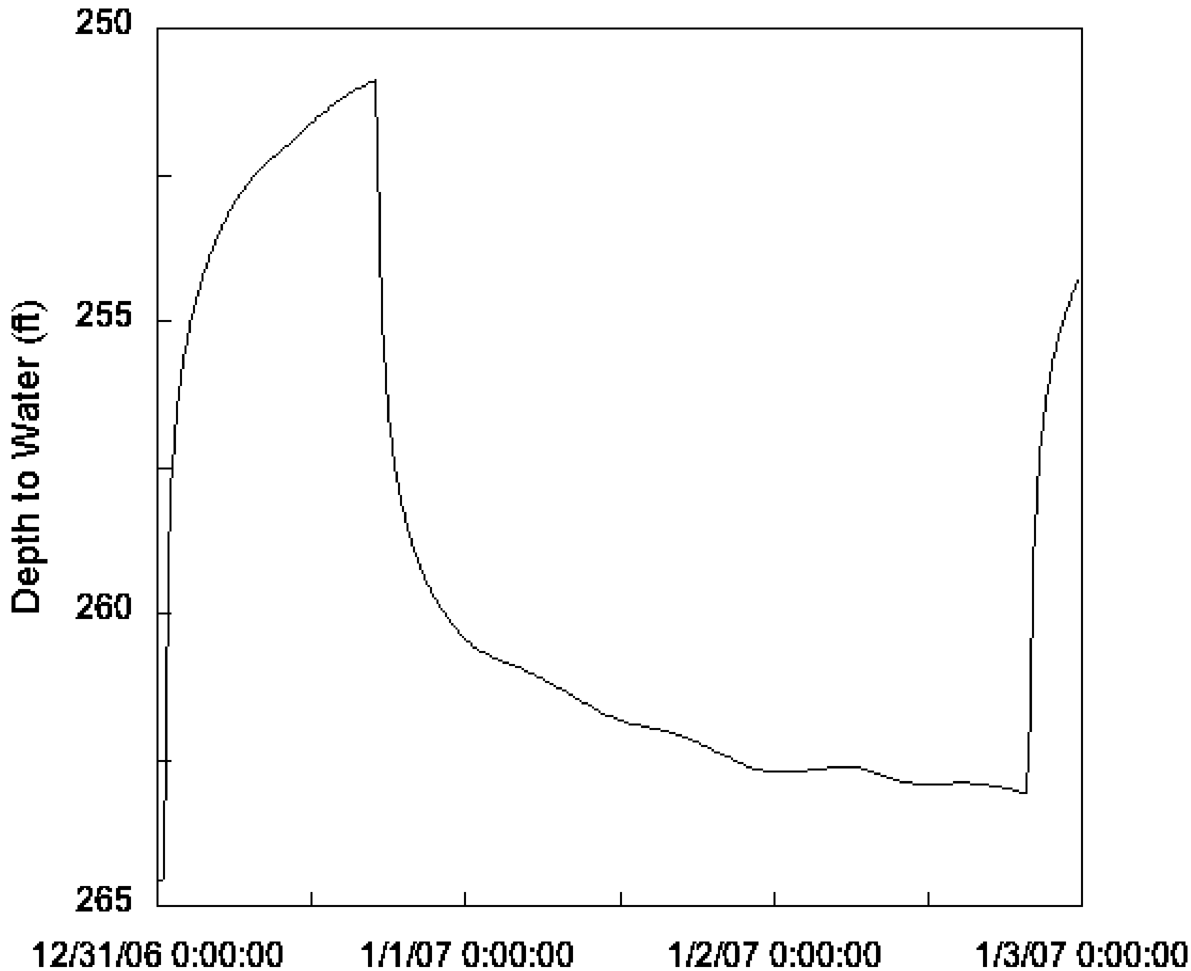

Figure 14. Hydrograph of OW-O for 12/31/06 to 1/2/07 showing approximately 12 feet of drawdown from the pumping of the City of Pittsburg Well 10.

altitude at any time during pumping is referred to as drawdown. The cone of depression expands and deepens with time in response to the fluid pressure drop caused by pumping with the greatest drop at the well. It is this drop in hydraulic head that induces ground-water flow to the well and allows the well to continuously produce water. When the pump is turned off at the end of the drawdown phase of testing, the potentiometric surface rises or recovers as the fluid pressure in the aquifer is restored over time. Recovery can also be tracked using the observation wells.

Well tests in the Pittsburg field focused on pumping water from production wells 10 and 8 and using OW-O and OW-S as observation wells (Figure 13). Other nearby wells (Pittsburg well 11 and the outside well at the Crawford Co. RWD 5 Kansas Highway 126 plant) were also used to observe water levels in the Pittsburg well 10 test but not used to estimate the aquifer properties because of the small number of measurements taken.

Method of data analysis

Estimates of aquifer transmissivity and storativity can be made using analytical solutions to the partial differential equation that describes the flow of ground water to a pumping well. The Theis equation is a solution to the ground-water flow equation for nonequilibrium radial flow to a pumping well in a confined aquifer of infinite areal extent (Domenico and Schwartz, 1990).

$$s = (Q/4\pi)W(u), \qquad \text{Eqn. 1}$$

where. s is the drawdown, Q is the steady pumping rate, W(u) is the well function and u is defined as:

$$u = r^2S/4Tt \qquad \text{Eqn. 2}$$

In Eqn. 2, r is the distance from the pumping well to the observation well; S and T are the storativity and transmissivity, respectively, of the aquifer; and t is the time since pumping began. Starting from Eqn. 1, Cooper and Jacob (1946) developed a straight-line method of analysis that recognizes the log-linear relation between t and s for large values of t:

$$s = (2.3Q/4\pi T)\log(2.25Tt/ r^2S). \qquad \text{Eqn. 3}$$

This method is appropriate if:

$$r^2S/4Tt < 0.05, \qquad \text{Eqn, 4}$$

The Theis (1935) residual drawdown analysis for data from the recovery portion of a pumping test was used make additional estimates of transmissivity and:

$$s' = (Q/4\pi T)[\ln(t/t') - \ln(S/S')], \qquad \text{Eqn. 5}$$

where s’ is residual drawdown, Q is the pumping rate, T is transmissvity, t is time since pumping began, t’ is time since pumping stopped, S is storativity during pumping, and S’ is storativity during recovery.

The input parameters used to estimate transmissivity and storativity during the pumping phase of testing are: (1) measures of drawdown taken periodically in observation wells, (2) the pumping rate, and (3) the distance between the pumping and observation well(s). Since the aquifer parameters govern both the rates of drawdown and recovery, water level data are also collected during the recovery phase of well testing and used as unrecovered drawdown to estimate these parameters All data were analyzed using the AQTESOLV Professional v.4.0 for Windows software (HydroSOLVE, 2002).

Preparation of the Raw Data for Analysis

Ideally, well tests are conducted starting from a condition where the aquifer’s potentiometric surface is under an equilibrium or static condition, which indicates a region of no flow within the aquifer. This would be the case if all pumping ceased and the hydraulic head was allowed to achieve complete recovery. Typically, complete recovery of the potentiometric surface is not possible. In the case of the Pittsburg wellfield, tests were conducted in the vicinity of other wells that had been or were being pumped. If pumping begins following incomplete recovery of water levels back to a static condition the actual drawdown is reduced by the rise of water-levels due to recovery. Thus, the water-level change observed in observation wells is the apparent drawdown as described in the following algebraic equation:

$$s_A = \text{Amount of Recovery Since Test Start (t)} + \text{Drawdown due to Pumping (t)}, \qquad \text{Eqn. 6}$$

where s_A is the apparent drawdown at any time t after the start of the test.

Fluctuations in atmospheric pressure may also impact water levels in wells, by lowering the water level when it increases and raising the water level when it decreases. Thus it is important to track changes in atmospheric pressure during well testing and take them into account during the analysis. During the well tests atmospheric pressure data were collected in inches of mercury and converted to feet of water using the equation:

Atmos. Pressure (feet of water) = Atmos. Pressure (in Hg) X 1.19 feet of water/in Hg Eqn. 7

To take the variation in atmospheric pressure into account, monitoring of water levels and barometric pressure should be carried out under static conditions in the aquifer. These data are then used to estimate the aquifer barometric efficiency (B.E.):

$$B.E. = \gamma_w dh/dP_a, \qquad \text{Eqn. 8}$$

Where γ_w is the density of water and dh/dP_a is rate of change in hydraulic head (h) with the rate of change in atmospheric pressure (dP_a). In this project, the barometric efficiency could not be estimated because of the effects of pumping outside of the wellfield. To compensate the apparent drawdowns were corrected by assuming minimum and maximum likely barometric efficiencies of 60% and 95% respectively using the equation:

$$s = s_A - B.E.(p_t - p_0), \qquad \text{Eqn. 9}$$

where s is the actual drawdown from pumping in feet, s_A is the apparent drawdown, B.E. is the barometric efficiency (water-level change in feet/atmospheric pressure change in feet of water), and p_0 and p_t are the atmospheric pressures at the beginning of the test and at any time t after test start in feet of water.

Monitoring methods and locations

Pittsburg well 10 test

Mini-TROLLs (programmable pressure transducers with on-board data storage and manufactured by In Situ, Inc.) with a calibrated pressure range of 30 pounds per square inch (psi) were installed below water level in OW-O and OW-S. A baro-TROLL (In Situ, Inc.) for tracking atmospheric pressure fluctuations was suspended approximately 10 feet below casing top in OW-S. Attempts were made to install a pressure transducer in the water-level access tube of Pittsburg Well 11 to no avail. It was determined that only manual measurements could be taken in this well. The outside well at the Crawford County RWD #5 plant on Kansas Highway 126, east of Pittsburg located approximately 1.5 miles northeast of the Pittsburg wellfield, was also monitored (Figure 13). Because of the small size of the opening into the well from the surface and the lack of personnel, only occasional manual measurements of depth to water were taken at this location during the test.

Pittsburg well 8 test

The same monitoring devices and setup were used in this test as in the Pittsburg well 10 test. Due of the lack personnel available to assist with this pumping test, no other wells were monitored.

Preparations for well testing and pre-test monitoring

Pittsburg well 10 test

City of Pittsburg personnel pumped wells 8 and 9 to build up storage in the water distribution system in advance of a 16-hour shutdown of all wells in the field which began 4:00PM 2/19/07. The 16-hour shutdown was designed to allow the Ozark aquifer potentiometric surface to at least partially recover from previous pumping, but its duration was largely controlled by the amount of water in storage and customer demand. Figure 15 shows that the potentiometric surface was still recovering from previous pumping until test start and the recovery at late time is log-linear in nature at 8.70 feet per log cycle (Figure 16). No pre-test monitoring of water levels in the Springfield Plateau aquifer was done in OW-S.

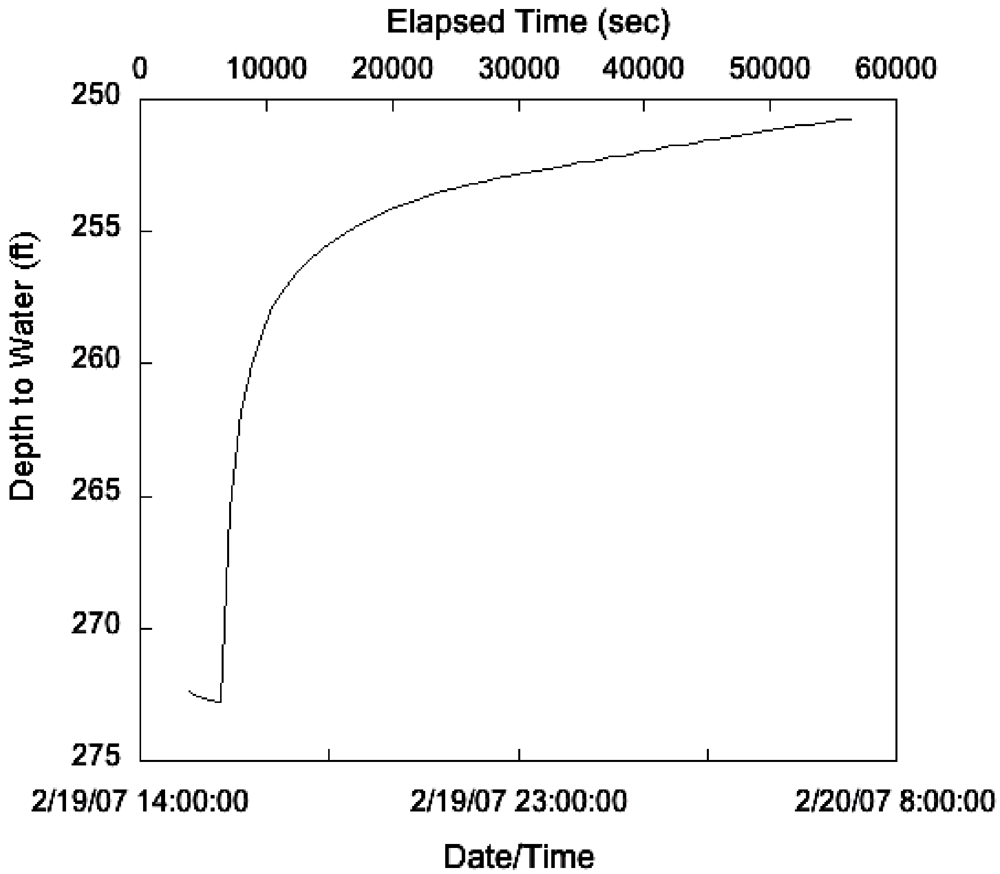

Figure 15. Hydrograph from OW-O showing the potentiometric surface recovery from earlier pumping in the wellfield prior to the well 10 test. Pittsburg well 9 was turned off at 4:00PM 2/19/07.

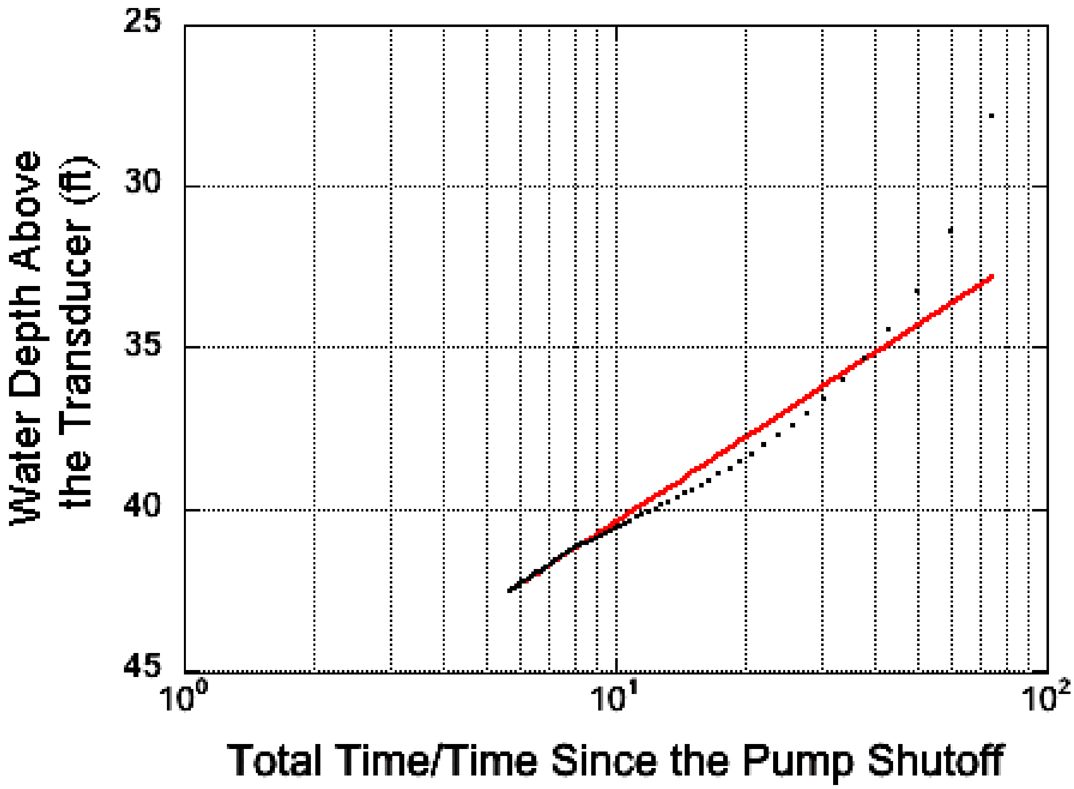

Figure 16. The assumed Theis (1935) residual drawdown model fitted to the data collected at OW-O from the pumping of production wells 8 and 9 in the Pittsburg wellfield prior to the well 10 pumping test. To estimate the continued recovery from previous pumping the linear fit was extrapolated into the future (decreasing values of the time ratio) until the end of well 10 testing.

Pittsburg well 8 test

Prior to the test the city again pumped wells 8 and 9 to build up storage in the water distribution system prior to a 12-hour shutdown of all wells in the field which began 8:00PM 3/18/07.

Data showing depth of water above the transducer data were collected from OW-O every 30 seconds from 7:50:00PM 3/18/07 to 7:30:30AM 3/19/07 and every 30 seconds in OW-S from 7:50:00PM 3/18/07 to 7:44:30AM 3/19/07. Well 8 was turned off earlier in the day. Pre-test monitoring began just prior to shutoff of Well 9 at 8:00PM 3/18/07 (Figure 17). The water-level data show the recovery of water levels from the combined pumping of well 9 and well 8. Total recovery was approximately 10 feet. Figure 18 shows that water levels in OW-O were recovering at a rate of 5.94 feet per log cycle of time prior to the testing of well 8. In contrast to the hydrograph of OW-O during recovery, the water level in OW-S declined almost 0.3 feet from pump shutoff to about 1:30AM on 3/19 and rose slightly over the next few hours until about 7:18:30AM at which point the data show an abrupt rise in water level (Figure 19). The abrupt rise in water level is believed to have occurred because of a transducer malfunction.

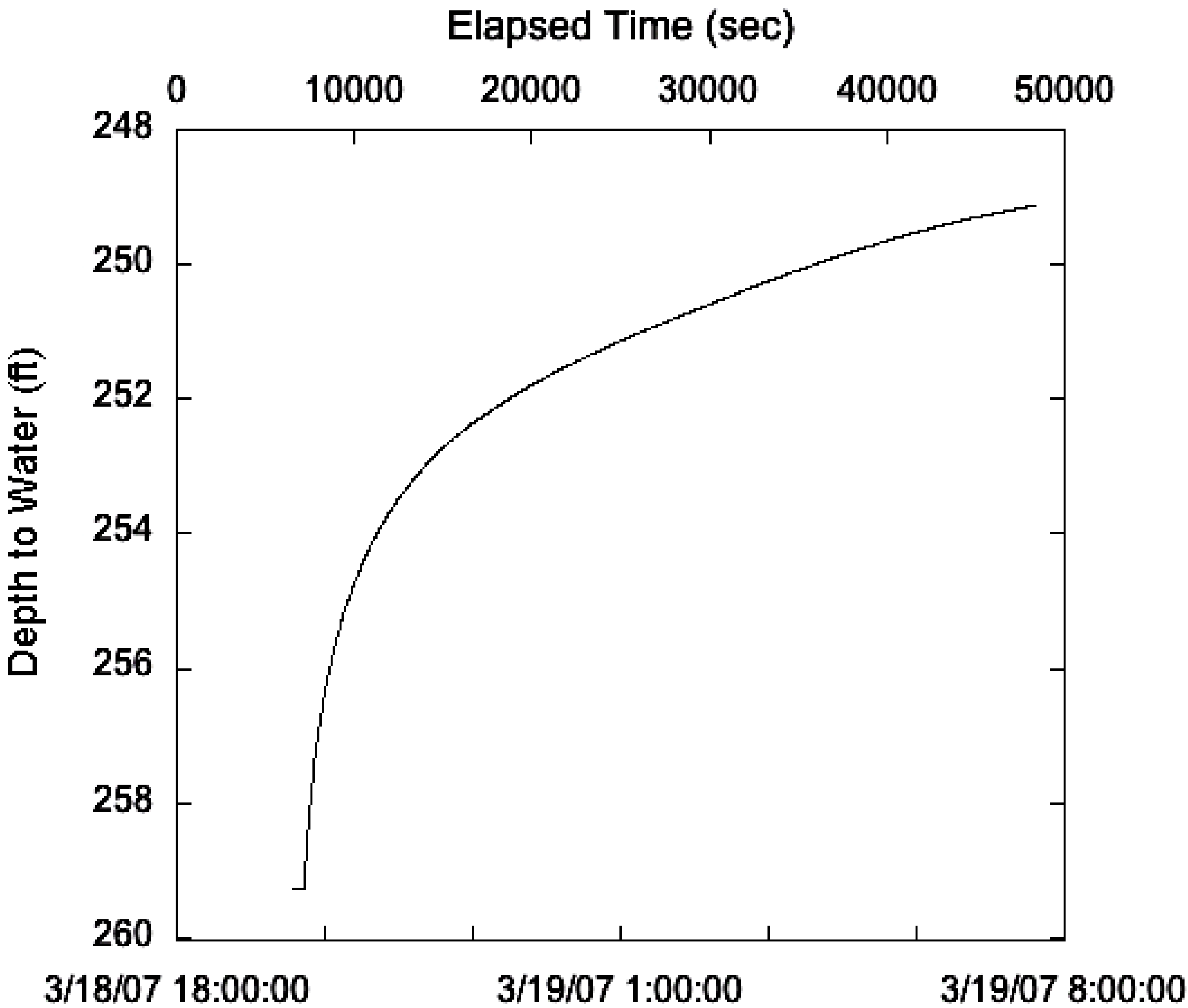

Figure 17. Pre-well 8 pumping test water levels in OW-O with measurements recorded and stored in a mini-TROLL transducer every 30 seconds.

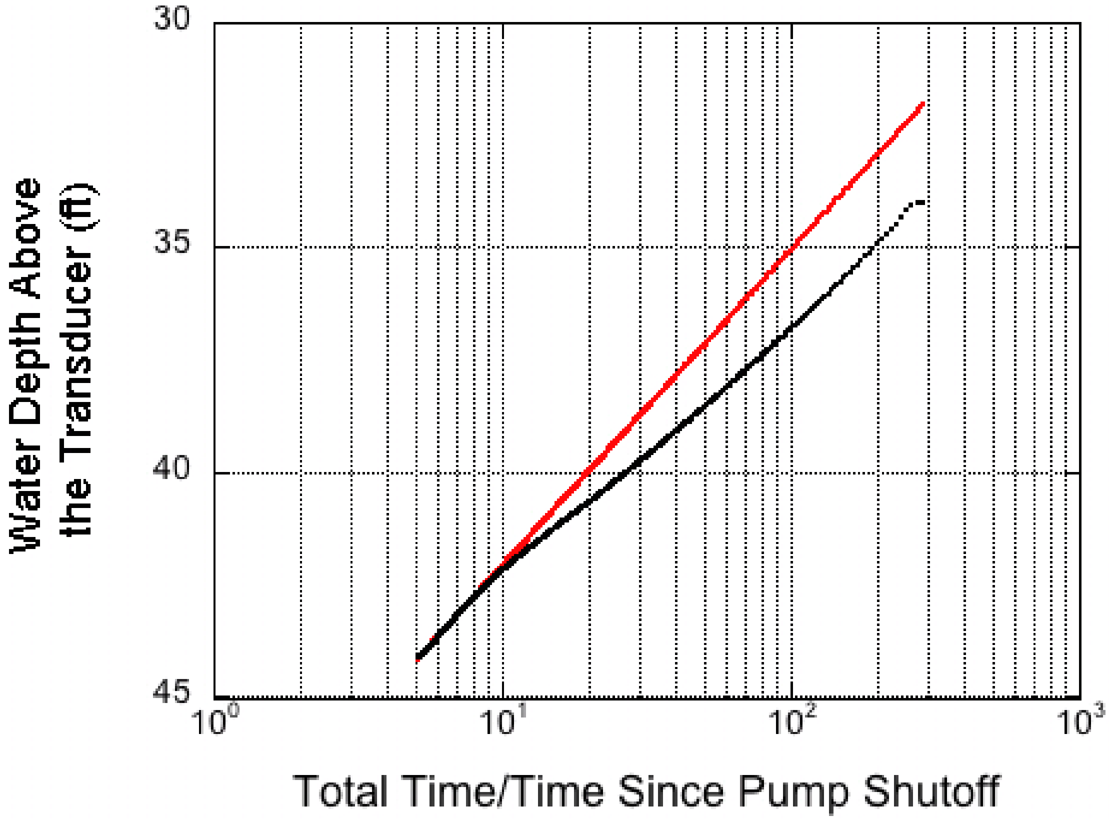

Figure 18. The assumed Theis (1935) residual drawdown model fitted to the data collected from OW-O during recovery of the aquifer from the pumping of well 11 in the Pittsburg wellfield. To estimate the continued recovery from previous pumping the linear fit was extrapolated into the future (decreasing values of the time ratio) until the end of well 8 testing.

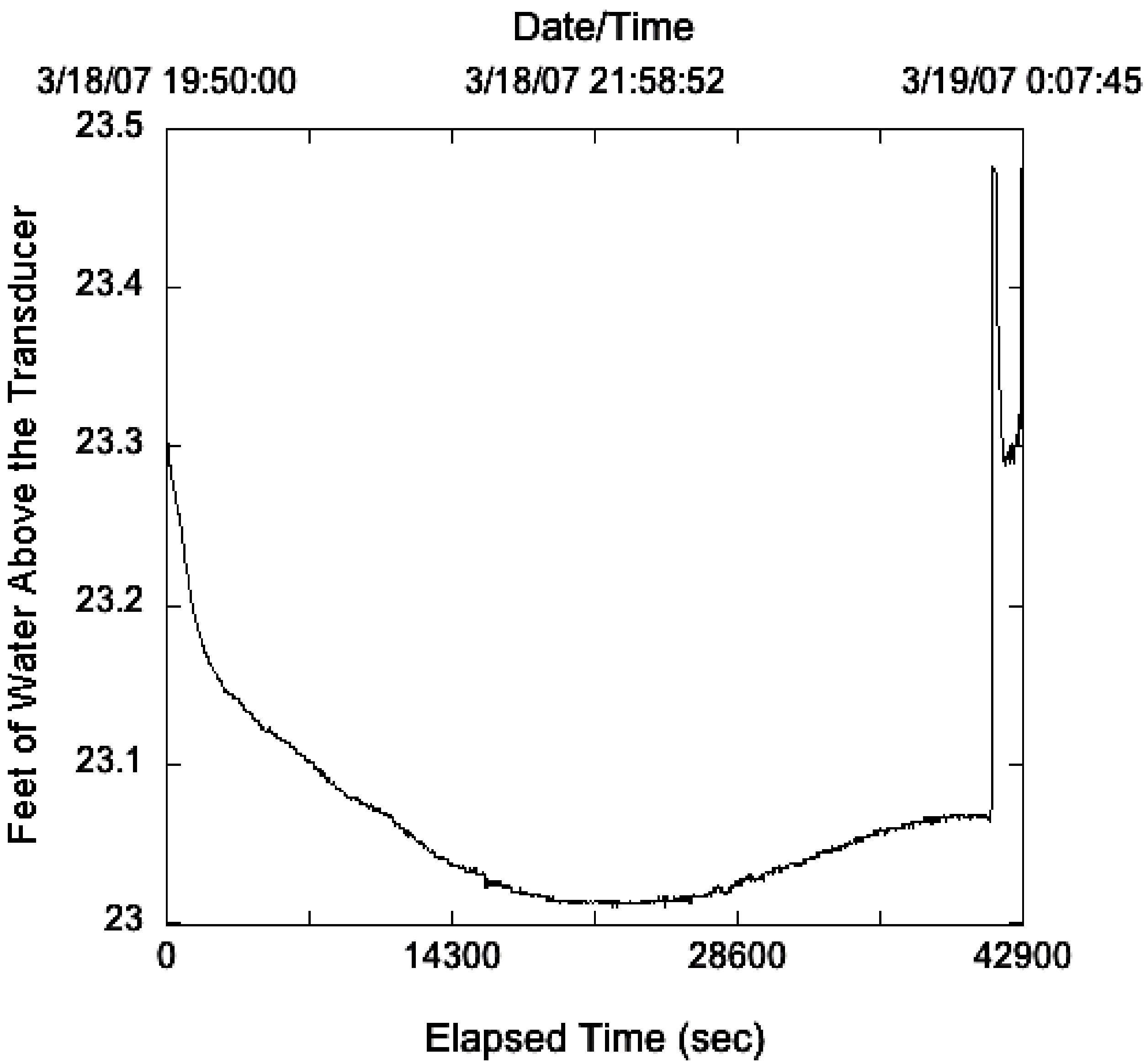

Figure 19. Raw water-level data collected from OW-S prior to the well 8 test. Water levels are referenced to the height of the water column above the mini-TROLL sensor. Accurate depth to water measurements to transform the data to depth to water measures could not be obtained using a steel tape.

Well-test data collection

Well 10

Readings of the amount of water pumped from well 10 were not taken consistently throughout the tests and were difficult to take with the analog meter. Consequently, estimates of the pumping rate were made based on the total number of hours and the estimated total amount of water pumped from the production well. Overall, well 10 produced water at an average rate of 2,005 gallons per minute (4.456 cubic feet per second).

Baro-TROLL data for the well 10 tests

The baro-TROLL in OW-S was programmed to start data collection at 8:00:00AM 2/20/07 at the rate of one point every 10 seconds (Figure 20). Barometric pressure generally increased throughout the period of testing.

Well 10 test data from OW-O

The test was set to start 8:00AM 2/20/07 with only Well 10 in operation. In order to start the pumping test as close to 8:00AM as possible, the well was turned on approximately 10 minutes before test start to allow for priming of the turbine pump. Fortuitously, the pump started producing water within 60 seconds of the official start time.

The mini-TROLL in OW-O was programmed to start data collection at 8:00:00AM 2/20/07 at the rate of one point every 10 seconds (Figure 21). This rate of data collection was maintained until 3:32:00PM 2/21/07 (113,520 seconds into the test) at which point 11,352 data points were in storage. The data were downloaded to a laptop for closer inspection and a new "test" was started at 15:37:57 (113,877 seconds after test start). Because the drawdown was increasing at a much slower rate at this point than at the beginning of the test, the mini-Troll was programmed to collect data every 15 minutes (900 seconds). This "test" continued until it was discovered that the pump had developed mechanical problems that needed attention. It was decided to end the test early at noon on 2/22/07 and to monitor the early part of the aquifer recovery from pumping. At 11:07:57AM (184,077 seconds after test start) the current "test" was stopped to adjust the rate of data collection back to one measurement every 10 seconds for the recovery period. A new "test" was started at 11:30:00AM (184,400 seconds after the start of pumping) and continued until 3:56:10PM during which water depth data were collected every 10 seconds near the end of the pumping test and during the first almost 4 hours of recovery.

After processing to remove the effects of recovery from previous pumping, the results from the OW-O transducer indicate that the total drawdown was more than 16 feet and the total recovery was more than 8 feet during the testing of this well (Figures 22-23).

Well 10 test data from OW-S

The transducer in OW-S was programmed to start collecting data every 10 seconds beginning 8:00AM at the start of the pumping test (Figure 24). However, at 10:36:10AM (9,370 sec after test start) the transducer stopped data collection for unknown reasons. Data collection resumed with the start of a new "test" at 1:33:03PM (18,783 seconds after test start). Review of the data on 12/21/07 indicated that significant water-level change had occurred in OW-S. Until this point in the test a mini-TROLL with a total measurement range of 30 psi was collecting the data. To improve the quality of the data, collection was temporarily halted at 12:34:13PM (102,853 seconds after the start of pumping), a more sensitive transducer was installed and data

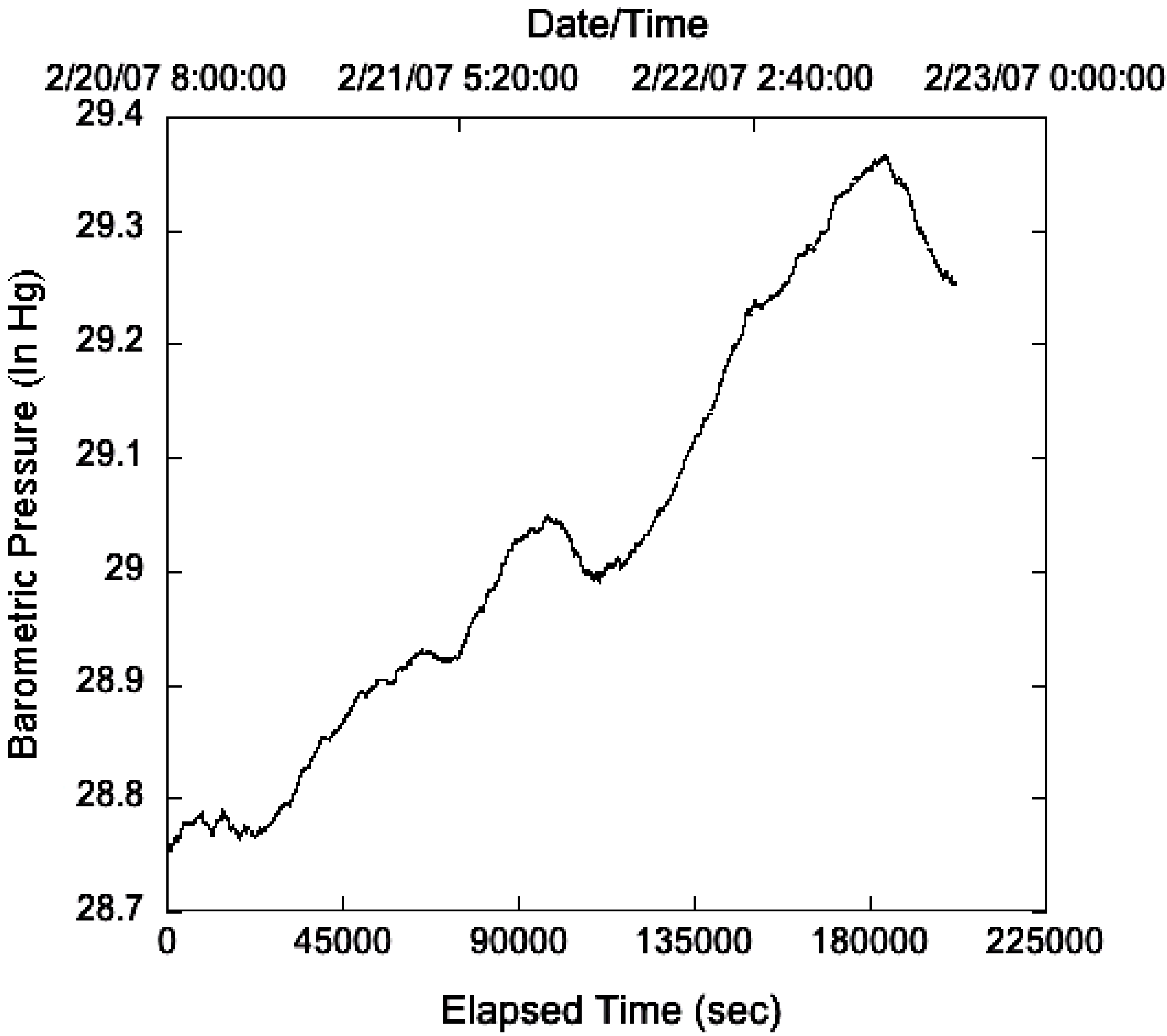

Figure 20. The barograph showing atmospheric pressure changes recorded by the baro-TROLL in OW-S during the pumping of well 10 and the following period of aquifer recovery.

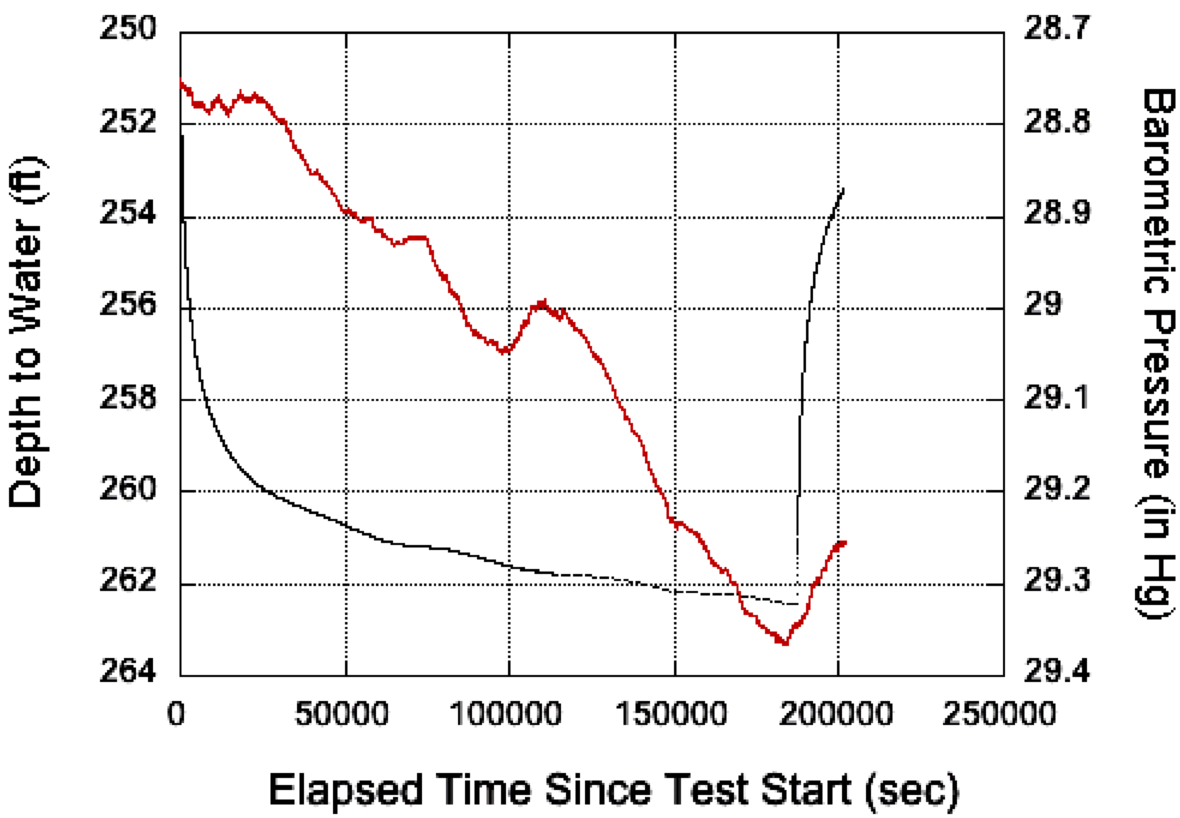

Figure 21. Plot showing the unprocessed depth to water and barometric pressure data from OW-O during the pumping and recovery phases of the Pittsburg well 10 test.

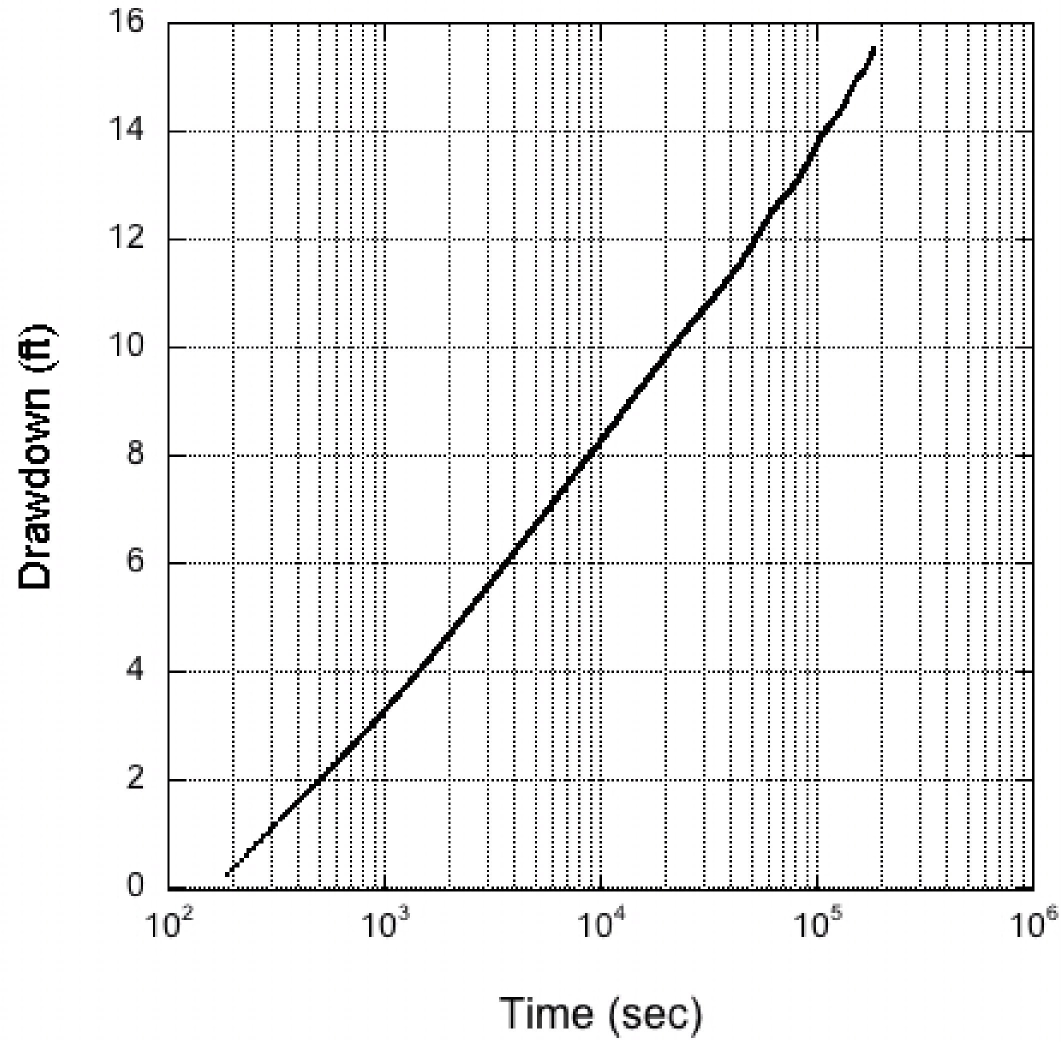

Figure 22. Drawdown in OW-O from the pumping of Pittsburg well 10 after removal of the effects of recovery from previous pumping and assuming a 95% barometric efficiency of the aquifer.

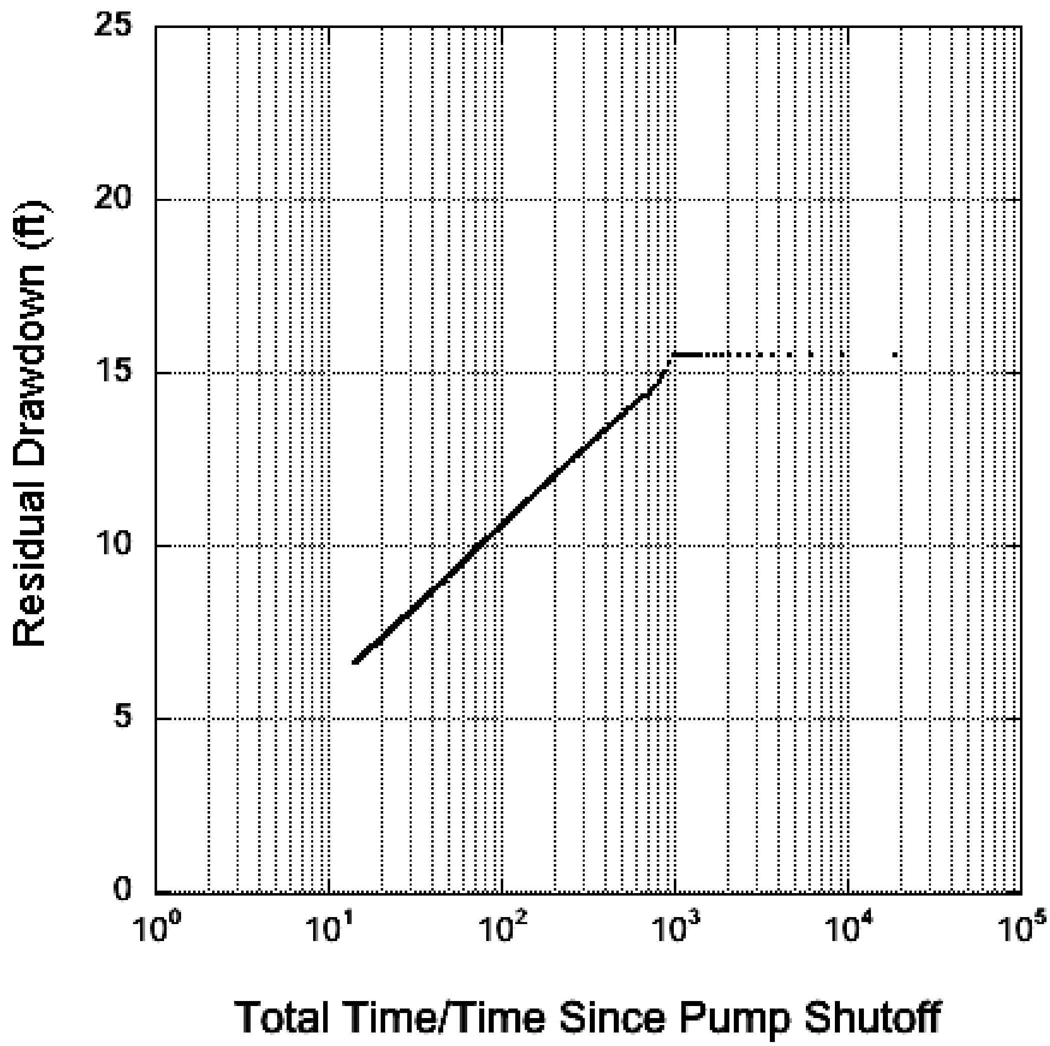

Figure 23. A log-linear plot of the ratio of total time/time since the pump shutoff vs. residual drawdown in OW-O from the pumping of well 10 after removal of the effects of recovery from pumping prior to testing and assuming a barometric efficiency of 95% for the aquifer. Data were collected every 10 seconds over 4-hour period immediately following pumping.

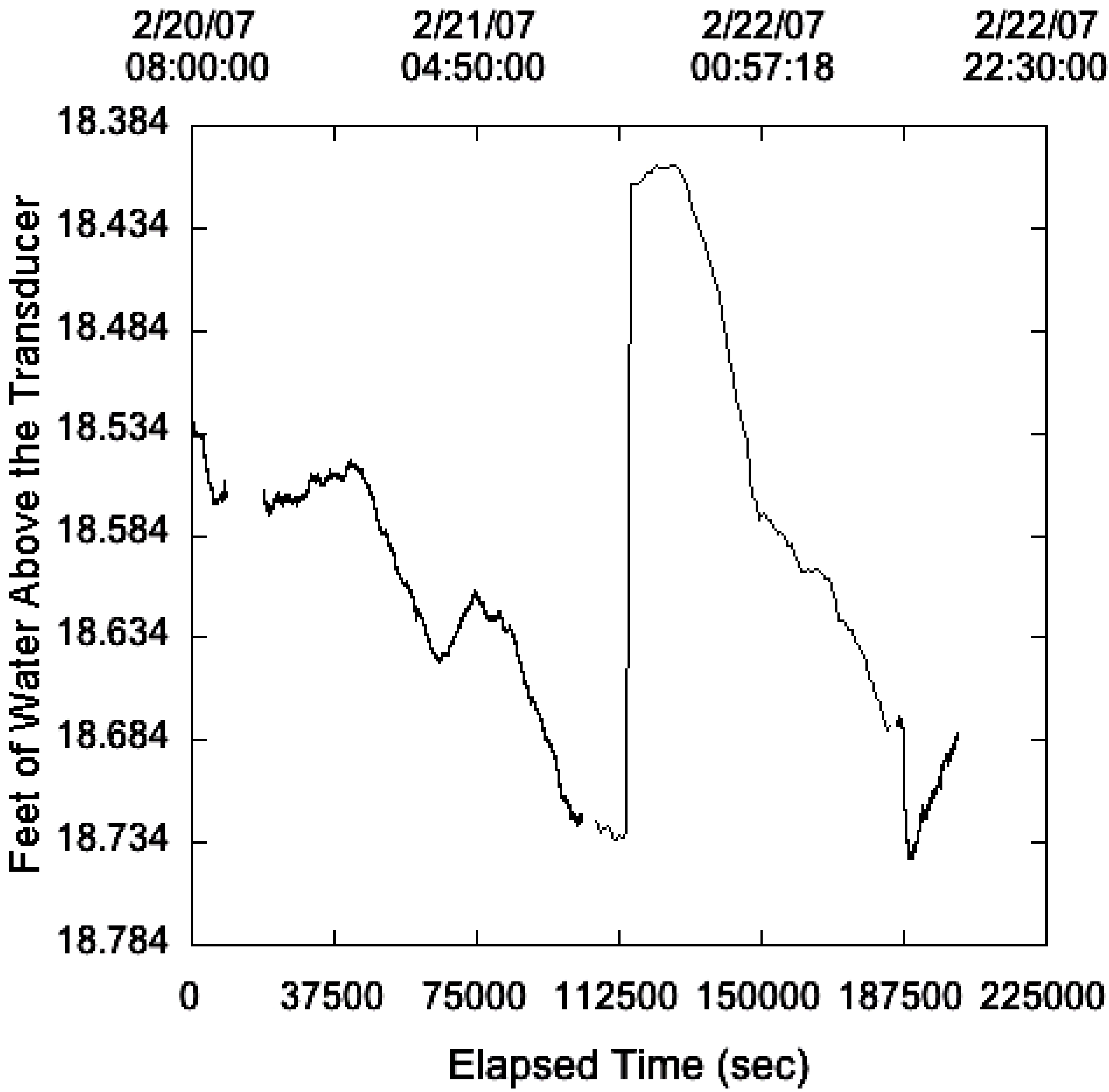

Figure 24. Raw water-level data from OW-S during the well 10 test. Water levels are referenced to the height of the water column above the mini-TROLL sensor. Accurate depth-to-water measurements to transform the data to depth-to-water measures could not be obtained using a steel tape.

collection resumed with one measurement every 900 seconds at 12:51:31PM (106,453 sec after pumping started). Data collection continued at this rate until 10:21:31AM 11/22/07. The data were downloaded to the laptop. A new "test" was set to start at 11:30:00AM (185,400 seconds after pumping started) with one measurement every 10 seconds in order to capture a more detailed record of water-level change from the recovery that would begin at noon that day. Data collection was halted at 3:59:40PM (201,580 seconds after test start).

The plot of time vs. raw water-level change data shows that there was an irregular, apparent drop in water level that occurred during pumping followed by a small apparent rise during the recovery period (Figure 24). The plot also shows an apparent steep abrupt rise of water level caused by the downward movement of the transducer in the well as a result of slippage between the cable holding the transducer and the fastener holding the cable at the surface. Prior to this event, the transducer and cable had been removed from OW-S to attach a more sensitive mini-TROLL to the cable, and collect more accurate data. A total of 11,054 data points were collected during the pumping of Well 10 and the following recovery.

Well 10 test data from other observation points

Depth-to-water measurements were made manually by DWR and KGS personnel in well 11 during the period when well 10 was pumping (Figure 25). This well is approximately 790 feet south of well 10.

Depth-to water-measurements were also made manually by DWR and KGS personnel in the outside well at the Crawford County RWD 5 main plant on Kansas Highway 126 during the period when well 10 was pumping (Figure 26). This well is approximately 8,200 feet northeast of well 10 and approximately 50 feet east of the main plant well inside the treatment plant building. Pumping was not monitored in either well at this plant.

Well 8

The test was set to start 8:00AM 3/19/07 with only city well 8 in operation. In order to start the pumping test as close to 8:00AM as possible, the well was turned on approximately 10 minutes before test start to allow for the priming of the turbine pump. The pump started producing water within 90 seconds of the official start time.

Periodic readings of the amount of water pumped from well 8 were not taken during the test but the average withdrawal rate was estimated from the total amount of water pumped from the well and the number of hours the well was pumped. Overall, well 8 produced water at an average rate of 1,875 gallons per minute (4.167 cubic feet per second).

Baro-TROLL data from the well 8 tests

The baro-TROLL in OW-S was programmed to start data collection at 8:00:00AM 2/20/07 at the rate of one point every 10 seconds (Figure 27).

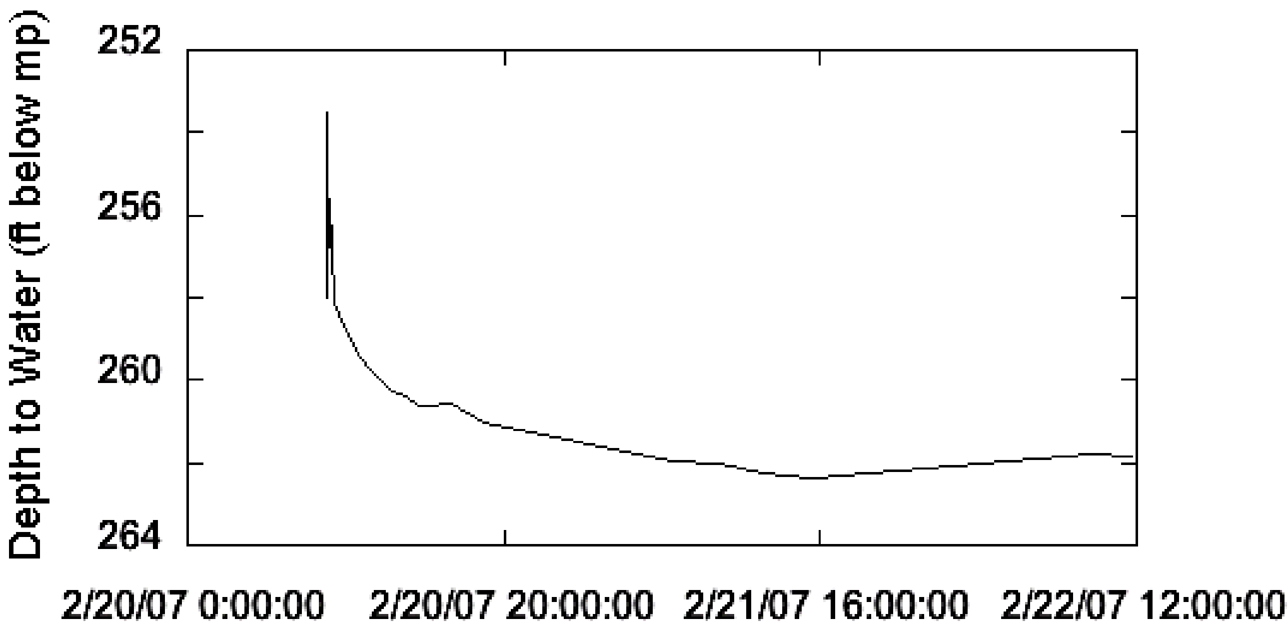

Figure 25. Depth water in Pittsburg well 11 during the pumping of Pittsburg well 10.

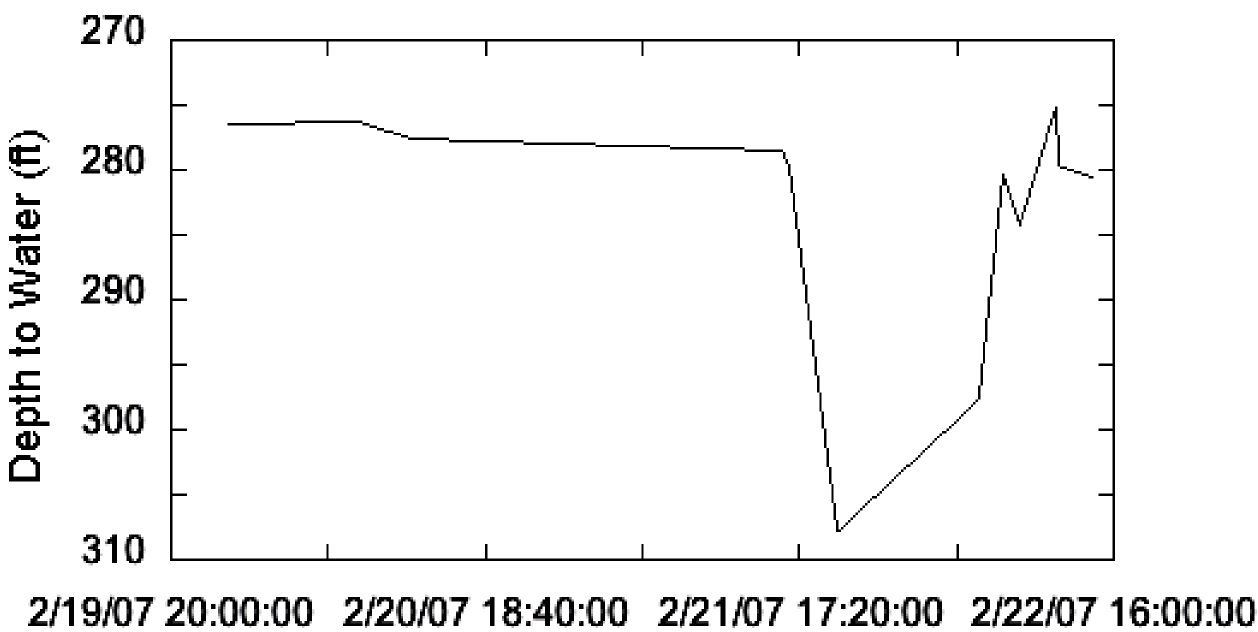

Figure 26. Depth to water in the outside well at main Crawford County RWD 5 treatment plant on Kansas Highway 126.

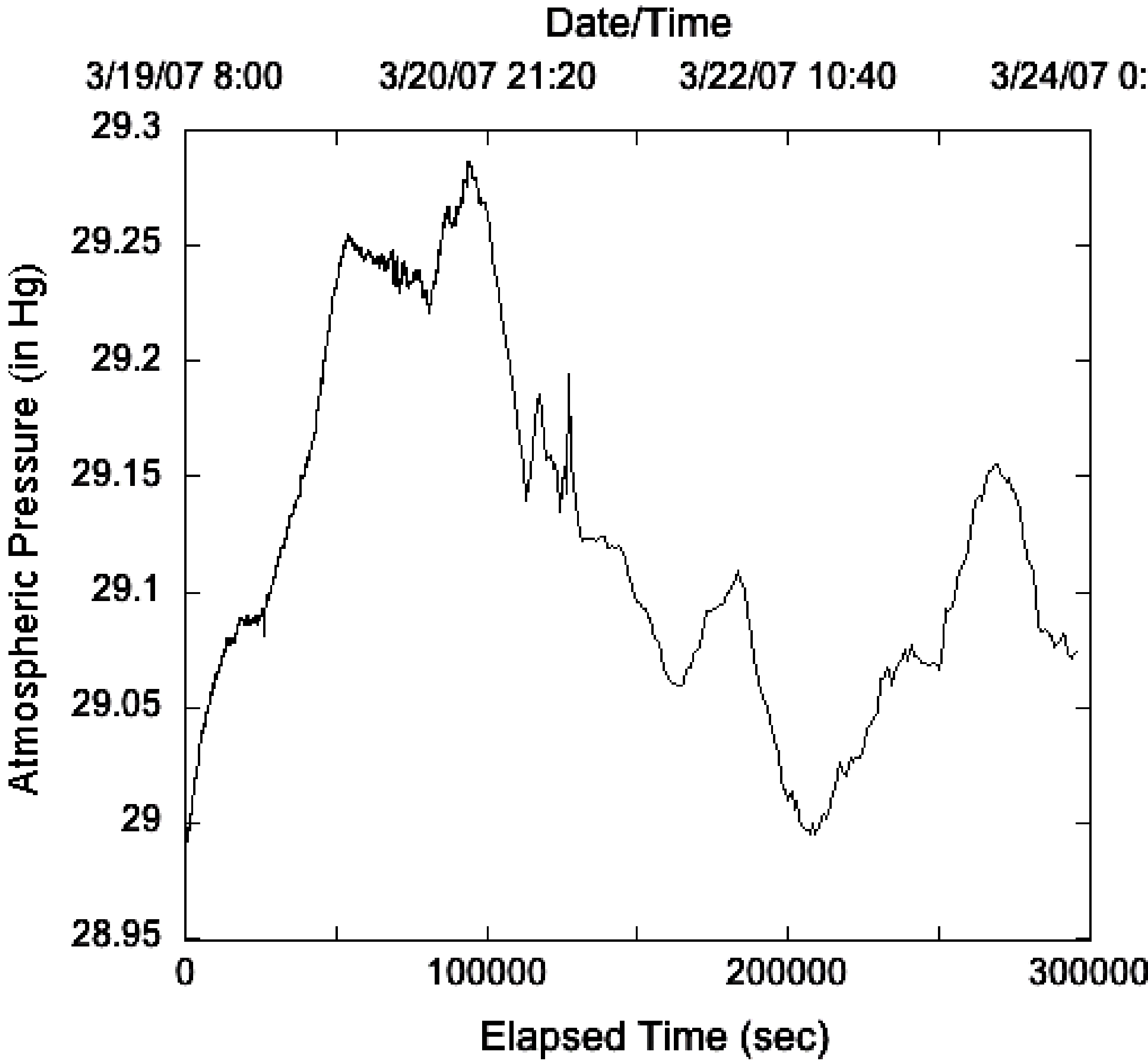

Figure 27. Barometric pressure fluctuation during the tests conducted on well 8.

Well 8 test data from OW-O

The mini-TROLL transducer in OW-O was programmed to collect data every 10 seconds starting a few minutes prior to 8:00AM startup of well 8 (Figure 28). This rate of data collection was maintained for the OW-O transducer from test start until 11:11:10AM 3/20 (98,770 seconds into the test) at which point 9,870 data points were in storage. At this point the data were downloaded to a laptop for closer inspection. A new "test" was started 11:30:00AM (99,900 seconds after test start) and the mini-Troll was programmed to collect data every 15 minutes (900 seconds). This test continued until the city's water storage was full. Well 8 pumping continued for 67.75 hours (243,900 seconds). Pumping was followed by an 11.5-hour (41,400 second) recovery period before Well 9 was turned on and OW-O experienced a new cycle of drawdown and recovery.

After processing to remove the effects of recovery from previous pumping the results from the OW-O transducer indicate that the total drawdown was more than 16 feet and the total recovery was more than 12 feet during the testing of this well (Figures 29-30).

Well 8 test data from OW-S

The mini-TROLL was programmed to collect data every 10 seconds starting at 7:45AM (Figure 31). This rate of data collection was maintained until 11:23:30AM 3/20 (98,770 seconds into the test) at which point 9,870 data points were in storage. At this point the data were downloaded to a laptop for closer inspection. A new "test" was started 11:45:00AM (100,800 seconds after well 8 started pumping) and the mini-Troll was programmed to collect data every 15 minutes (900 seconds). This test continued until the city's water storage was full. Well 8 pumping continued for 67.75 hours (243,900 seconds) (Figure 31). Pumping was followed by an 11.5-hour (41,400 second) recovery period before Well 9 was turned on and OW-1 experienced a new cycle of drawdown and recovery.

The unprocessed data show that water levels generally declined approximately 0.8 feet in OW-2 during the pumping of Well 8 and rose slightly following Well 8 shutoff (Figure 31). A total of 10,168 data points were collected during the pumping and recovery periods of the well 8 test.

Data from the monitoring in between tests of wells 8 and 10

Water-level data were collected every 15 minutes from OW-O and OW-S beginning at the end of the well 10 recovery period at 4:00PM 2/22/07 to 7:30PM 3/18/2007 prior to the pumping test of Well 8 (Figure 32).

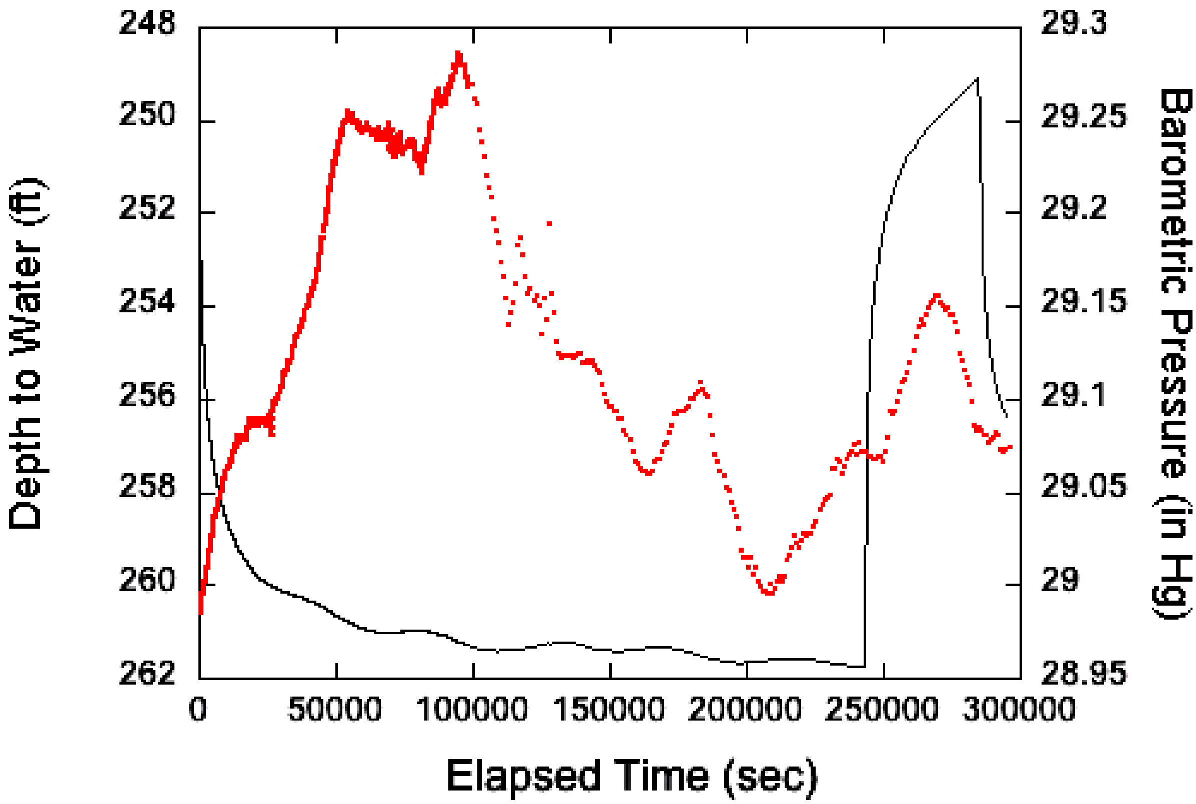

Figure 28. Unprocessed water level data from OW-O and barometric pressure data from OW-S collected during and after the well 8 pumping test in comparison with fluctuations in the barometric pressure.

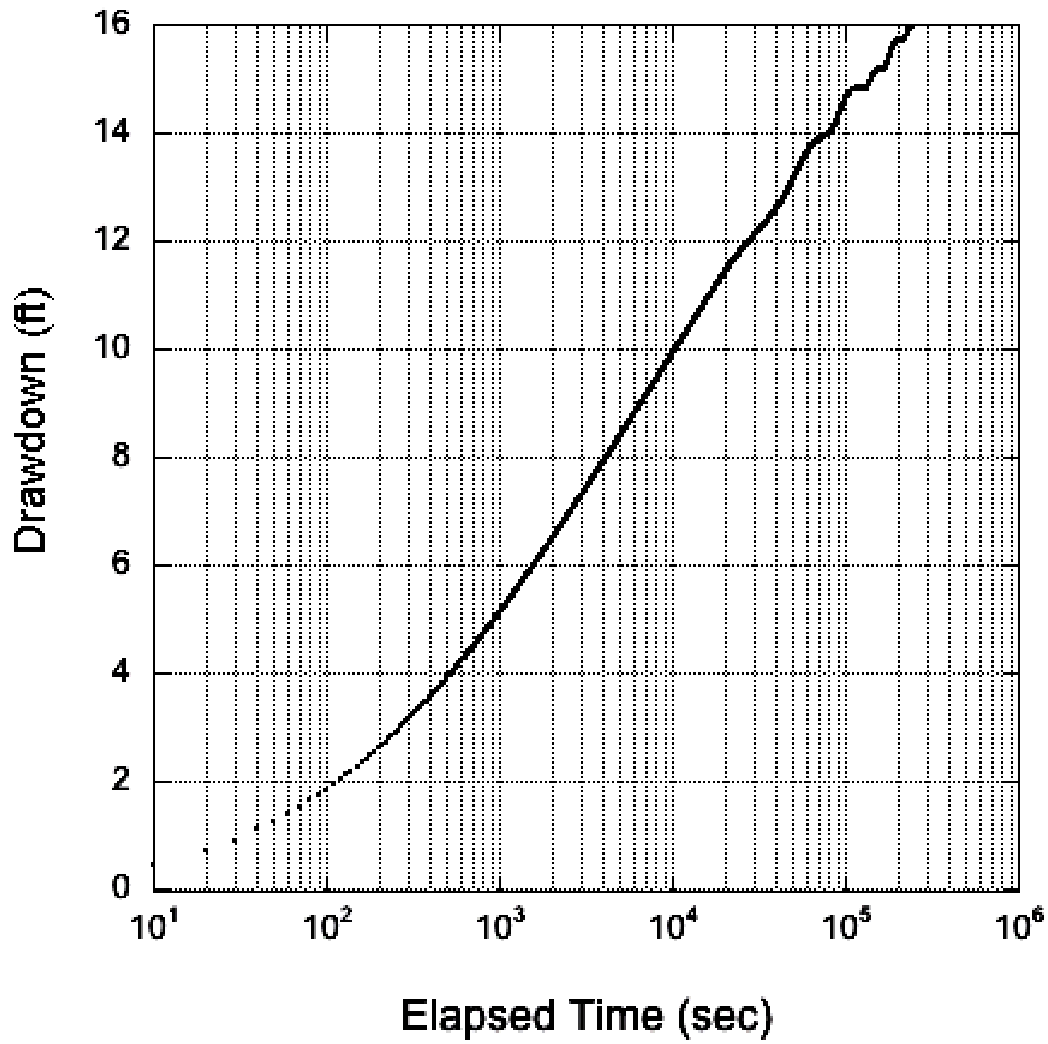

Figure 29. Log-linear plot of time vs. drawdown for processed data from the OW-O in the well 8 pumping test after removal of the effects of recovery from previous pumping and assuming a 95% barometric efficiency of the aquifer.

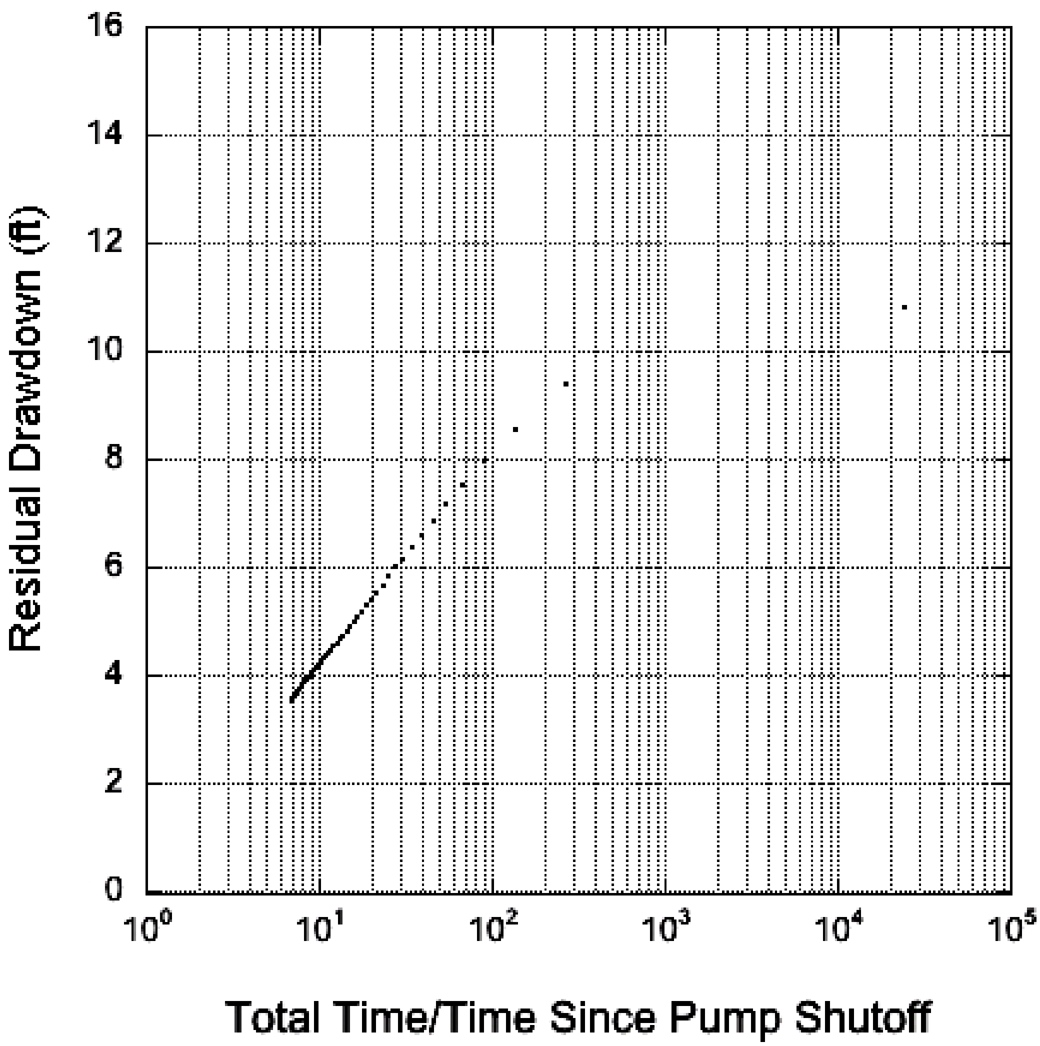

Figure 30. Plot of log of the ratio of total time/time since the pump shutoff vs. residual drawdown in OW-O in the tests of Pittsburg well 8 after removal of the effects of recovery from prior to the start of the well 8 test and assuming a 95% barometric efficiency in the aquifer.

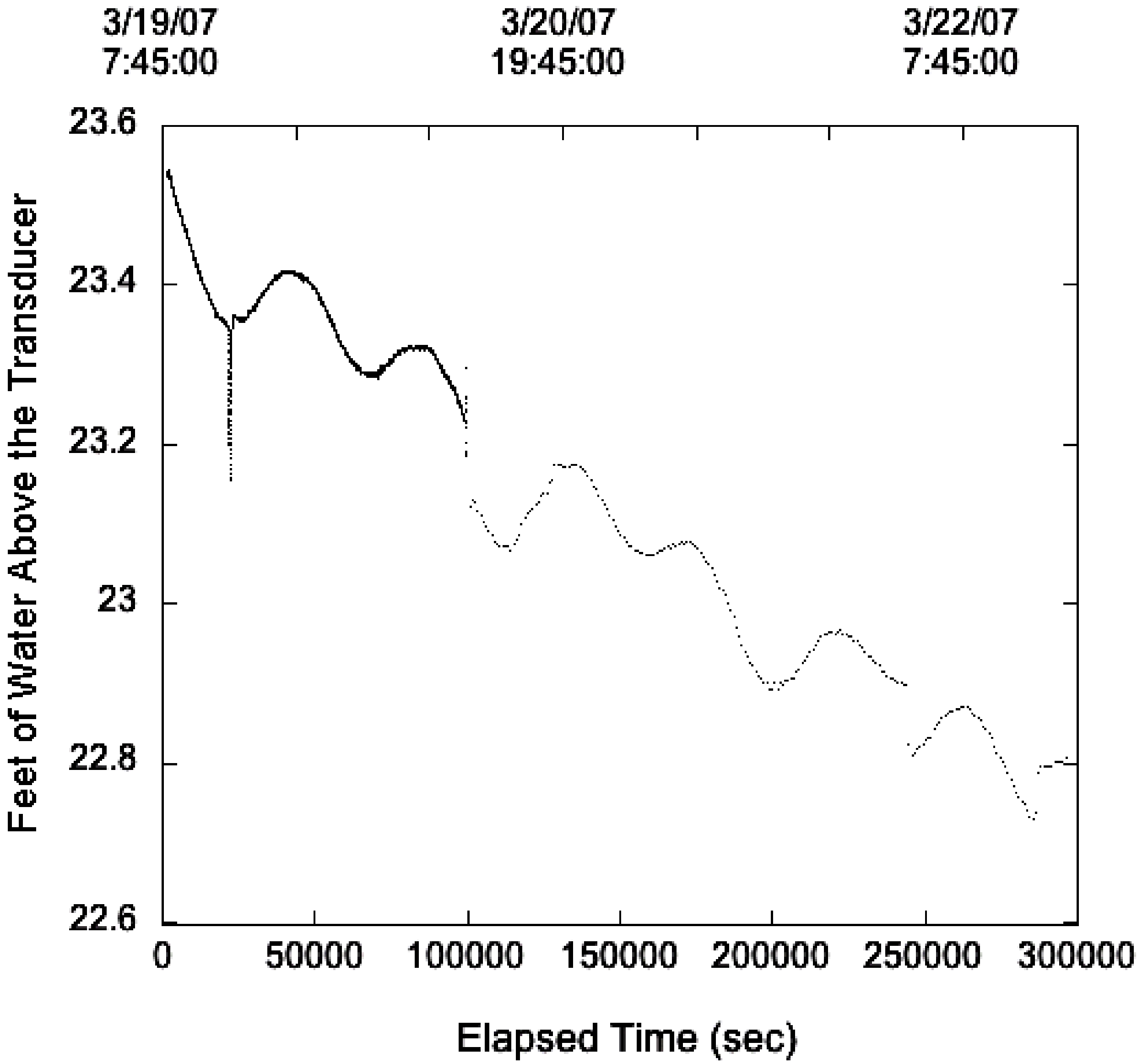

Figure 31. Raw water-level data from OW-S during the well 8 test. Water levels are referenced to the height of the water column above the mini-TROLL sensor. Accurate depth to water measurements to transform the data to depth to water measures could not be obtained using a steel tape.

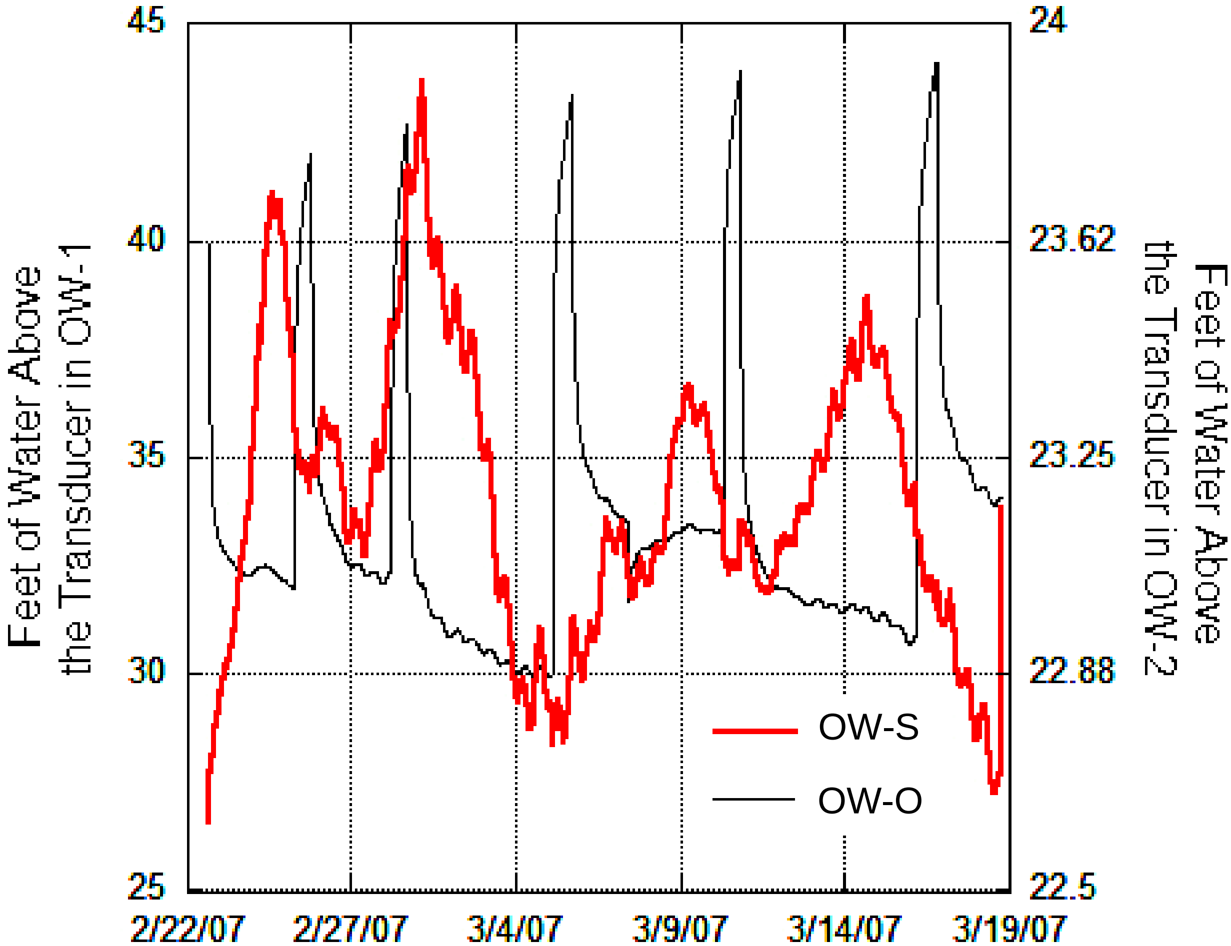

Figure 32. Water-level fluctuations in monitoring wells OW-S and OW-O during the period between the well 10 and well pumping tests (4:00PM 2/22/07 to 7:30PM 3/18/2007). Note the lack of correspondence between the highs and lows in the two monitoring wells.

Well-test analysis results from OW-O

Well 10 drawdown/recovery from pumping at OW-O

In situations where a well is pumping water at a constant rate from a homogeneous and isotropic confined aquifer of infinite areal extent, the drawdown during the course of the pumping test should eventually plot as a straight line on a graph of the logarithm of time vs. drawdown (Cooper and Jacob, 1946). However, visual inspection of the plotted drawdown curve from the well 10 pumping test indicates that it can be subdivided into at least 3 straight-line segments (0-900 seconds, 1,000-3,000 seconds, and 3,000-40,000 seconds) followed by a non-uniform segment of fluctuating drawdown with time from approximately 40,000 seconds to the end of the test (Figure 33).

Due to the restriction on the analysis imposed by Eqn. 4, the data in segment 3 from 4,000 to 25,000 seconds were used to estimate the transmissivity and storativity, based on the average pumping rate (Figure 34). Using the Cooper-Jacob analysis, the estimated transmissivity and storativity are 13,540 ± 3.2 ft^2/day and $1.32 \times 10^{-4} \pm 9.2 \times 10^{-8}$, respectively for a barometric efficiency of 95% and 13,560 ± 3.0 ft^2/day and $1.31 \times 10^{-4} \pm 8.4 \times 10^{-8}$, respectively for a barometric efficiency of 60%. Ozark aquifer hydraulic conductivity is approximately 11.3 feet/day. Using the estimated parameters, the value of $r^2S/4Tt$ is approximately 0.04, which from Eqn. 4 indicates that the Cooper-Jacob method was used appropriately.

To further evaluate the time-drawdown data in the 4,000-25,000 second interval of pumping, the time derivative was calculated for short segments of the data to determine if the log-linear slope was relatively constant throughout the period being analyzed (Figure 35). To perform this analysis, the raw time derivatives for the drawdown data assuming a 95% barometric efficiency were smoothed using the Bourdet algorithm in AQTESOLV with a default parameter value of 0.2 (HydroSOLVE, 2002). Most of the later time smoothed slope values fall along a line with a slope value of approximately 2.25. The early time slope values are scattered about the line because the algorithm had an insufficient number of data points to produce smoothed slope values. The relatively stable time derivative values provide further evidence that the data are producing high-quality estimates of transmissivity and storativity with this segment of the time-drawdown data. It is assumed that the data adjusted for a 60% barometric efficiency behave in a similar manner.

Water-level data from the recovery period following the pumping of Well 10 were analyzed using the Theis (1935) residual drawdown method described in Eqn. 5 to estimate aquifer properties (Figure 36). For the period 187,470-201,370 seconds after pumping began, aquifer transmissivity and the ratio of S/S’ were 15,410 ± 9.3 ft^2/day and 0.706 ± 0.002, respectively adjusted for a barometric efficiency of 95% and 15,290 ± 8.1 ft^2/day and 0.650 ± 0.001, respectively for a barometric efficiency of 60%. Most of the data fall along the Theis (1935) model to produce a low standard error, which indicates a good model fit. The transmissivity estimate from the recovery data is approximately 14% higher than the value obtained from the analysis of the drawdown data.

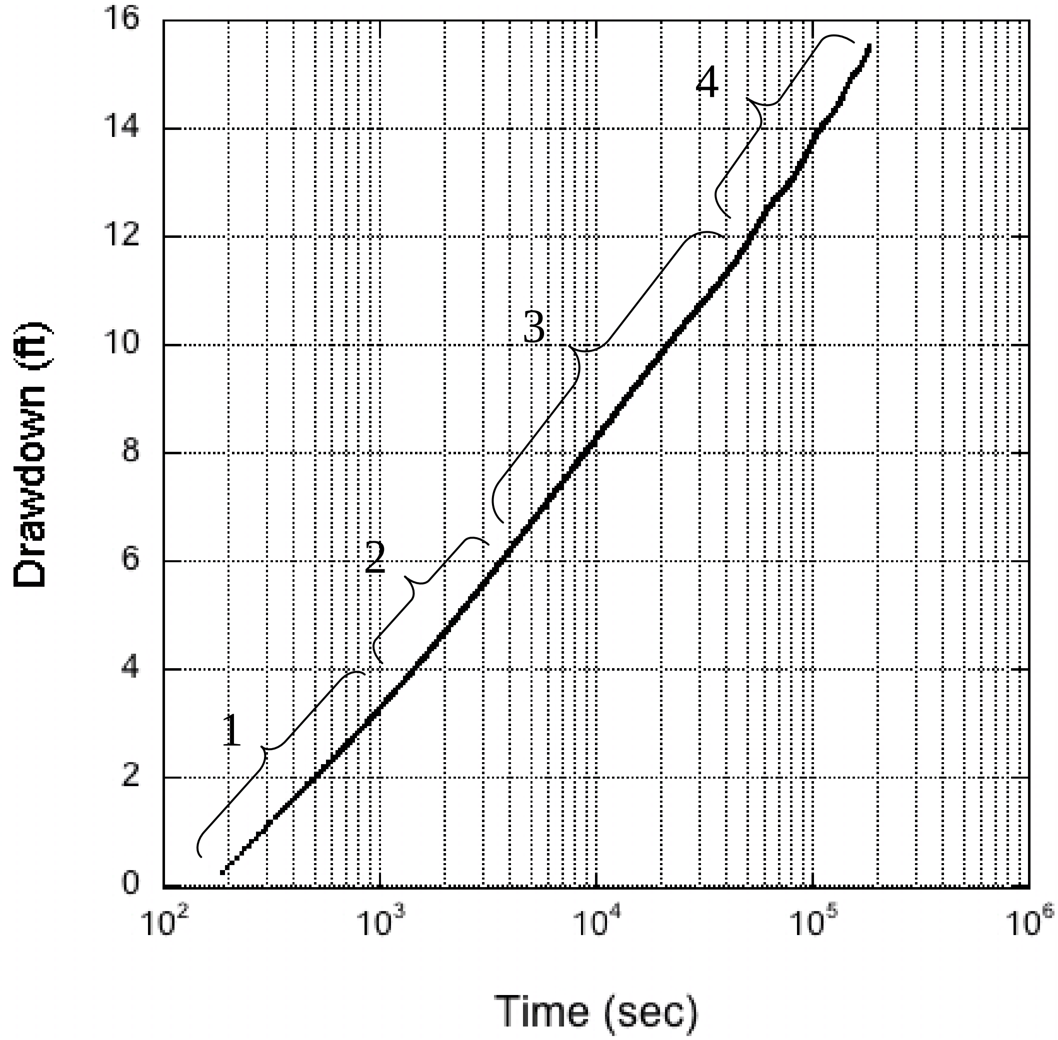

Figure 33. Drawdown observed at OW-O over the duration of the well 10 pumping test showing the segmentation in the rate of increase in drawdown. Within sections 1 through 3 the rate of drawdown increase is relatively constant but higher than in the previous section and lower than in the succeeding section. In section 4, the slope of the drawdown is variable, possibly due to pumping from other wells outside of the Pittsburg wellfield.

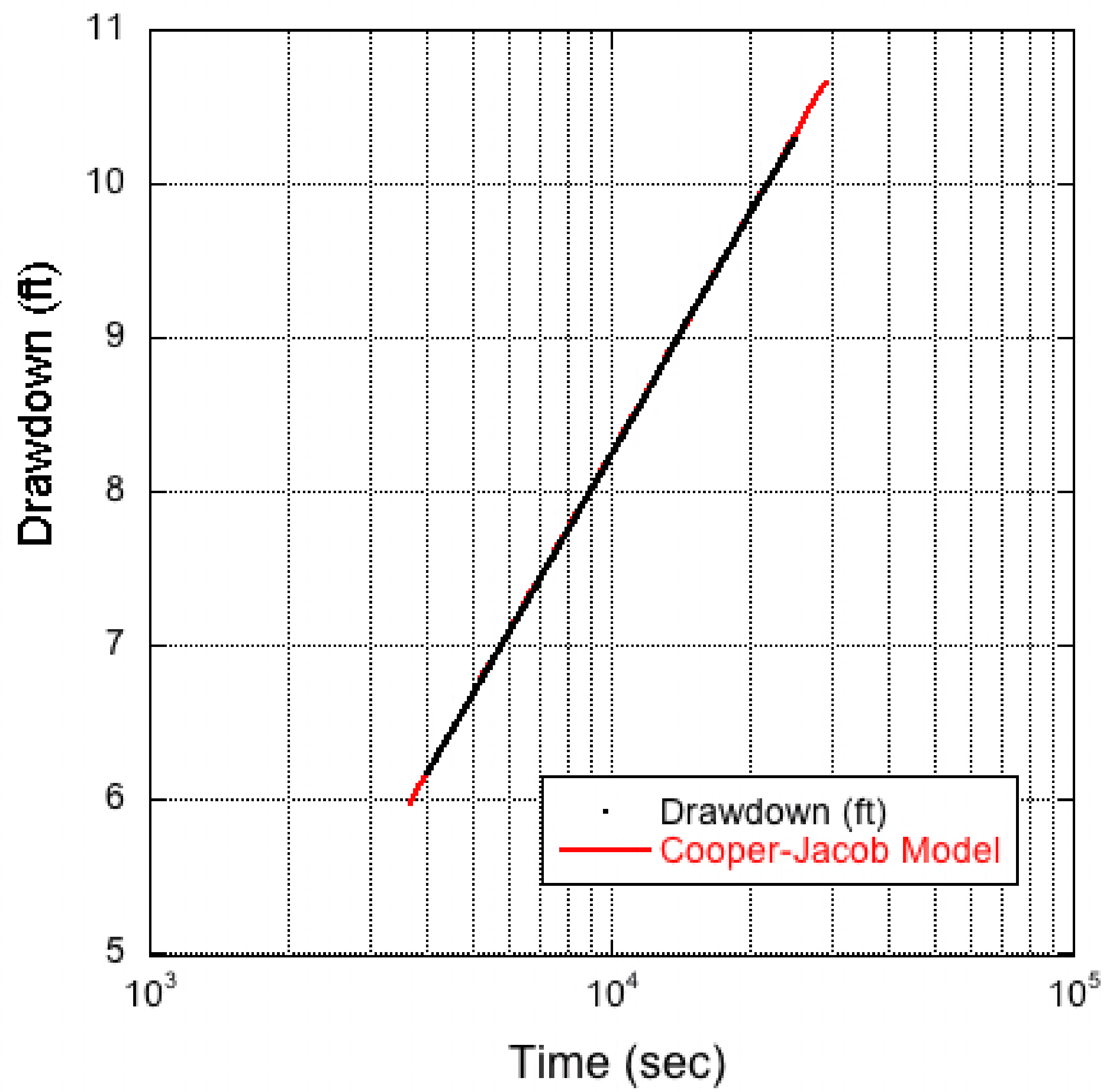

Figure 34. Curve fit of the data from 4,000-25,000 second of the well 10 pumping test to a Cooper-Jacob (1946) type analysis in the AQTESOLV well-test software adjusted for a 95% barometric efficiency.

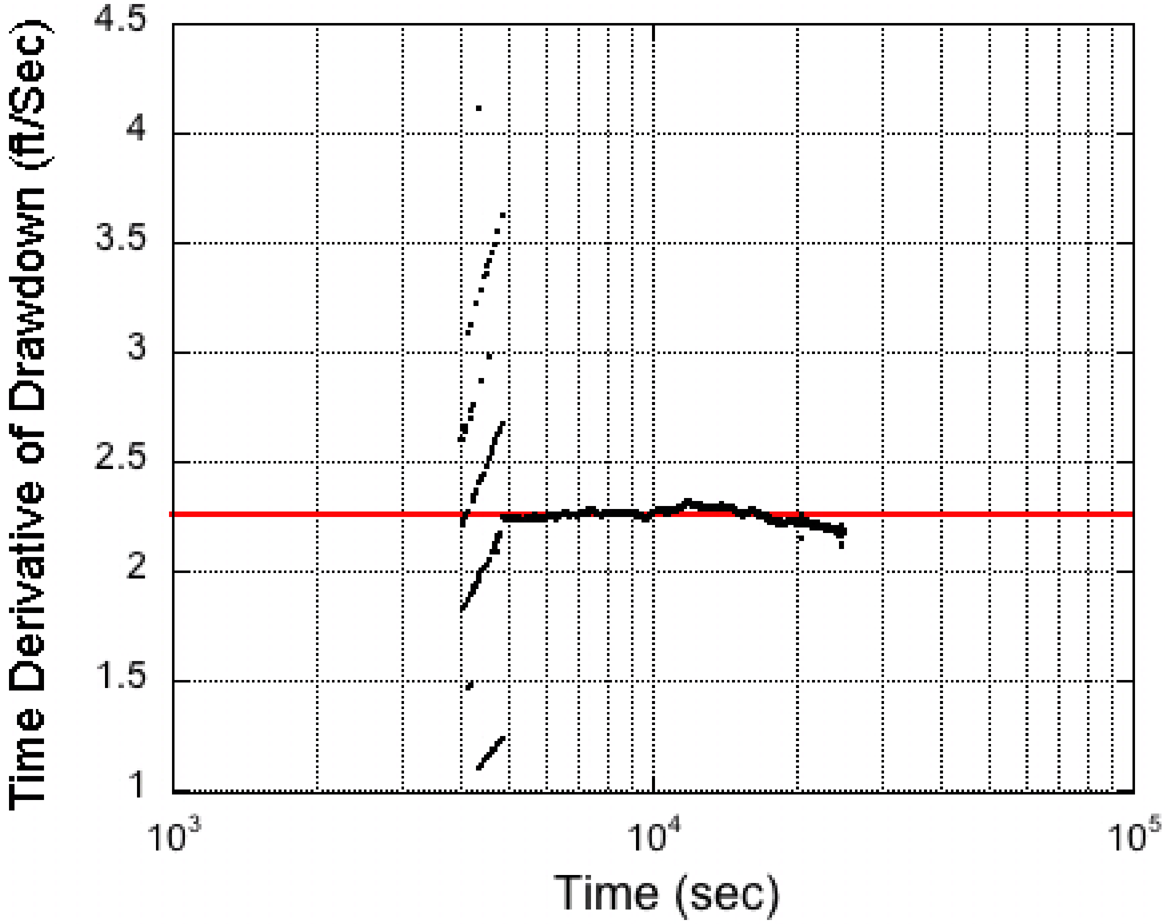

Figure 35. Time vs. the time derivative of drawdown for the data from the 4,000-25,000 second interval of the well 10 pumping test adjusted for a 95% barometric efficiency.

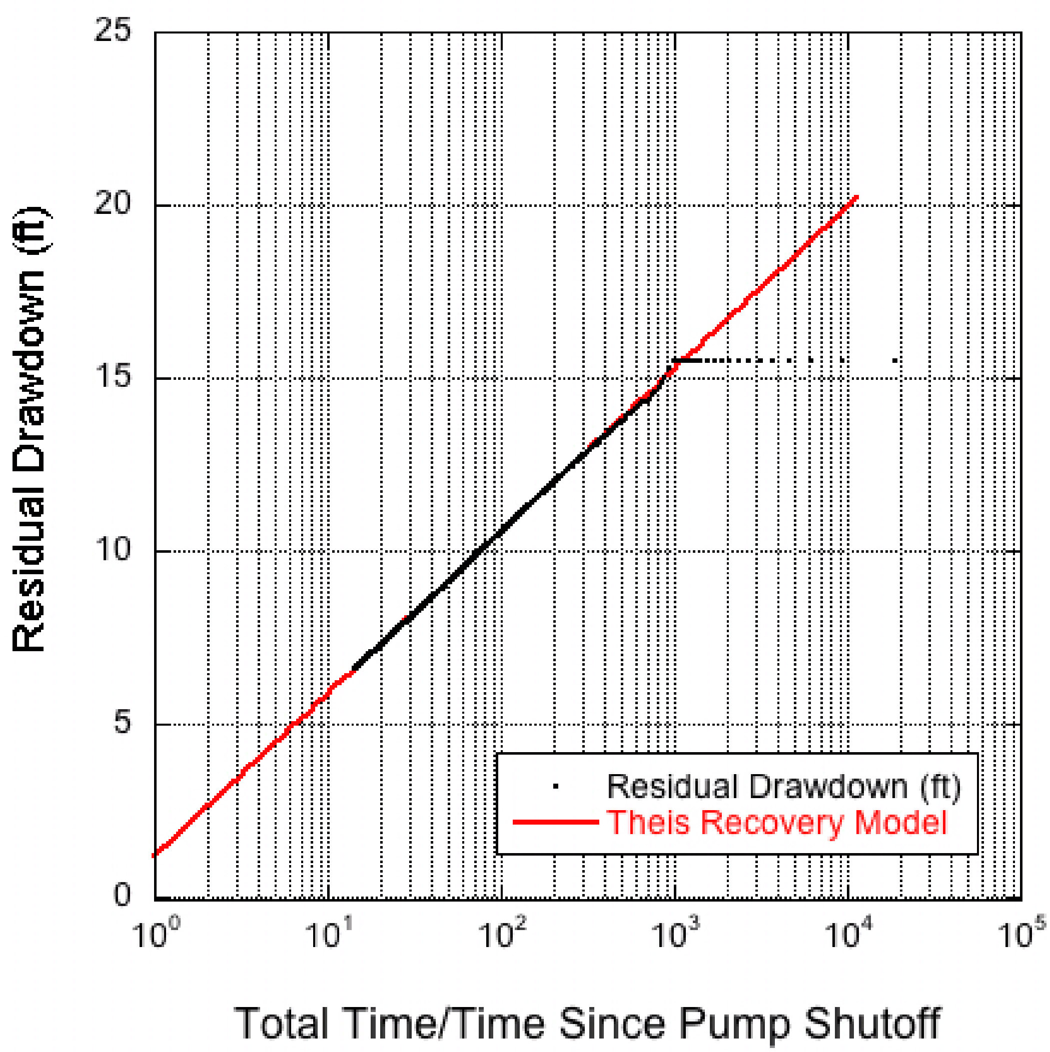

Figure 36. The residual drawdown data fitted to the Theis (1935) model for data from the recovery period of the well 10 test adjusted for a 95% barometric efficiency.

Well 8 drawdown/recovery from pumping at OW-O

In the early part of the well 8 pumping test measurable drawdown begins approximately 10 seconds after the start of pumping and rate of drawdown increase accelerates through the first few hundred seconds of pumping before achieving a relatively constant rate. With minor fluctuations this rate of increase remains relatively constant up through about 22,000 seconds of pumping (Figure 29). After this segment fluctuations in the rate of drawdown increase characterize the curve to the end of the pumping period. During the recovery phase of the test, the curve defined by the ratio of total time/time since the pump shutoff and residual drawdown appears to asymptotically approach one Theis (1935) model at time ratio values in the range of 8-

100, and another at time ratios less than 8 (Figure 30). It is unclear why this happens based on the data collected during this part of the test.

As with the data from the well 10 test, the well 8 time-drawdown data from 4,000 to 20,990 seconds were used in the analysis to produce estimates of aquifer transmisivity and storativity (Figure 37). Using the Cooper-Jacob analysis, the estimated transmissivity and storativity are 13,460 ± 2.4 ft^2/day and 1.13 x 10^{-4}± 7.4 x 10^{-8}, respectively, adjusted for a barometric efficiency of 95% and 13,370 ± 2.4 ft^2/day and 1.14 x 10^{-4}± 7.8 x 10^{-8}, respectively, for a barometric efficiency of 60%. Using the estimated parameters, the value of $r^2S/4Tt$ is approximately 0.04, which from Eqn. 4 indicates that the Cooper-Jacob method is an appropriate analytical technique. Ozark aquifer hydraulic conductivity is approximately 11.2 feet/day from this part of the well 8 pumping test. As in the analysis of the well 10 drawdown data, the stability of the time derivatives indicates that transmissivity and storativity estimates are high quality using the Cooper-Jacob analysis (Figure 38).

A Theis (1935) residual drawdown method of analysis was run on the recovery data (Figure 39). The ratio of total time/time since the pump shutoff vs. residual drawdown curve has two linear segments that differ in their slope value. Using the later recovery data from 276,310-284,410 seconds, aquifer transmissivity and the ratio of S/S' were 15,930 ± 321 ft^2/day and 1.059 ± 0.042, respectively assuming a barometric efficiency of 95% and 14,920 ± 346 ft^2/day and 1.172 ± 0.051, respectively assuming a barometric efficiency of 60% (Figure 40). Using the earlier recovery data from 247,510-274,510 seconds, aquifer transmissivity and the ratio of S/S' were 15,930 ± 106 ft^2/day and 1.088 ± 0.021, respectively assuming a barometric efficiency of 95% and 16,130 ± 96.6 ft^2/day and 1.022 ± 0.018, respectively assuming a barometric efficiency of 60%. These estimates of transmissivity are approximately 18-21%% higher than the estimated value computed from the Cooper-Jacob analysis of the drawdown data. The difference between these sets of values is difficult to explain but could be related to pumping outside of the wellfield from wells at the Crawford County RWD #5 treatment plant on Kansas Highway 126.

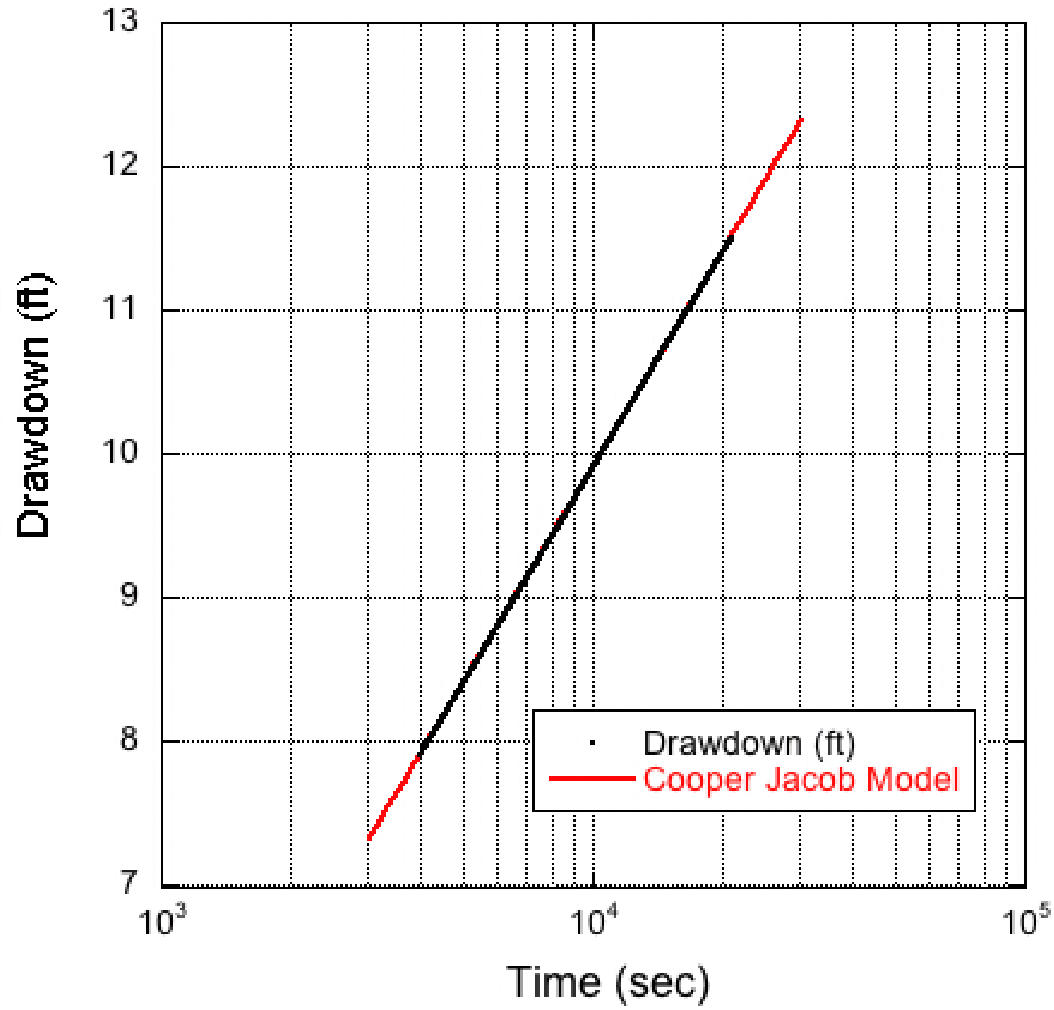

Figure 37. Curve fit of processed data collected from OW-O from 4,000-20,990 seconds of the well 8 pumping test using a Cooper-Jacob type analysis in the AQTESOLV well-test analysis software adjusted for a 95% barometric efficiency.

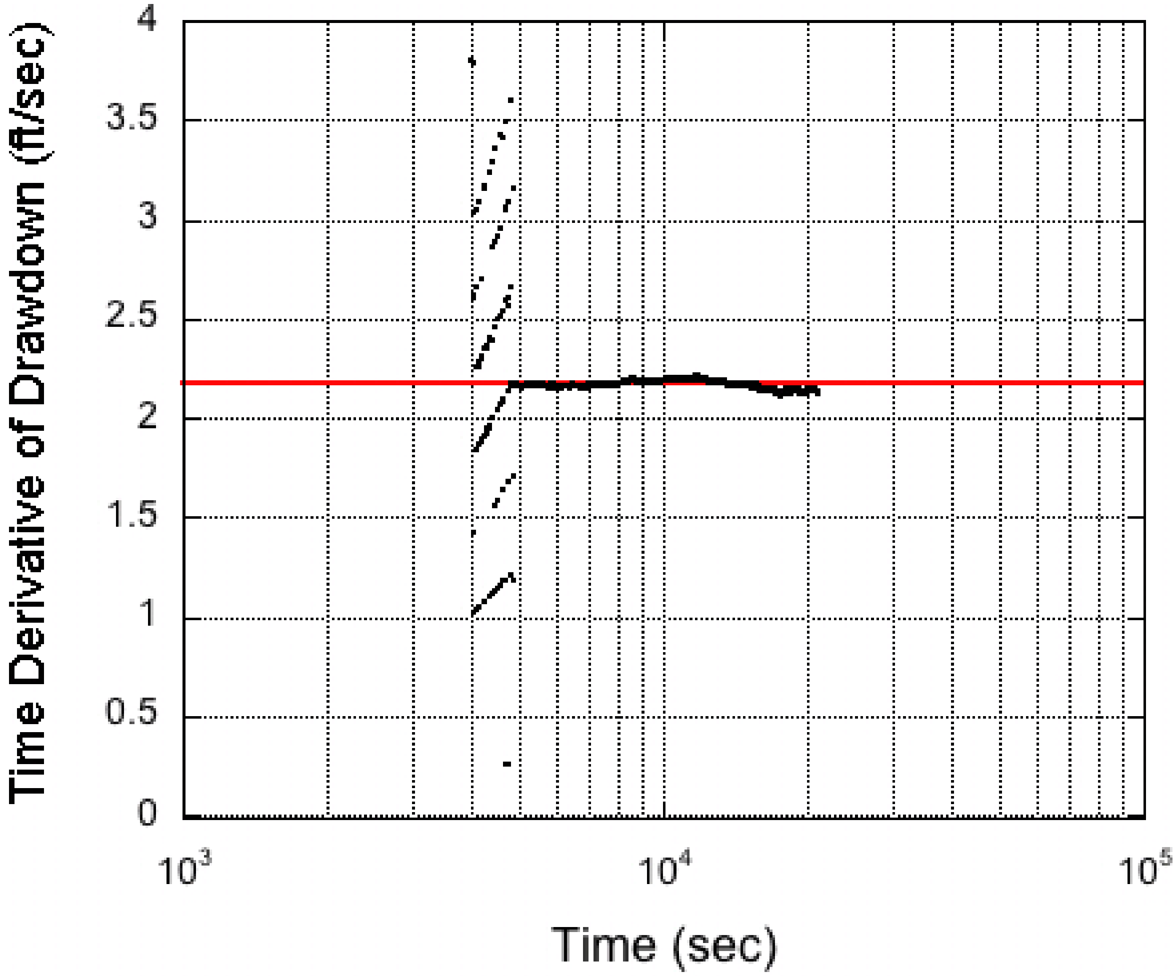

Figure 38. Time vs. the time derivative of drawdown for the data from the 4,000-20.990 second interval of the well 8 pumping test adjusted for a 95% barometric efficiency.

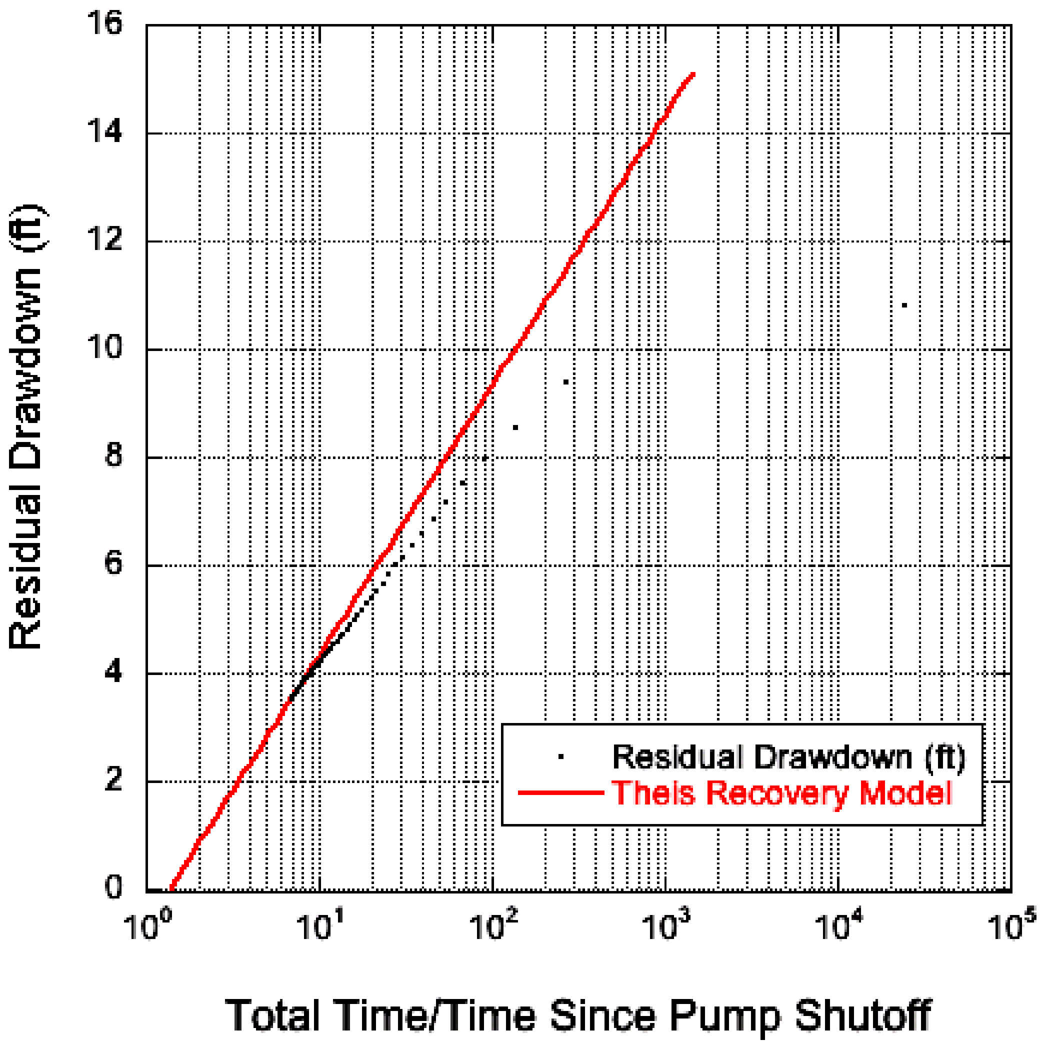

Figure 39. The Theis (1935) recovery (residual drawdown) model fitted to the late time data during the recovery phase of the well 8 pumping test.

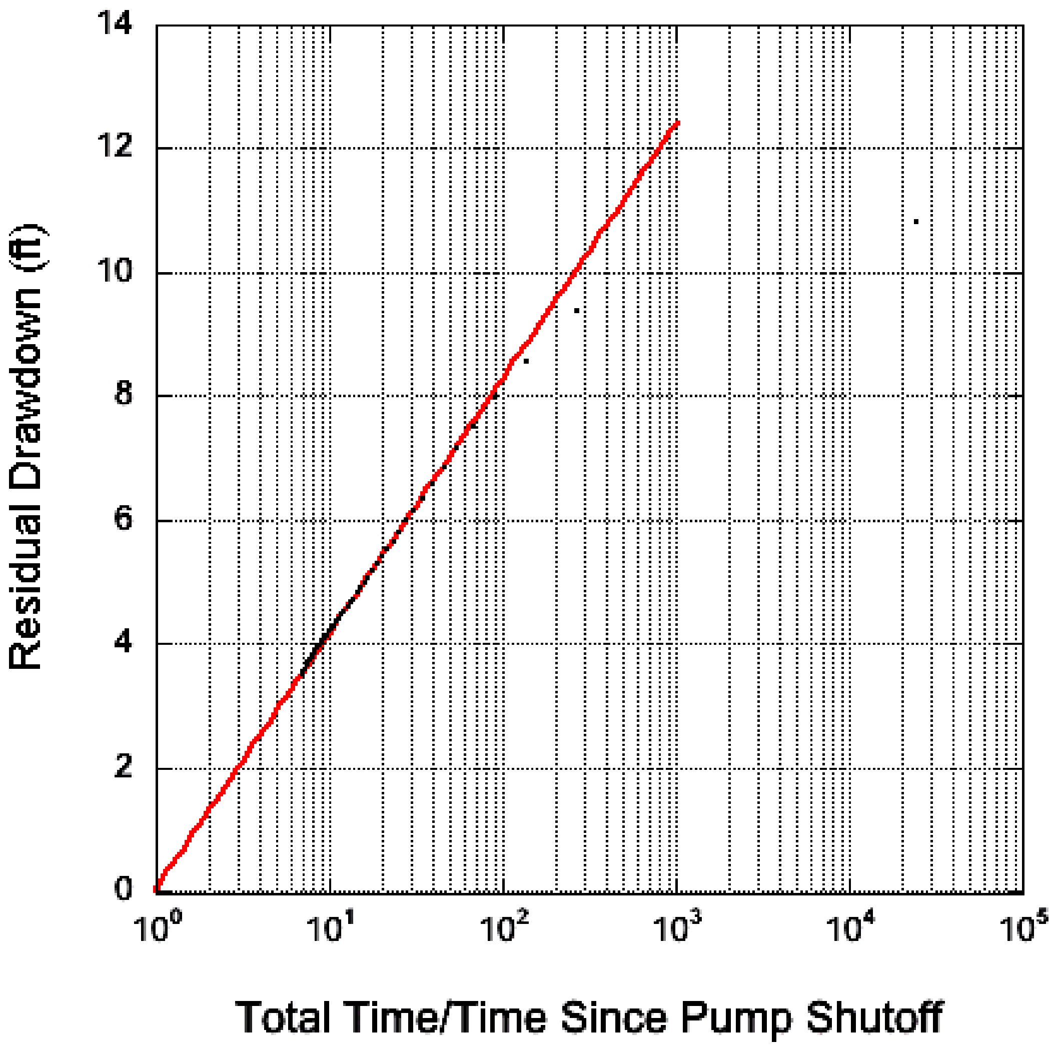

Figure 40. The Theis recovery (residual drawdown) model fitted to the earlier time data during the recovery phase of the well 8 pumping test.

Discussion of the Results

The apparent nonlinearity of the drawdown curves in the well 10 and 8 pumping tests could have resulted from changes in pumping rate during the test, the turning on and off of nearby pumping wells outside of the Pittsburg wellfield, back pressure in the pipe leading from the water treatment plant to the well (Jim Butler, personal communication, 2008), or the effects of flow boundaries. Based on an inspection of the pump during the well 10 test, the treatment plant operator informed KGS personnel that the pump was developing significant, mechanical problems. These problems could have reduced the pumping rate. If the actual rate were lower than average used in the analysis, the actual drawdown at the end of the pumping period would have been less and the reduction would have affected the analytical results from the recovery data. Note that the S/S' ratio is significantly less than 1, which is usually interpreted a source of recharge to the aquifer during pumping. In this case, the ratio appears to indicate that the pumping rate most likely declined at least during the latter part of the test. The higher estimate of transmissivity is consistent with this interpretation.

At late time, fluctuations in the rate of drawdown increase for both tests could have been caused by the propagation of additional drawdown through the aquifer from the pumping of Crawford Co. RWD #5 wells at the Kansas Highway 126 water treatment plant (Figure 13). These wells are completed as open-boreholes beginning in the lower part of the Springfield Plateau aquifer and ending in the Ozark aquifer (Roubidoux Formation). The RWD #5 wells are set to cycle on and off automatically in response to customer water demand. During the pumping test the outside well was turned off and only the inside well was operational. It is possible that pumping from this well could have had an impact on the drawdown observed at OW-O during both tests. However, water-level data have not been collected to determine the magnitude of this effect.

Fluctuations in the rate of drawdown increase could also be attributed to fluctuations in back pressure propagated through the water lines to the pumps from the water treatment plant as a result of normal operations. Well 8 is closer to the plant than well 10 and pumps water at a lower rate. Well 8 is located at approximately the same elevation as the water treatment plant, but well 10 is more than 10 feet lower in elevation. In the Figure 41 the arrow in each plot indicates the approximate time when the fluctuations began during pumping. Note that the time when these fluctuations occur is earlier in the well 8 test than in the well 10 test. Note also that the amplitude of the fluctuations is greater in the well 8 data than in the well 10 data. None of these effects are manifested in the recovery curves from either test, which suggests that back pressure in the water lines rather than pumping by other wells outside of the wellfield could be the cause of the observed fluctuations in late time rates of drawdown increase. Since the water lines are of the same pipe diameter, the water pressure of water in the lines from well 10 would be greater than the pressure in lines from well 8 because of the higher rate of pumping and the greater head differential between the water treatment plant and well site. Thus, the back pressure pulses coming from the plant would be dampened more at well 10 than well 8 because of the greater pressure in the line coming from well 10 than from well 8.

Deviations of the well 10 and well 8 test drawdown curve from the Cooper-Jacob model suggest the possibility of flow boundaries within the aquifer (Figure 41). In the well 8 test the rate of drawdown increase is less than would be predicted from the Cooper-Jacob model, which would suggest that a source of recharge is being added to the aquifer. In the well 10 test the rate

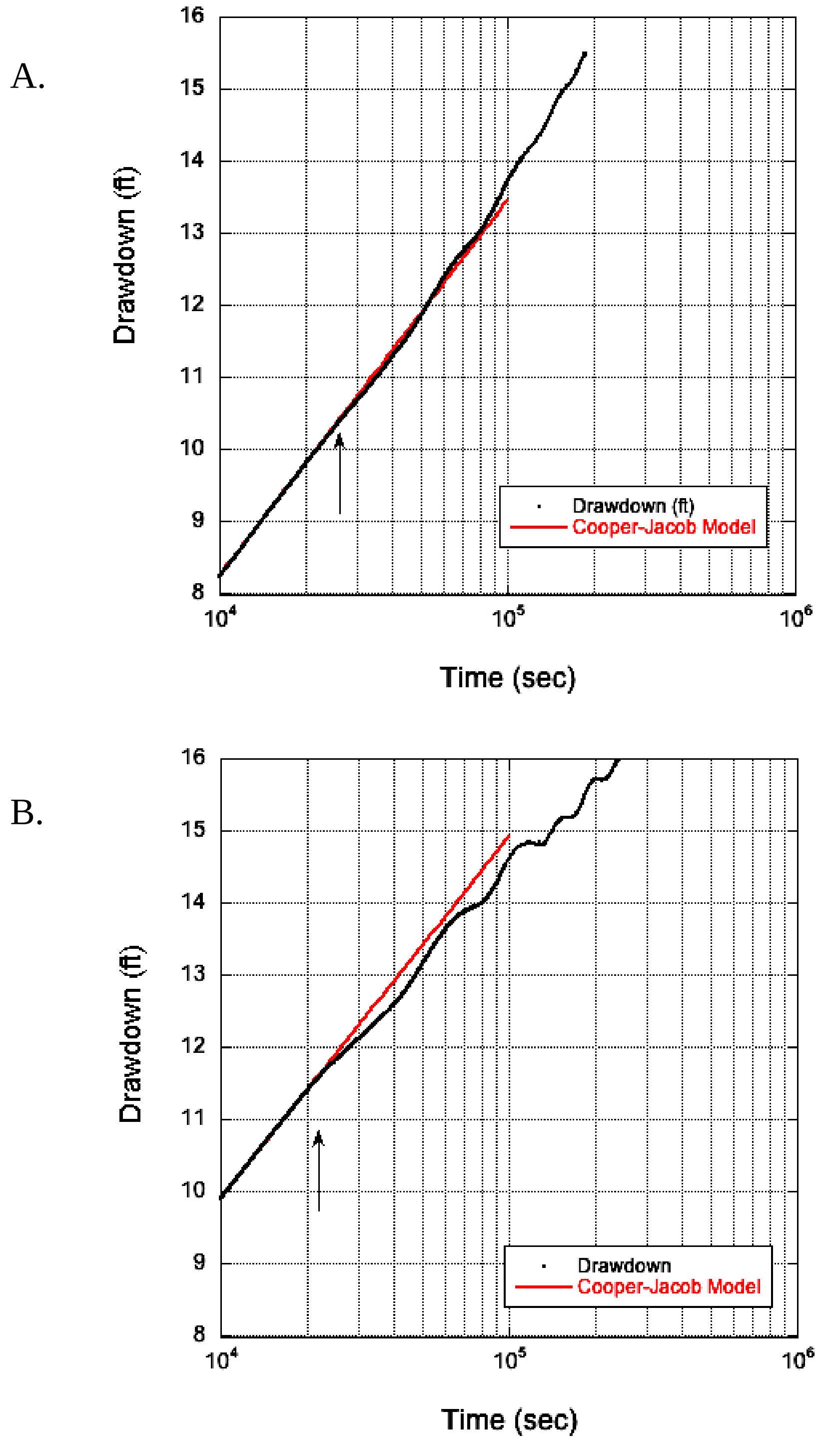

Figure 41. Comparison of the times of onset and magnitudes of the fluctuations in the rates of drawdown in the well 10 and well 8 pumping tests.

drawdown increase is slightly higher than would be expected even with the reduced rate of pumping. This suggests the existence of a lower permeability boundary that is being sensed by well 10 as it pumps. However, lack of detailed data on the geology in the wellfield vicinity precludes thorough evaluation of the existence of physical boundaries within the Ozark Plateaus aquifer system.

Summary of the Pumping Test Analysis Results

The aquifer properties estimated from the pumping tests are summarized below in tabular form.

Table 2. Aquifer properties estimates derived from the test pumping of Pittsburg wells 8 and 10 and using data collected from OW-O.

Well	Test Type	Test Segment (Since Pumping Began, sec)	Transmissivity (ft^2/day)	Storativity (S or S/S') (dimensionless)
10	Pumping	4,000-25,000[1]	13,540 ± 3.2[2] 13,560 ± 3.0[3]	$1.32 \times 10^{-4} \pm 9.2 \times 10^{-8}$ $1.31 \times 10^{-4} \pm 8.4 \times 10^{-8}$
10	Recovery	187,470-201,370[1]	15,410 ± 9.3[2] 15,290 ± 8.1[3]	0.706 ± 0.002 0.650 ± 0.001
8	Pumping	4,000-20,990[1]	13,460 ± 2.4[2] 13,370 ± 2.4[3]	$1.13 \times 10^{-4} \pm 7.4 \times 10^{-8}$ $1.14 \times 10^{-4} \pm 7.8 \times 10^{-8}$
8	Recovery	247,510-274,510[1] 276,310-284,410[1]	15,930 ± 106[2] 16,130 ± 96.6[3] 15,930 ± 321[2] 14,920 ± 346[3]	1.088 ± 0.021 1.022 ± 0.018 1.059 ± 0.042 1.172 ± 0.051

[1] Parameters estimated automatically.
[2] Assuming a barometric efficiency of 95%.
[3] Assuming a barometric efficiency of 60%

Reliability of the Aquifer Properties Estimates

The low errors associated with the individual aquifer properties estimates from the Cooper-Jacob analysis of the drawdowns from each test indicates that the results are of high reliability and quality. It is, however, important to recognize that the estimates apply to the aquifer in the wellfield and its immediate vicinity. Carbonate aquifers tend to be highly heterogeneous with respect to the variation in aquifer properties because of variability in their complex network of interconnected porous zones. Additional factors that could not be controlled for and could have influenced these parameter estimates include variability in the pumping rate of well 10 and the pumping by other nearby wells. These factors could account for the difference in transmissivity values estimated from the pumping and recovery data. Nevertheless the reasonably close agreement of the pumping and recovery period-derived parameter values suggests that these factors have not seriously compromised the value of the tests.

Comparison with Previous Pittsburg Pumping Tests

In the 1950s aquifer tests were conducted using wells in the old Pittsburg wellfield located in the downtown area, approximately 2 miles west-northwest of the current site (Stramel, 1957). Well construction was such that the city tapped sources of water in both the Springfield Plateau and the Ozark aquifers. Depth to the top of the Springfield aquifer and the top of the Ozark aquifer was reported to be 240 feet and 615 feet below surface, respectively, in well 7 located at the southeast edge of the field. Casing lengths were 250 feet, 325 feet, 293 feet, and 584 feet from surface for wells 1, 2, 3, and 7, respectively, and all wells were open-borehole completions. The longest test was 300 minutes (18,000 seconds) with well 1 pumping and well 7 as the observation well approximately 200 feet to the southeast. The transmissivity and storativity values calculated manually from the drawdown data were 250,000 gallons per day per foot (33,422 ft^2/day) and 2.2 x 10^{-4}, respectively. Re-analysis of the data using the Cooper and Jacob (1946) solution method in AQTESOLV yielded transmissivity and storativity values of 34,460 ft^2/day (standard error of 195 ft^2/day) and 1.8 x 10^{-4} (standard error of 4.5 x 10^{-6}), respectively. All values form the other tests conducted at the old wellfield were close to the values calculated from the well 1 test using well 7 as an observation point.

The transmissivity values calculated from well tests in the old wellfield are at least twice the values calculated from tests in the new wellfield. Transmissivity is a function of both hydraulic conductivity and aquifer thickness. Wells in the current field only tap sources in the Ozark aquifer and have open-borehole lengths on the order of 525 feet. This open borehole length is less than half the length of the open boreholes in all of the old city wells with the exception of well 7 [if it is assumed that those wells were drilled to approximately 1,233 feet, the depth of well 7. Note that Stramel (1957) provided no information on well depths other than well 7]. The longer borehole length would permit water from the Springfield Plateau aquifer to enter the well and thus add to the transmissive character of the aquifer. Note that the transmissivity value derived from the well 1 test in the old wellfield is about twice the values calculated for the well 10 and 8 tests.

The Impact of Secondary Porosity on Aquifer Properties

The value of hydraulic conductivity calculated from the well 10 pumping test (32 feet/day) suggests a more open or connected network of solution channels in the carbonates rather than flow through a network of fractures or through a rock matrix. The rock units that form these aquifers have been episodically subjected to karstic processes and tectonic adjustments of basement blocks caused by the imposition of regional stress fields resulting in networks of interconnected fractures and solution openings (Berendson and Blair, 1986). Such adjustments would tend to open up fracture apertures under tension or shrink them under compression. However, evidence of bilinear flow, a characteristic of flow through fractures, was not found in the pumping test results from the new or the old wellfield. Further, the typical range of hydraulic conductivity values for aquifers that consist of dolomite or fractured carbonate rocks is on the order of 0.0003 feet/day to 3 feet/day which contrasts with the 0.3 to 3 x 10^7 feet/day range for karstified limestone with caverns (Brahana et al., 1988). This suggests that solution-developed porosity and permeability may be small-scale but widespread within both aquifers and thus a more important influence on the aquifer properties than fractures.

Water-Level Surveys

Data Collection

Water level data were collected from network wells in Phases I and II and the newly installed monitoring wells in Phase II by KGS and DWR personnel. In Phase I the surveys of all the available Ozark aquifer and Ozark Plateaus aquifer system wells were conducted semiannually by the KGS. On the basis of these surveys 25 water supply wells currently in use or unused wells were assigned to the network as part of the Phase I work (Appendix 2, Macfarlane et al., 2005). However, in Phase II that list of wells was modified slightly for the purposes of this study with the addition of new wells or deletion of included wells (Table 3). The new monitoring wells

Table 3. The modified network of wells included in the water-level surveys of Phase II of the project.

Well Owner/ Water Supply	Well ID	Township S	Range E	Sec.	Qualifier
Cherokee Co. RWD 2	1	34	25	8	SWNWSW
Cherokee Co. RWD 9	1	34	25	20	NWNENW
Cherokee Co. RWD 8	1	34	25	21	NWNESE
Cherokee Co. RWD 8	2	34	25	28	NWNWNW
Galena	1	34	25	23	SENENE
Galena	4	34	25	13	SWSWSW
Galena	3	34	25	14	NWNWNE
Baxter Springs	6	34	24	36	NENWNW
Baxter Springs	5	34	24	36	NWNWSW
Cherokee RWD 3	1	34	24	17	SWSWSE
Jayhawk Fine Chemicals	PW 1	34	25	4	NENWNE
Jayhawk Fine Chemicals	PW 2	34	25	4	NENWNE
Cherokee RWD 1	1	33	25	18	NENESE
Cherokee RWD 1	2	33	25	9	SENESE
Columbus	4	32	23	13	NENENW
Cherokee RWD 4	1	32	24	29	NWNWNW
Weir	1	31	24	27	NWSESW
Arma	1	29	25	5	SESESW
Frontenac	North	30	25	9	NENWNE
Pittsburg	11	30	25	28	SESESE
Girard	3	30	24	21	NESENE
Arcadia	2	28	25	1	NESWNE
Crawford RWD 1C	North	30	24	2	SESESE
Crawford RWD 4	1	30	24	28	NENENE
Crawford RWD 4	3	31	24	16	NENENE
Crawford RWD 5	1	30	25	23	SESWSW

were added to the inventory upon completion of their installation and development. The data from these surveys are tabulated in Attachment 4. The geographic distribution of the water supply and monitoring wells is shown in Figure 42.

Water-level surveys were conducted during May 2004, December 2004, late August-early September 2005, March 2006, late May-early June 2006, and October 2006. In addition 8 wells from the network were visited monthly during 2006 and early 2007 to collect additional water-level data for another ongoing KGS project funded by the Kansas Water Resources Research Institute. All water-level measurements were made using an unweighted steel tape and chalk and were taken in reference to an established measurement point, typically the top of casing or the vent pipe.

Results

The results are presented as hydrographs that show depth-to-water fluctuations between measurement cycles at each well from May 2004 to March 2007 (Figures 43 - 47). In the case where measurements were taken in more than one well at a water supply's wellfield, the data are given as the elevation of the water level above mean sea level (a.m.s.l.). This modification in presentation style affects the hydrographs for Pittsburg well 11, the Pittsburg OW-O monitoring well, Girard well 3, and Girard well 4 (Figure 48).

Discussion

The purposes of the water-level surveys were primarily to collect the data needed to assess changes in the potentiometric surface over time and, secondarily, to capture a snapshot of the potentiometric surface of the Ozark aquifer for the USGS Tri-state regional aquifer study. These surveys were conducted initially on a semiannual and later on quarterly basis.

The metric used to assess changes in the potentiometric surface over time has traditionally been the hydrograph, which is a graph of time versus depth to water from a measurement point or the altitude of the water level above sea level. The premise behind these surveys is that the water-level data collected from the wells represent water levels out in the aquifer beyond the cone of depression, a condition referred to as the static condition. However, almost all of the data were collected from recently pumped wells or unused pumping or monitoring wells generally within the cone of depression of one or more pumping wells. Interpretation of the hydrographs in Figures 43-48 is problematic because:

- The collected survey data are more likely to be representative of pumping conditions within the cone of depression than static conditions in the aquifer beyond the cone of depression,
- The long intervals of time between individual measurements may provide a distorted picture of water-level trends locally within the aquifer depending on when the initial survey measurement was taken and the spacing between measurements, and
- Human error associated with the act taking the water-level measurements may be significant even under the best of circumstances.

These factors are not ordered according to their level of significance in contributing to the total error in the measurement. The total error in this case is the difference between the static or fully

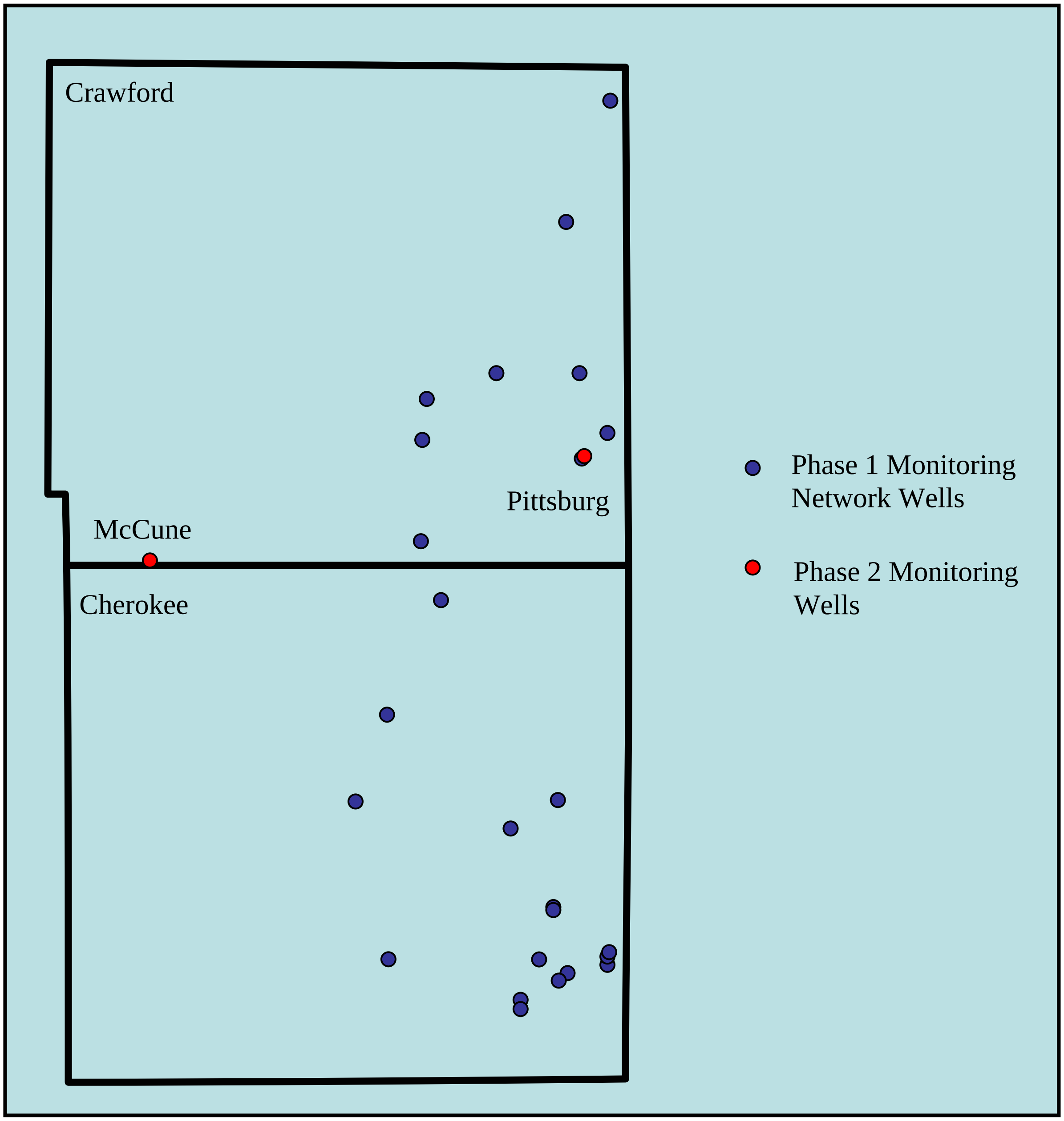

Figure 42. Distribution of the Phase 1 monitoring network wells and the Phase 2 monitoring sites in Crawford and Cherokee counties, Kansas.

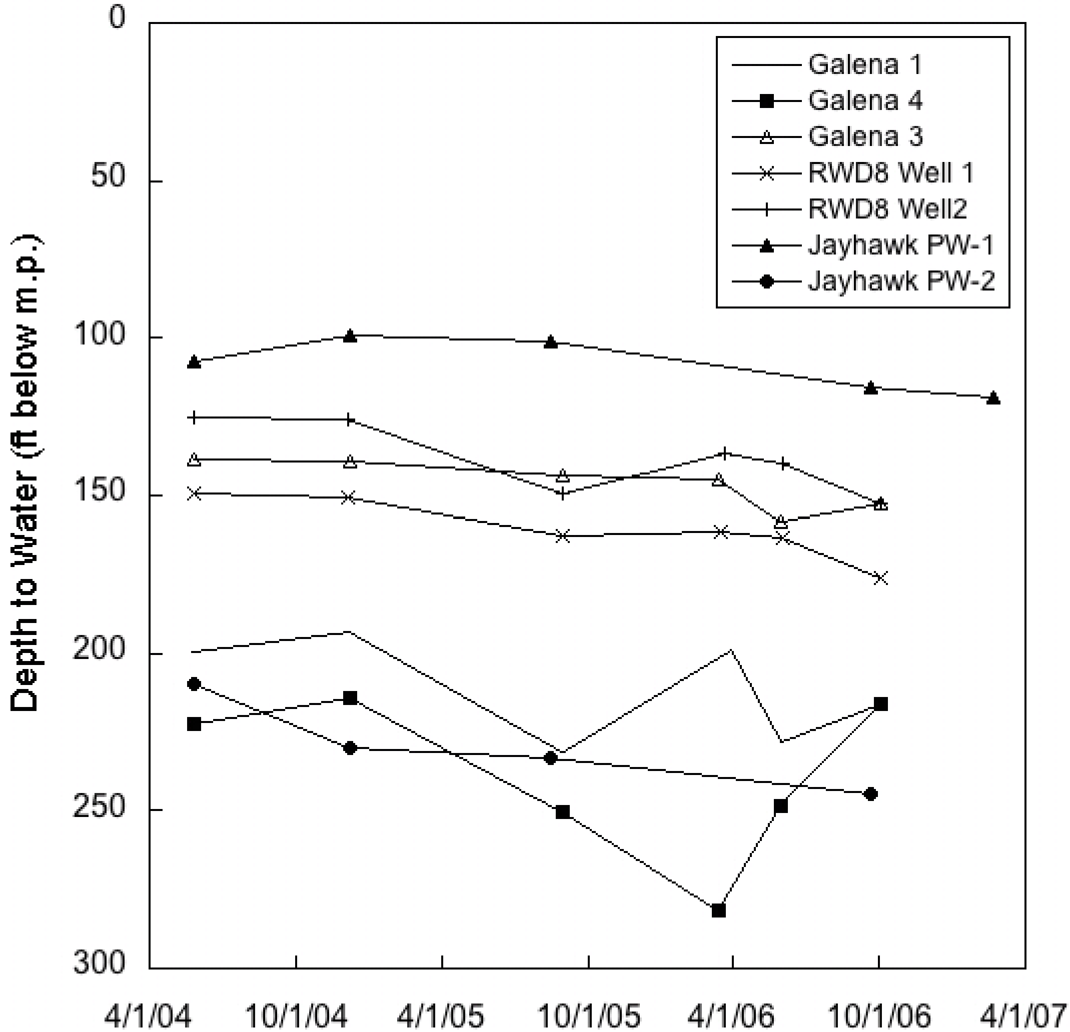

Figure 43. Hydrographs of water-supply wells at Galena and adjacent areas from semiannual and quarterly surveys.

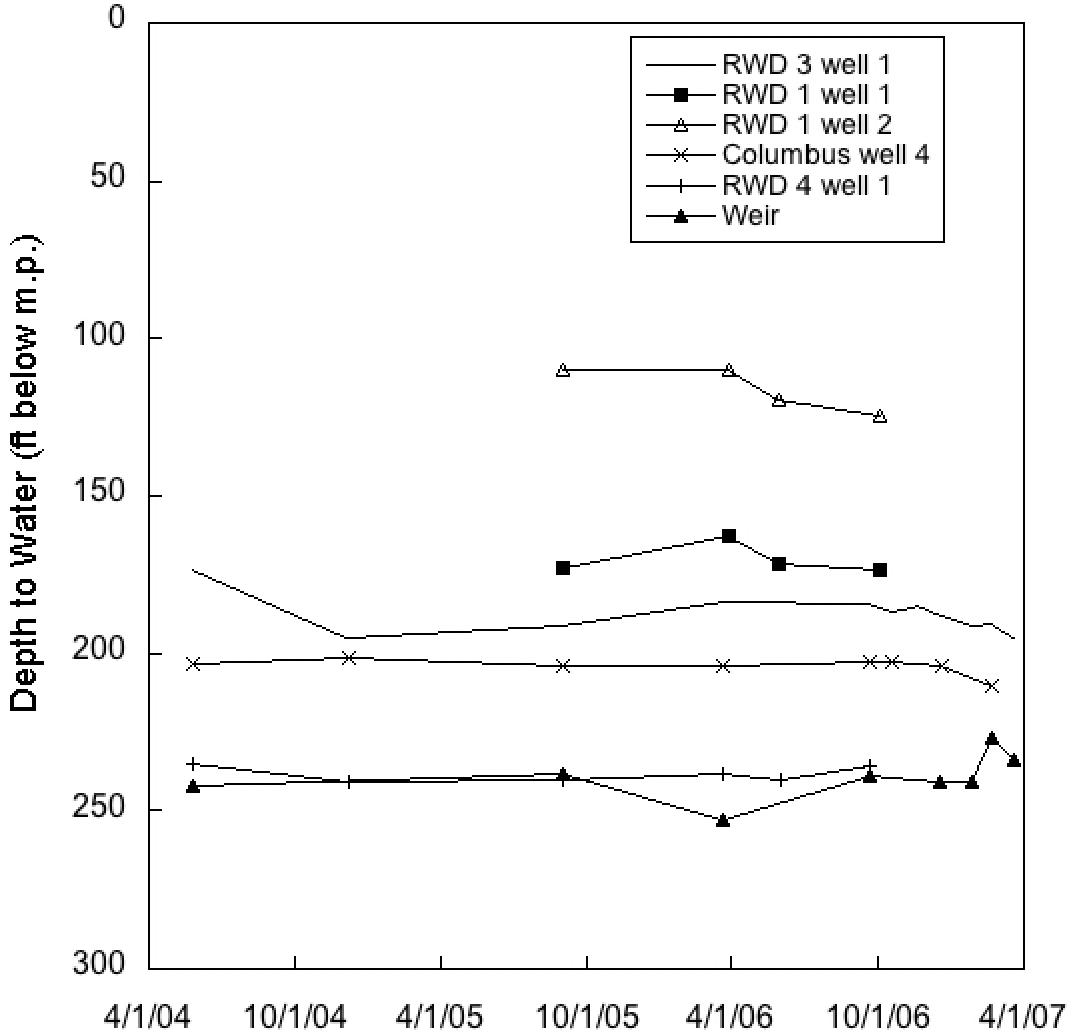

Figure 44. Hydrographs of water-supply wells in the northern half of Cherokee County and Cherokee RWD 3 from semiannual and quarterly surveys.

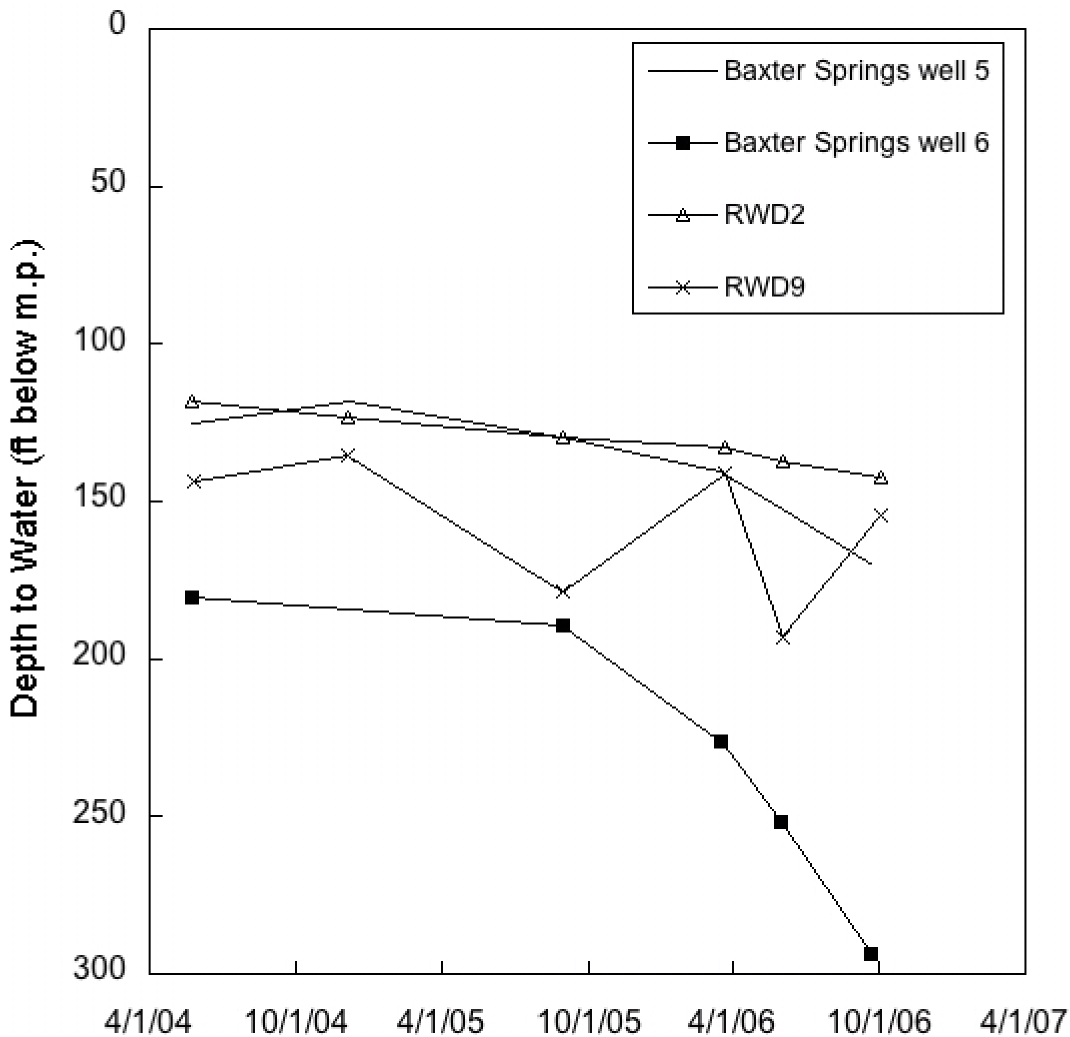

Figure 45. Hydrographs of water-supply wells in the Riverton-Baxter Springs areas from semiannual and quarterly surveys.

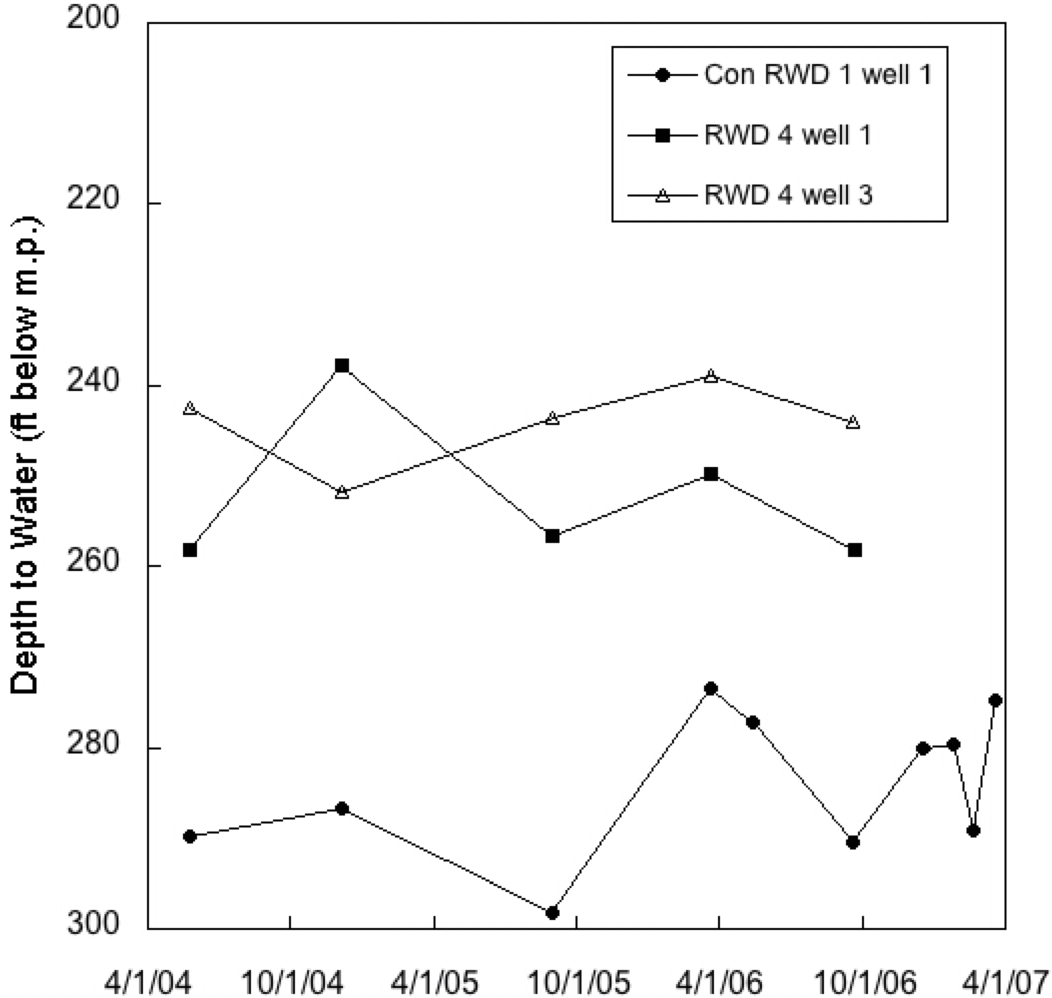

Figure 46. Hydrographs of rural water district water supply wells in southern Crawford County from semiannual and quarterly surveys.

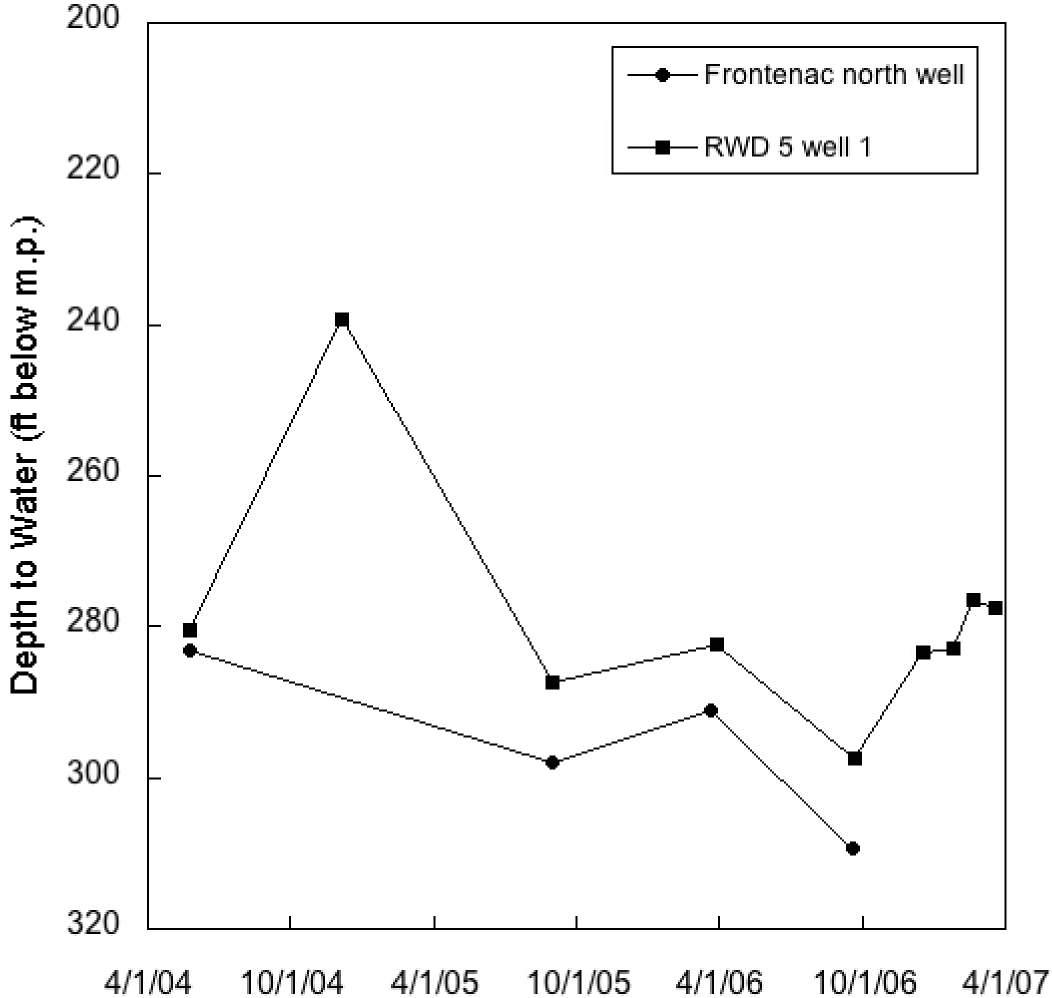

Figure 47. Hydrographs of water-supply wells at Frontenac and at the main water treatment plant for Crawford County RWD 5 on Kansas Highway 126 east of Pittsburg.

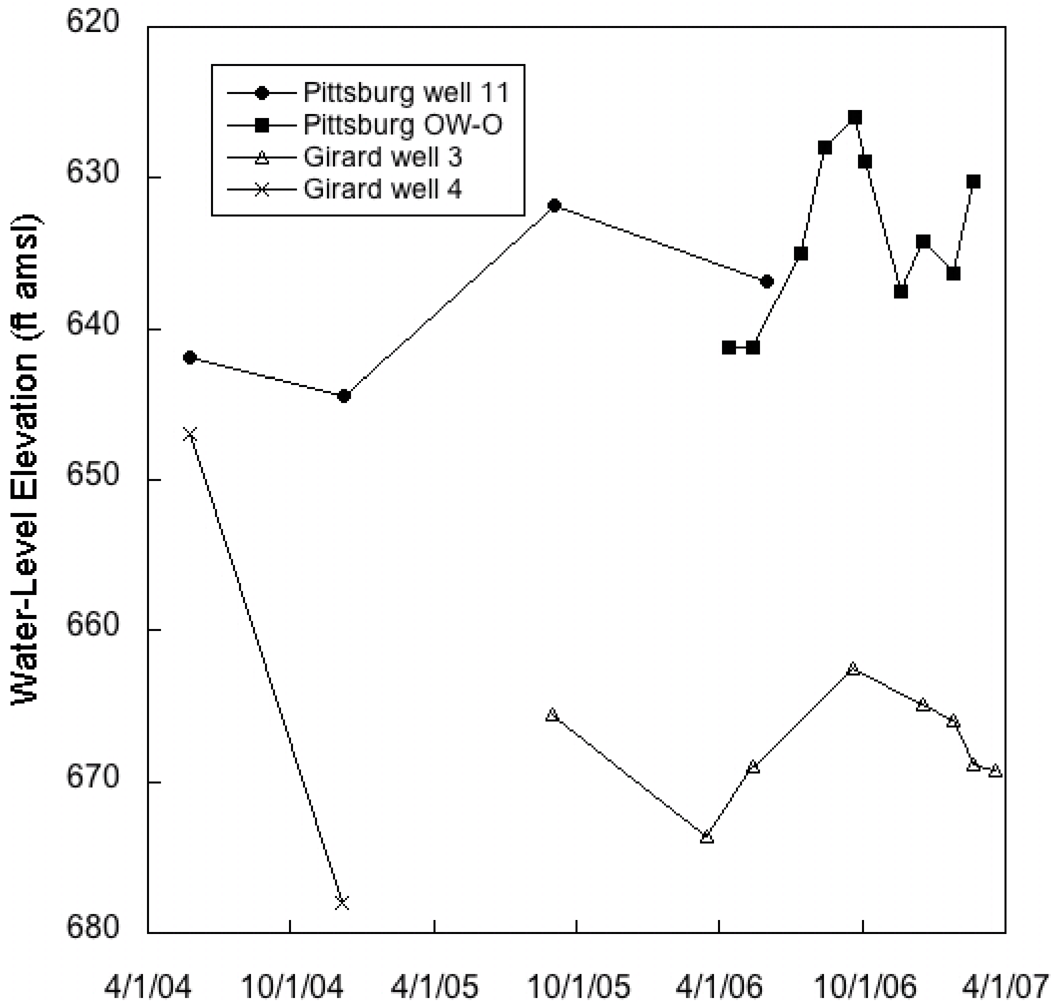

Figure 48. Hydrographs of water-supply wells at Pittsburg and Girard and OW-O at the Pittsburg monitoring site from semiannual and quarterly surveys.

recovered water level and the actual measurement. The total error can be evaluated at least qualitatively from continuous, high-frequency water-level monitoring using a pressure transducer.

Water-level measurements were typically taken not long after the well had been turned off (typically less than 2 hours) when the rate of recovery is the highest as shown by the recovery data collected from OW-O during the Pittsburg well 10 pumping test (Figure 49). At OW-O, which is more than 500 feet away from Pittsburg well 10, the rate of recovery is on the order of 5 feet per hour in the first 30 minutes following pump shutoff and declines thereafter. However, it is important to note that significant recovery continues beyond the approximately 12 hours of data as indicated by the upward slope of the line at late time. The data indicate that measurements taken within the 2-hour window would significantly overestimate the depth to water in the surrounding aquifer outside of the cone of depression by at least several feet.

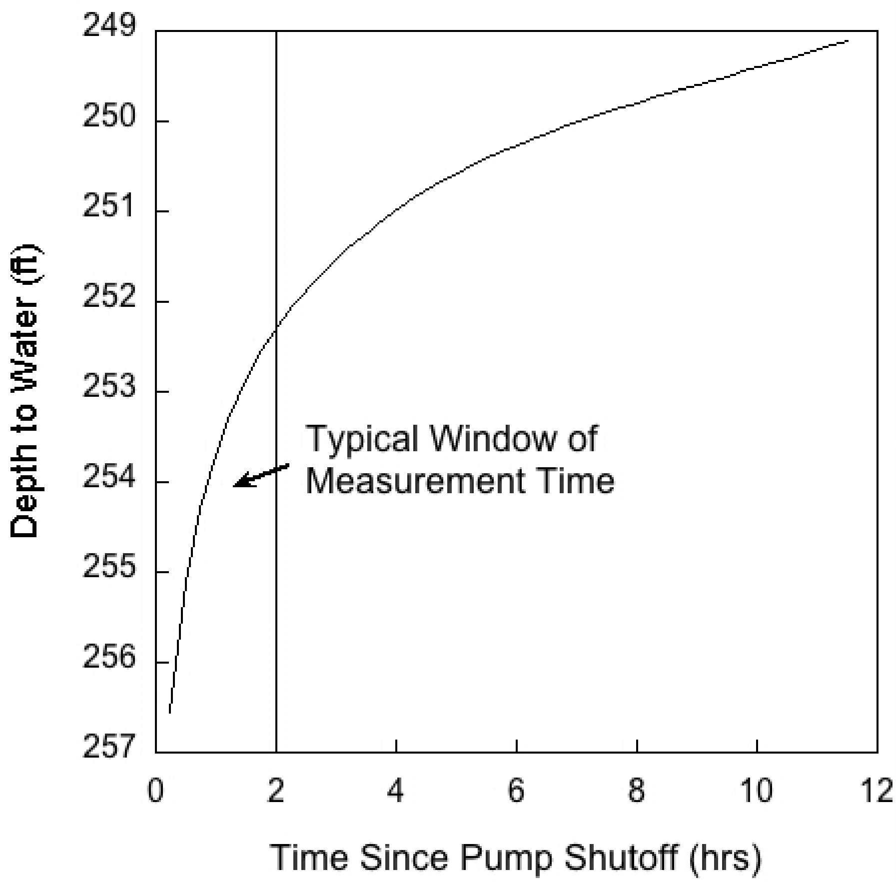

Figure 49. Water-level recovery in OW-O at the Pittsburg monitoring site following the pumping of Pittsburg well 8 as an example of water-level recovery in the higher transmissivity portions of the Ozark aquifer. OW-O is 557 feet south of Pittsburg well 8. The “typical window of measurement time” is the average amount of time wells were typically turned off prior to taking a water-level measurement in the surveys conducted for this project and is based on field notes.

When the pump in a well is turned off, the water level in the well rises and the hydraulic head in the adjacent aquifer begins to rise or recover at a rate determined by the aquifer properties, which in a confined aquifer are the transmissivity and the storativity (Domenico and Schwartz, 1990). The total time required for recovery to static conditions is greater for confined aquifers with low transmissivity than for those with higher transmissivity. Also, the longer the well is pumped, the greater the drawdown and the longer the recovery period. Ozark aquifer properties are poorly known in the Tri-state region. However, the specific capacity (the rate of pumping in gallons per minute divided by the drawdown from pumping at that rate) can be used as a rough surrogate (Domenico and Schwartz, 1990; Macfarlane et al., 2005) of these properties with higher values signifying areas of the aquifer with higher transmissivity and perhaps higher storativity (Figure 50).

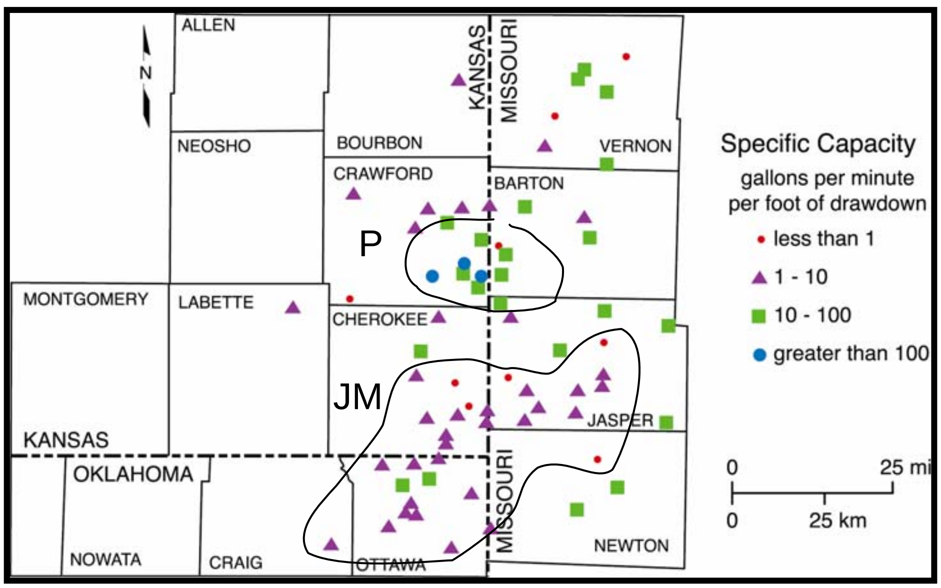

Figure 50. Distribution of specific capacity values derived from production tests of wells tapping the Ozark aquifer in southeast Kansas, southwest Missouri, and northeast Oklahoma. Note the band of lower values in the Joplin, MO-Miami, OK area (JM) and the area of higher values around Pittsburg, KS (P). Taken from Macfarlane et al. (1981).

Figure 50 generally shows much higher values of specific capacity in the Pittsburg area in southeast Crawford County than in the Baxter Springs-Galena-Joplin corridor area near where the states of Kansas, Missouri, and Oklahoma adjoin. The distribution of highs and lows suggests that aquifer transmissivity is higher in the Pittsburg area than in the Baxter Springs-Galena-Joplin corridor area. The limited aquifer properties data from pumping tests seems to confirm this conclusion. Recent tests conducted at Pittsburg yielded transmissivity values in the vicinity of 15,000 ft^2/day and Feder at al. (1969) reported a value of 540 ft^2/day from a series of pumping tests conducted at Webb City in the Joplin area. Thus, much longer recovery periods would be required to return the aquifer to static conditions in the Baxter Springs-Galena corridor than in the Pittsburg area. After 2 hours of recovery following pumping, the water level in OW-O had recovered at least 4 feet, but approximately 2 feet in Galena well 1 (Figures 49 and 51).

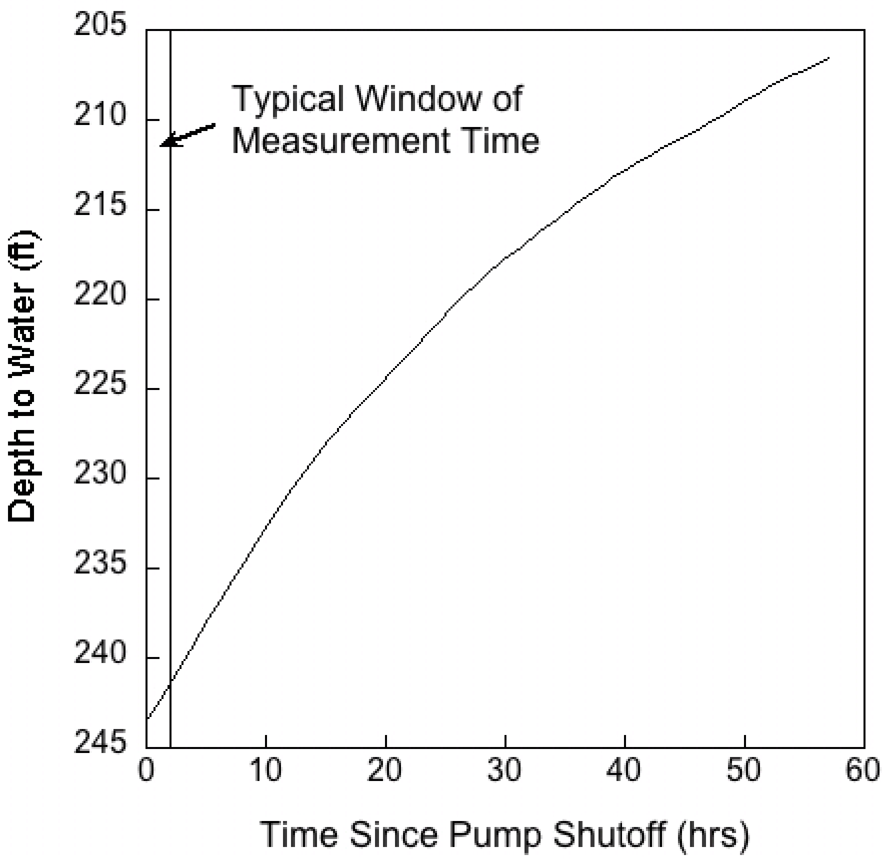

Figure 51. Water-level recovery in Galena well 1 from the pumping of Galena well 4 and other nearby wells in neighboring Missouri. Water-level data were collected hourly from 2PM 5/11/06 to 11PM 5/13/2006 and stored in a mini-TROLL suspended in the well.

These arguments clearly indicate that that the data collected from the water-level surveys do not necessarily represent static conditions in the surrounding aquifer, but the pumping condition. Because these conditions are likely to fluctuate one way or the other from day to day depending on the intensity of pumping, it is difficult to assess the significance of short-term fluctuations portrayed in the hydrographs.

These difficulties are compounded because of the long time intervals between water-level surveys and the lack of information about pumping history in between measurements (Figure 52). The hydrograph shown is for OW-O at the Pittsburg monitoring site based on hourly depth-to-water measurements from a pressure transducer placed approximately 294 feet below the top of the casing. OW-O is roughly equidistant from Pittsburg wells 8, 9, and 10 and roughly twice that distance away from Pittsburg 11. Note that in some cases the water-level can fluctuate more than 20 feet over a very short period depending on the amount of pumping within the wellfield. The abrupt upward spikes represent periods when none of the Pittsburg water supply wells in the field were pumping. The apex of each spike represents the highest water level achieved in recovery prior to the following pumping cycle. It is likely that conditions in the surrounding aquifer away from the immediate influence of pumping are represented best by the

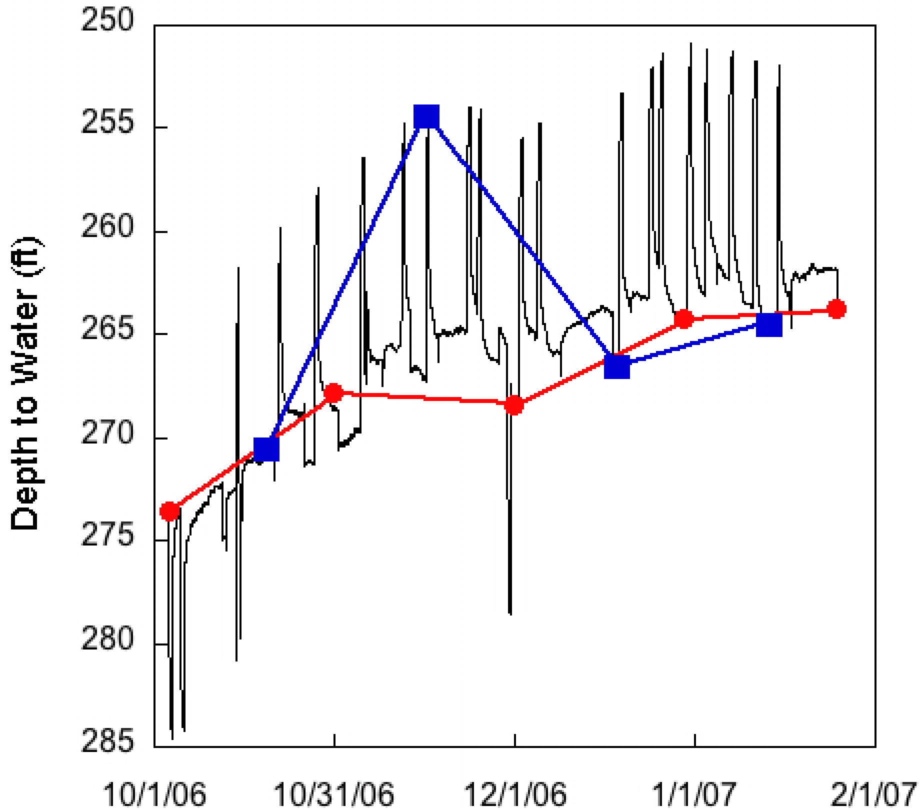

Figure 52. Hydrograph of OW-O at the Pittsburg monitoring site developed from depth to water measures taken hour with a transducer placed in the monitoring well. Superimposed are two hypothetical hydrographs based on monthly depth to water measurements.

highest water levels in the hydrograph. In this case, it is clear that the upward trend in water levels represents regional recovery from more intense pumping that took place in the previous summer. The downward pointing spikes indicate periods when more than one pumping well was operating with the lowest water level representing maximum drawdown from the pumping of multiple wells. The water-level data in between the highs and the lows represent a range of conditions from partial recovery from well shutoff to drawdown from the resumption of pumping.

Superimposed on the real hydrograph from OW-O are the results that might be hypothetically obtained from 2 surveys where the interval between measurements is approximately one month. Note that 2 different pictures of hydrologic conditions emerge, only one of which bears any resemblance to the true regional recovery of the aquifer from seasonal fluctuations in pumping intensity. The hydrograph in red more closely follows the trend of regional recovery than does the hydrograph in blue. With the exception of one measurement used to construct the blue plot neither hydrograph accurately represents the “true” (most recovered) depth to water in the surrounding aquifer.

Human error associated with the physical act of taking the measurements in wells can also be significant. When using a steel tape, there is the unfortunate possibility that it may not hang vertically in the well because the tape can wrap around or become entwined in the equipment hanging in the well without being detected at the surface by the person taking the measurement. This results in an overestimate in the depth to water. This source of error can be minimized if care is taken during the descent to insure that the downward progress of the tape is unhindered by hang-ups along the way and by comparing results with repeated or previous measurements taken at the well.

Conditions inside the well casing also bear on the measurer’s ability to obtain an accurate estimate of the depth to water from the measurement point. To obtain an accurate depth-to-water measurement, a distinct and recognizable water level must appear on the chalked tape when it is removed from the well. It was difficult to obtain accurate measures of depth to water in Weir’s city well for at least a portion of the year because of condensation above the water level and the build-up of oxidation on the inside of the casing or leakage from the conductor pipe that transports water up to the surface. Under these circumstances only rough estimates could be made. These estimates were based on a determination of the approximate point at which it appeared that the tape was below water level. Other supplies with this problem include Crawford County RWD 4 well 3, Girard well 3, and Cherokee County RWD 1 well 1. Only one well, Pittsburg well 11, in the current network is equipped with a water-level measurement tube that extends down to the water level in the well.

Recommendations for Obtaining Higher Quality Water-level Data

Uncertainty in the interpretation of water-level data can really only be reduced by investing in additional dedicated observation wells strategically placed in areas of the aquifer outside of the immediate influence of pumping wells. These and a select number of active wells should be monitored using transducers to gather high-frequency and high-quality water-level data. Water level histories from monitoring well data can be more easily correlated with the histories from the pumped wells to determine seasonal and longer-term trends that at the moment are difficult to discern with the current data sets.

Finally, access tubes should be required on all new wells to help minimize errors in manually obtaining depth to water estimates. Some of the wells in the network have airlines for determining water levels with reference to the bottom of the line typically placed near the top of the pump. These should not be used because over time they malfunction because of clogging, leaks in the line, malfunctioning pressure gauges, and because information on the depth to the bottom of the airline is typically unavailable.

The approach advocated here is similar to the index-well approach that is being tried in the western Kansas groundwater management districts (GMDs) that overlie the Ogallala aquifer. The situation in the western Kansas GMDs differs from that in southeast Kansas in that most of the pumping occurs during the growing season. The intervening long period of well shutdown allows for more aquifer recovery from pumping when measurements are made in the winter months than is possible in southeast Kansas. This approach will require substantial initial investment in drilling new wells and in instrumentation. However, the data gathered will be of higher quality and will more accurately depict hydrologic conditions within the aquifer.

Other Network Water-level Monitoring

Continuous monitoring of water levels was conducted in PW-1 at the Jayhawk Chemical Plant and in well 1 at Galena during the course of the project using mini-TROLL pressure transducers. Atmospheric pressure was also monitored in PW-1 using a baro-TROLL (Figures 53-54). Monitoring was suspended in Galena well 1 for a period of several months because of equipment malfunction and repair. The baro-TROLL stopped collecting data in June 2006 because of a loss of power to the sensor.

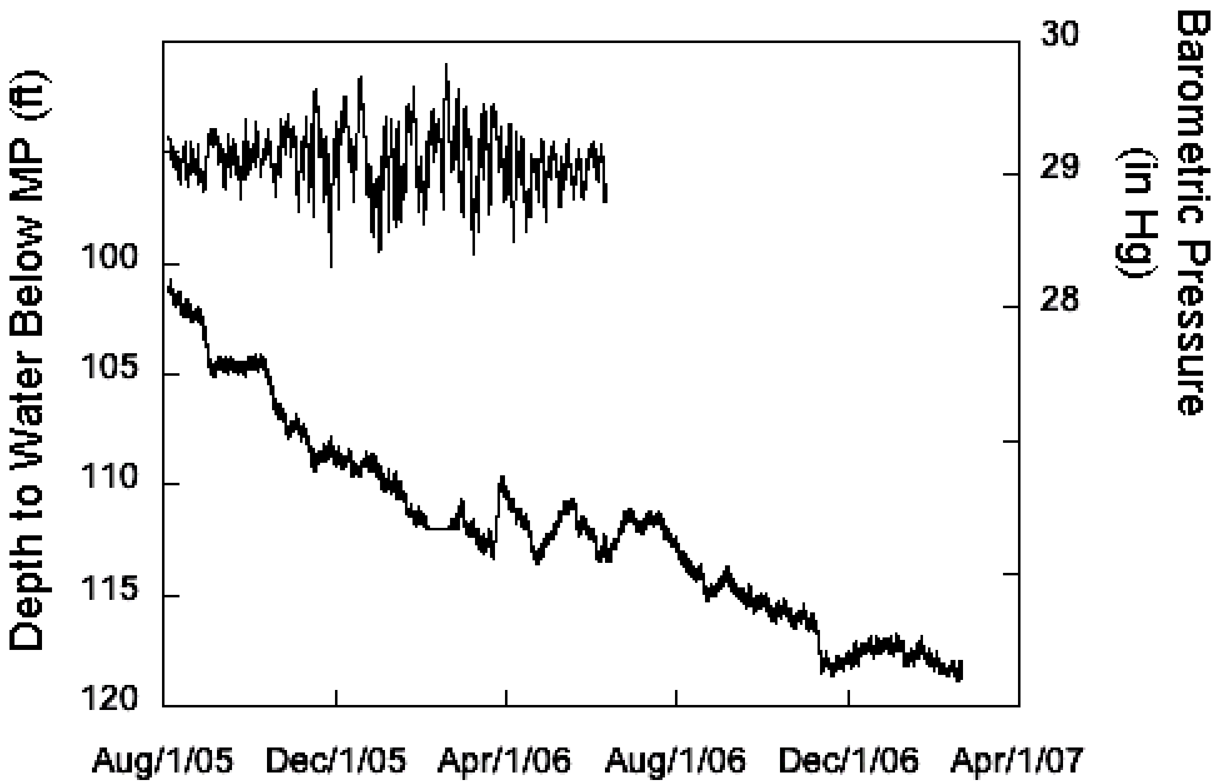

Figure 53. Hydrograph showing the decline of water levels in PW-1 at the Jayhawk Chemical Plant. PW-1 is located approximately 300 feet south of the plant water well, PW-2, where the depth to water is approximately 150 feet below the water level in PW-1.

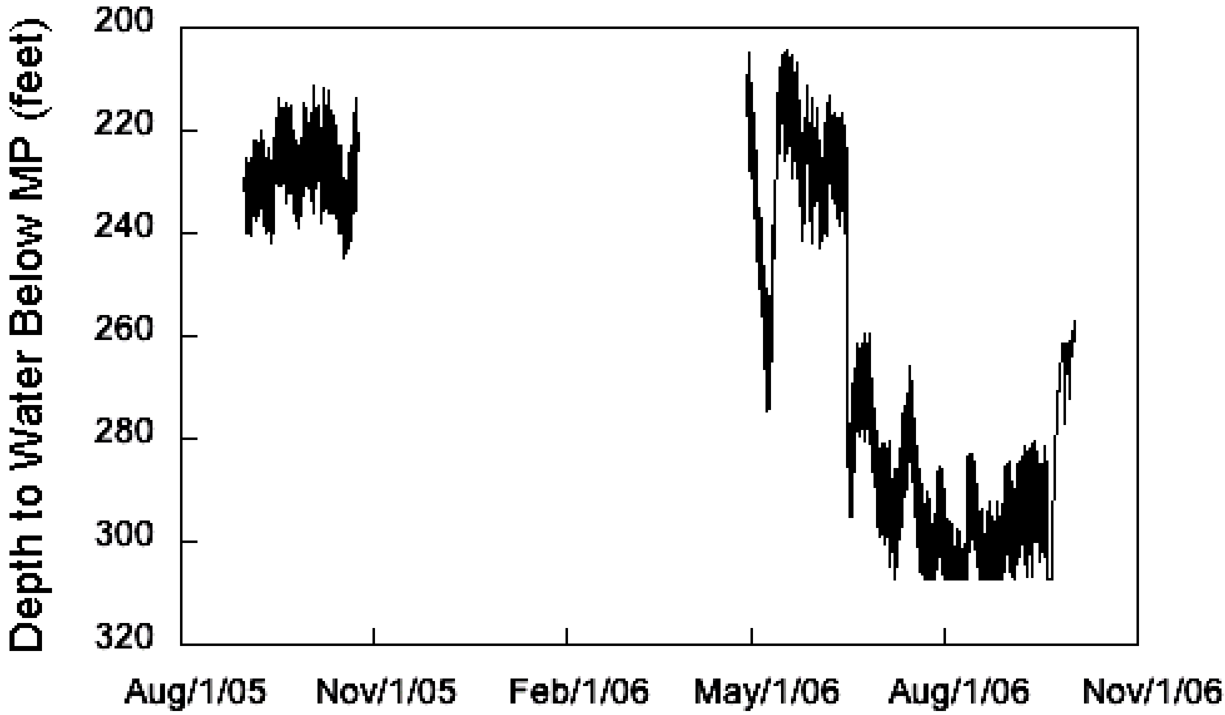

Figure 54. Hydrograph showing the depth to water in Galena well 1. The interval of missing data from November 2005 to April 2006 was caused by an equipment malfunction and the repair of the transducer in the mini-TROLL.

The Jayhawk plant site wells are located in a part of the aquifer where specific capacities are less than 10 gallons per minute per foot of drawdown (Figure 50). Abernathy (1943) reported specific capacity values of less than 3 gallons per foot of drawdown when PW-1 was first drilled down to 901 feet where the total depth is in the Roubidoux Formation. Much later PW-1 was cemented back to a depth of 650 feet in the Jefferson City Dolomite. PW-2 is located 300 feet north of PW-1 and was completed open hole from 687 feet down to total depth at 901 feet.

PW-2 is pumped on demand at approximately 450 gallons per minute to maintain reservoir levels in the plant tower. Depth to water measurements taken in PW-2 indicate that levels have been in the 210-290 feet below surface in 2004-2007 (Table 4). When PW-1 was completed, the depth to water in the well was approximately 65 feet below surface (Abernathy, 1943) and more recently it has dropped down to approximately 120 feet below surface (Figure 53 and Table 4). It is likely that most of the decline in PW-1 can be attributed to nearby pumping because of its close proximity to PW-2 with the rest of the decline due to regional pumping in southeastern Cherokee County.

Table 4. The history of water levels in wells completed in the Ozark aquifer at the Jayhawk Fine Chemicals plant site.

Date	Depth to Water from Surface (ft)		Remarks	Data Source
	PW-1	PW-2		
2/25/1942	65	--	Static water level on initial completion of the well	Abernathy (1943)
9/27/1979	229.45	--	Pump off 28 minutes	Macfarlane and Hathaway (1987)
8/4/2000	--	174	Pumping status or water level in the old well not recorded	WWC-5 record of well completion
5/26/2004	100.8	205.66	Pump in the new well off for 1 hour prior to measurement	Spring 2004 Water-level Survey
12/8/2004	97.33	226.07	Pump in the new well off for an unknown period of time prior to measurement	Fall 2004 Water-level Survey
6/17/2005	-	238.00	Pump had been on for approximately 1 hour	Site visit
8/15/2005	101.09	233.44	Pump or some time	Site visit
10/25/2005	107.02	-		Site visit
2/10/2006	113.02	289.45	Pump off for 15 minutes	Winter 2006 Water-level Survey
2/28/2006	111.45	-		Site visit
9/21/2006	115.60	244.61	Pump off for some time	Summer 2006 Water-level Survey
2/19/2007	118.70	-	PW-2 pump off	Site visit

Galena well 1 is also situated in a zone of low specific capacity within in the Joplin, MO-Miami, OK area (Figure 50) and is approximately 1,300 feet south of Galena well 4, which is pumped periodically to supplement the city's supply of water. Other public supply and industrial wells in the Galena-Riverton area and across the state line in Joplin, MO, are also nearby and actively pumping (Macfarlane et al., 2005). The hydrograph for Galena well 1 exhibits shorter-term fluctuations (on the order of a few days duration) and longer-term fluctuations (on the order of weeks to months duration; Figure 54). Shorter- and longer-term fluctuations in amplitude are on the order of 20 feet or less and 20 up to more than 80, respectively. Based on discussions with city personnel, the shorter-term fluctuations seem to coincide with Galena well 4 pumping. Longer-term fluctuations appear to be associated with the regional combined effects pumping other wells in the vicinity of Galena well 4. Note that the lowest water levels were recorded on the hydrograph in the late spring, summer, and early fall of 2006 when water demand is generally higher, whereas water levels were generally higher in the late fall, and early spring period when demand should be less.

Acknowledgements

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ATTACHMENT 1:

MONITORING SITE CONSTRUCTION CONTRACT SPECIFICATIONS

SPECIFICATIONS

SCOPE OF WORK

Construct and install two observation wells extending from land surface into the Springfield (Mississippian or Boone) aquifer and the Ozark (Roubidoux) aquifer no greater than 50 feet apart at a site in T. 30 S., R. 25 E. or the northern half of T. 31 S., R. 25 E., near the city of Pittsburg, Crawford County, Kansas.

It is expected that all drilling and installation will occur by April 2006. The contractor shall be responsible for securing and complying with any and all permits required by the State of Kansas or local authorities. It shall be the contractor's responsibility to determine and comply with any and all state and local regulations regarding aspects of the project he is quoting.

The Kansas Geological Survey (KGS) will have an on-site manager who shall oversee the direction of daily activities of the contractor. The KGS will secure right of entry for the contractor at the site.

It is the responsibility of the contractor responding to read and become completely familiar with all information in these Specifications and to become familiar with the project area, local facilities and difficulties, the requirements of these documents and of pertinent State and/or local codes, and to make due allowances in his bid for all contingencies including insurance, and other applicable fees.

The contractor shall provide and his bid shall include all equipment, tools, personnel, time, and other materials including cement grout, and casing to complete the scope of work outlined in these Specifications. The bid shall also include the provision of supplies, tools, parts and supervision for performance of the contract. Finally, the bid shall include cleanup of the drilling site, removal of all drilling and development equipment, and repair of any damage to fences, grass, crops, or personal property at the drilling site.

DRILLING AND CONSTRUCTION OF THE OBSERVATION WELL

DESIRED ACCOMPLISHMENT

Two boreholes are to be drilled at the location designated by the Kansas Geological Survey no greater than 50 feet apart. Within the shallow borehole hole one 5-inch diameter observation well and within the deeper borehole one 4.5-inch OD monitoring well that is in good hydraulic communication with the aquifer is to be constructed and installed. The attached figure is a sketch of the desired monitoring well construction at completion. The depth to the bottom of each completed well is to be approximately 375 feet and 800 feet, respectively, from surface. The lower approximately 175 feet of the shallow observation well and 350 feet of the deep observation well will be an open-hole completion. The shallow observation well will be cased using 4.5-inch OD blank steel or 5-inch PVC casing from surface down to approximately 200 feet and cemented in place. The deep observation well will be steel cased from surface down to 450 feet and cemented in place following the setting of 20 feet of surface casing. The appropriate length of blank casing for each monitoring well will be determined on-site by the

KGS representative. Following construction, each observation well will be developed a minimum of 8 hours, not including setup time, or until the well produces only formation water, whichever time period is longer. Acceptable methods of development include bailing and pumping. The contractor will install a locking cap for the well to prevent tampering by unauthorized personnel. All Kansas Department of Health and Environment rules and regulations regarding well drilling, construction, and protection of the environment shall be followed. Upon completion of drilling the contractor is responsible for cleanup of the site, including the filling of all dug pits and disposal of the drill cuttings.

METHODS AND EQUIPMENT/MATERIALS

Drilling Methods

During drilling, the contractor will penetrate the shales, sandstones, and limestones of Pennsylvanian age, limestones and cherty limestones of Mississippian age, Chattanooga Shale, and limestones, cherty limestones and dolomites of Ordovician age. Some cavities may be encountered during drilling. Flowing well conditions are not expected at this site. Fresh water is expected in this area.

a. Borehole diameter and drilling method

For the deeper monitoring well the diameter of the approximately upper 20 feet of the borehole must be a minimum of 12 inches to accommodate a minimum 8-5/8-inch diameter surface casing. Below this level, the borehole must be sufficiently large to allow placement of a 4.5-inch OD steel or 5-inch PVC casing and to not impede the flow of cement in the annulus outside of the casing. Accordingly, the borehole diameter must be a minimum of 7-7/8 inches.

For the shallower monitoring well, no surface casing is required. The borehole must be sufficiently large to allow placement of the casing and to allow proper placement of the bentonite grout and chlorinated sand backfill in the annulus outside of the casing.

The drilling method used must be suitable for drilling, construction, and installation of the described well under these conditions. Suitable methods are mud rotary or air rotary. The drilling method must be specified in the bid.

b. Drilling fluids

Materials used by the contractor to prepare the drilling fluid shall be composed of fresh, uncontaminated water and sodium-bentonite type drilling mud if the holes are to be drilled using mud rotary methods. All drilling additives used will comply with recognized industry standards and will be used as prescribed by the manufacturer. The drilling fluids program shall be agreed to by the KGS.

The contractor shall be responsible for maintaining the quality of the drilling fluid to assure the following:

1. the protection of water-bearing and potentially water-bearing formations exposed in the borehole;

2. a minimum of formation damage during drilling and construction because such damage will impair the hydraulic connection of the observation well with the surrounding aquifer;
3. the return to surface of good representative samples of the formations being drilled; and
4. the removal of drilling fluids and cuttings from the borehole at the completion of drilling.

c. Samples of drill cuttings

During drilling samples of the drill cuttings will be collected by the driller every 10 feet and placed in sample bags supplied by the KGS. Each sample bag will be labeled with the depth of the sample interval. These will be delivered to the on-site KGS representative during drilling. Driller's reports shall be maintained and delivered to KGS on request. Reports should include descriptions of the formations encountered every 10 ft; the amount of water, drilling mud, and additives used; fluid levels in the borehole; evidence of lost circulation or abnormal fluid pressures in the formation. A KGS representative will be on site during all drilling, installation of the casing, well development, and site cleanup to provide geologic input to decisions, assist the driller in recording information, and observe the progress of the work.

d. Determination of casing depth for the deep monitoring well/borehole depth for the shallow monitoring well

Determination of the casing depth for the deep monitoring well and the total depth of the borehole for the shallow monitoring well will be made on-site by the KGS representative from examination of the cuttings and other data. Other data may include gamma-ray logging of the deep borehole down to total depth.

e. Borehole protection

If the well is left uncompleted due to delay in construction, the contractor shall be responsible for covering the borehole and securing it to prevent contamination or injury.

f. Stand-by time during borehole logging

If required, the geophysical logging of the deep borehole should take less than 4 hours. The contractor will provide periodic estimates on the time of completion of the drilling so that KGS personnel in charge of geophysical logging can be contacted sufficiently ahead of time to allow for the timely delivery of service at the site.

g. Borehole abandonment

In the event of borehole abandonment all measures should be taken to assure isolation of aquifers from each other in the borehole using appropriate means agreed to by the on site KGS representative. This means that the contractor is expected to follow all KDHE plugging standards. Upon completion, the driller must present documentation of how the abandonment was accomplished in writing and a sketch of the completed abandonment.

Relocation of the succeeding borehole shall be no closer than 50 ft away from the abandoned borehole. All relocation and borehole redrilling and materials costs shall be at the driller's expense.

Materials

a. Casing and centralizers

All well casing shall be new and made of materials conforming to ASTM standards. The outside diameter of the steel casing shall be 4.5-inch and of the PVC casing 5 inches. Selection of the casing segment length will be at the discretion of the driller in consultation with the KGS representative on site. Centralizers will be used as necessary to position the casing in the center of the borehole in order to allow uniform thickness of cement in the annular space between the casing and the borehole wall. It is recommended that centralizers be used every 40 to 50 feet along the length of the casing. The length of the casing required for the deep monitoring well shall be calculated as the depth to the top of the Ordovician from surface plus 24 inches. Likewise the length of the casing required for the shallow monitoring well shall be calculated as the depth to the top of the Mississippian from surface plus 20 feet plus 24 inches. The additional 24 inches will allow the casing to extend above ground surface by that amount.

b. Surface casing

A surface casing will be used to seal off any shallow water-bearing zones or contamination sources from the deeper aquifers for the deep monitoring well. The length of casing required is 20 feet.

d. Cement

The contractor shall use grouting material consisting of a mixture of Portland cement (ASTM C150) and water in the proportion of 5.2 gallons of water per 94 lb sack of Portland cement. API type A cement will be used to make the grout. The use of special cements, bentonite to reduce shrinkage, or other mixtures (ASTM C494) to reduce permeability, increase fluidity, and/or control the time of set or the composition of the resultant slurry shall be approved by the KGS on-site representative. Resultant grout slurry must be free of lumps and thoroughly mixed prior to placement in the hole. Potable water shall be used to make the grout.

e. Bentonite grout

The contractor may use bentonite grout to produce a seal in the annular space that will prevent surface water and shallow ground water from moving downward into the Springfield Plateau aquifer (the Mississippian aquifer). The composition of the bentonite grout should be such that the downward flow of water is prevented and should follow accepted standards of practice to accomplish this goal.

WELL DESIGN AND INSTALLATION

Method of Installation and Construction

Construction and installation of each observation well shall follow accepted industry standards and be agreed upon by the KGS. Placement of the grout shall be accomplished using the Halliburton or other methods agreed upon by the KGS. If the Halliburton method is used, return of cement grout to the surface in the annular space will indicate successful completion of the cementing operation. Placement of bentonite grout shall be by means of a tremie pipe. Cementing and grouting will be completed in such a way as to prevent hydraulic communication between the deeper aquifers and overlying water-bearing zones. Once cementing is complete, the contractor shall allow an appropriate length of time on the order of 24–36 hours for the cement to cure before proceeding to the casing perforation phase.

Well Development

Following construction, each observation well will be developed a minimum of 8 hours, not including setup time, or until each well produces only formation water, whichever time period is longer. Acceptable methods include bailing or pumping. The water from the development should be free of drilling mud and any water added during the drilling of the borehole and well construction. Well development progress will be monitored by the on site KGS representative.

Well Protection

During installation, the contractor shall use reasonable precautions to prevent tampering with the observation wells or the entrance of foreign material into them.

The casing shall extend a minimum of 24 inches above the surrounding ground surface and the contractor shall install a suitable slip-on flanged cap to prevent contaminants from entering the well. The ground surface shall be sloped away from the observation well to prevent contamination.

CLEANUP

The drill site around the observation well will be cleaned and restored to its original condition to the extent possible. Slush pits and ditches will be filled, and all drill cuttings not used as backfill and other materials shall be leveled or removed from the site as directed by KGS personnel.

INSTRUCTIONS TO BIDDERS

Submission of a bid to perform the work described will be deemed sufficient proof of the bidder's capabilities and financial responsibility to perform the contract. Bid prices shall remain fixed during the contract. Bids shall be on an itemized unit price per foot for each item listed with a total price for the entire project calculated as the total of the units prices. All work will be performed as directed by the KGS, and work will be paid at the unit price listed on the bid.

The work to be accomplished under the description section of the itemized bid list is approximate and may vary based upon investigative findings. The successful bidder will be allowed no change in bid prices as a result of modification or changes from the assumed or anticipated work presented in this project description. Construction and installation of the observation well must be based on the fixed unit prices as submitted by the bidder.

All work shall be performed at the direction of the KGS on-site personnel.

All required contractor-supplied materials and spare parts must be on site in adequate quantities at commencement of operations in order to insure uninterrupted operations.

Final payment of services will be contingent on completed work by the contractor and acceptance by the KGS.

A bidder finding discrepancies in or omissions from the bid document or having any doubt as to their meaning should contact Allen Macfarlane at (785) 864-2068 at once.

The contractor's interest in all property herein described, if any, or any personal liability to him arising from this agreement to whatever extent shall be considered to be covered by the applicable insurance by the contractor to the extent required. Notwithstanding any language to the contrary, no interpretation shall be allowed to find the Sate of Kansas or any of its agencies responsible for loss or damage to personal property nor to hold contractors harmless from any such occurrences. Contractors shall posses Workman's Compensation Insurance in the amount required by law.

After careful review of the bidding document covering the referenced project, the contractor agrees to provide the service called for in the documents providing all equipment, materials, personnel, and labor required to complete the work in a thorough workmanlike and satisfactory manner in accordance with the specifications for the following prices to wit:

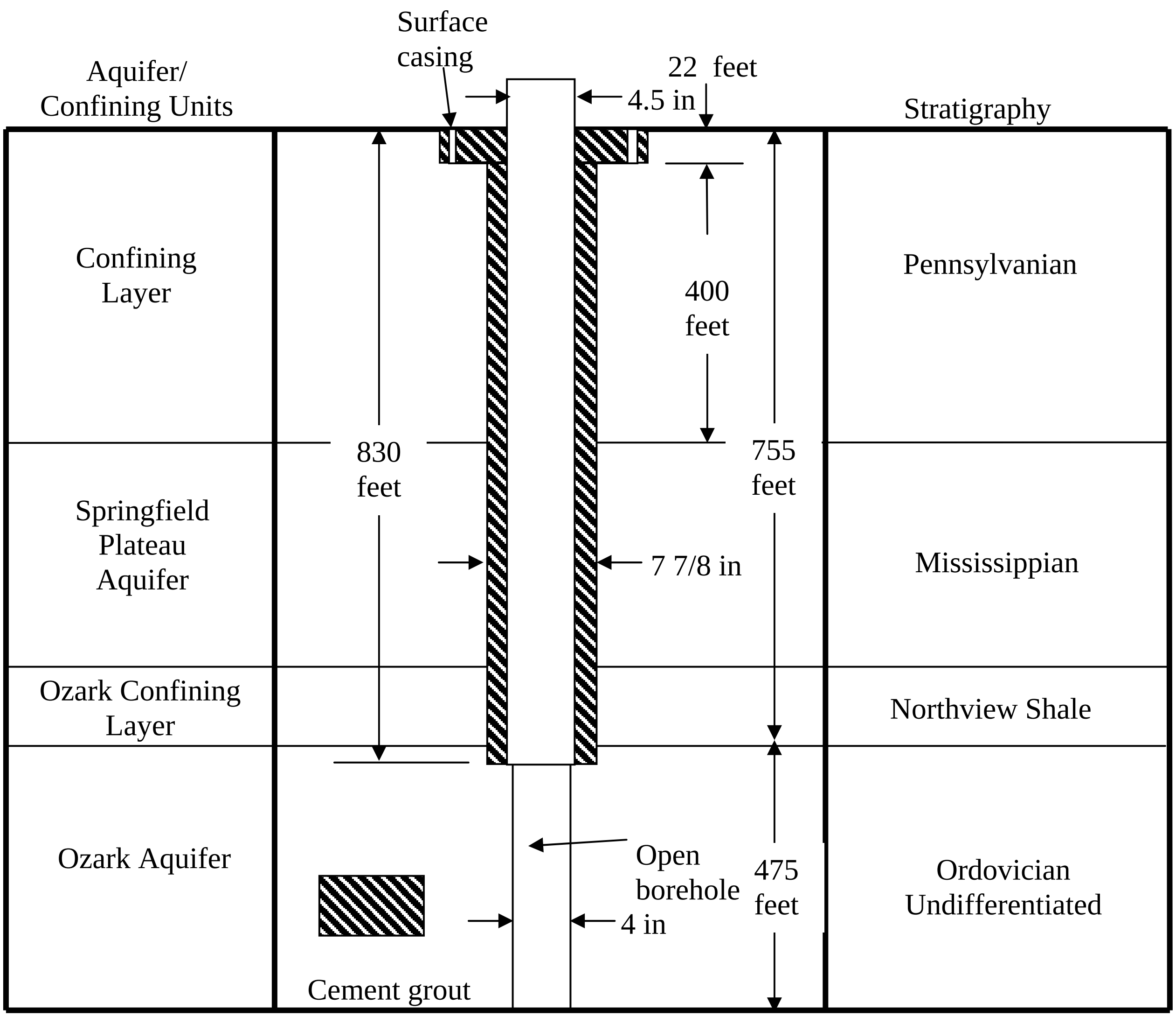
Item	Description	Quantity	Depth	Unit Price	Total
1	Observation well, 4-inch diameter	1	800 LF	_________	$__________
1	Observation well, 4-inch diameter	1	375 LF	_________	$__________

Vender Name:______________________________ FEIN # ______________________

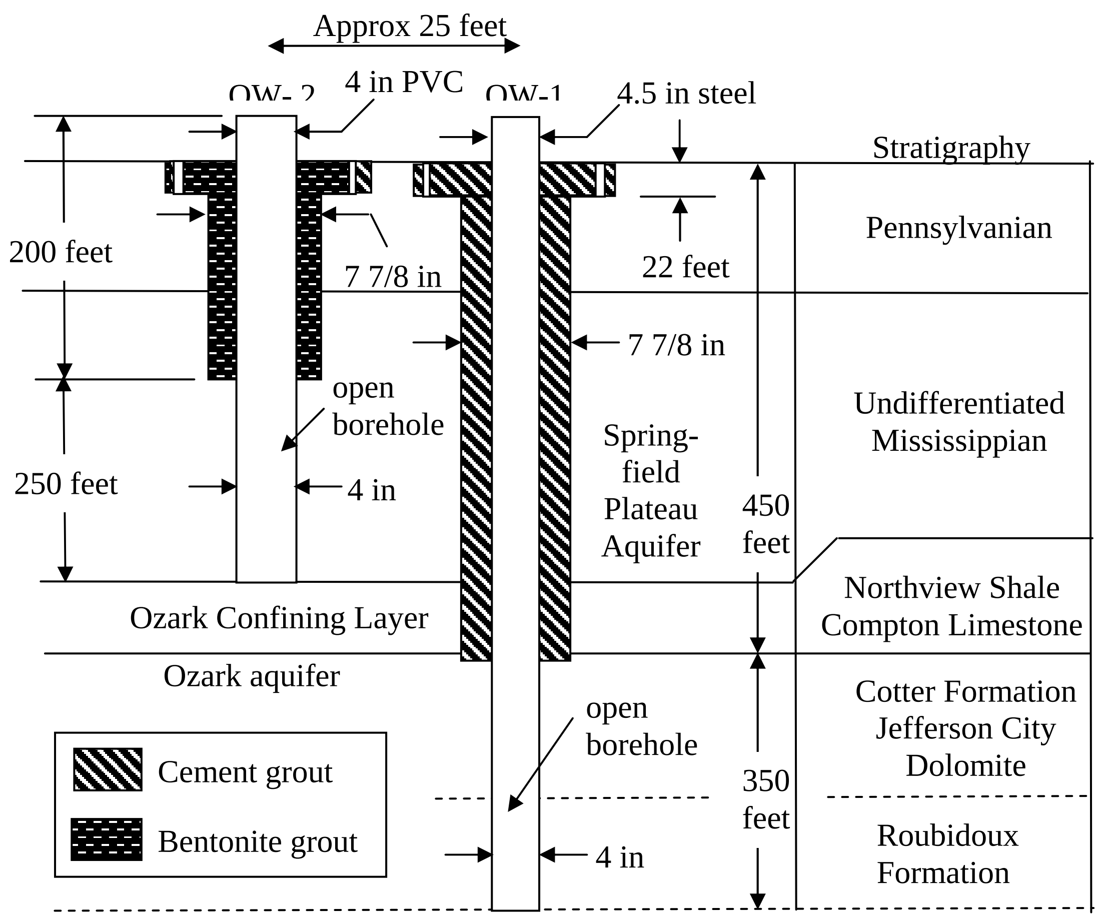
Address ____

Signed By _________________________________ Title ________________________

Signature __________________________________ Date _________________________



McCune Monitoring Well Design



Pittsburg Well Design

ATTACHMENT 2:

WWC-5 RECORDS FOR THE PITTSBURG MONITORING WELLS

WATER WELL RECORD **Form WWC-5** Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Crawford | Fraction: SE ¼ NE ¼ SE ¼ | Section Number: 28 | Township Number: T 30 S | Range Number: R 25 (E)/W

Distance and direction from nearest town or city street address of well if located within city?
602 S. Free King Hwy Pittsburg, KS 66762

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude:
Longitude:
Elevation:
Datum:
Data Collection Method:

2 WATER WELL OWNER: KS. Dept of Agriculture
RR#, St. Address, Box # : 901 KS. Ave
City, State, ZIP Code : Topeka, KS 66612

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

N / W / E / S — NW, NE, SW, SE (X in SE)

4 DEPTH OF COMPLETED WELL ....900........................ ft.

Depth(s) Groundwater Encountered (1) 300-336.. ft. (2) 780-900... ft. (3)..................... ft.
WELL'S STATIC WATER LEVEL 262......... ft. below land surface measured on mo/day/yr 3/27/06....
Pump test data: Well water was..................ft. after................. hours pumping.................... gpm
Est. Yield...12...gpm: Well water was...................ft. after.................. hours pumping.................... gpm
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) (10) Monitoring well ....

Was a chemical/bacteriological sample submitted to Department? Yes .... No .X.....; If yes, mo/day/yrs
Sample was submitted. NO..................... Water well disinfected? Yes .... No .X.....

5 TYPE OF CASING USED: (1) Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below) ....
CASING JOINTS: Glued........ Clamped........ Welded.......................... Threaded X....................
Blank casing diameter ...8"....... in. to ..22'........ ft., Diameter. ..5"........ in. to 515....... ft., Diameter .... in. to ....ft.
Casing height above land surface....18................ in., Weight....15............lbs./ft. Wall thickness or guage No. ....

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 2 Brass 3 Stainless Steel 4 Galvanized Steal 5 Fiberglass 6 Concrete tile 7 PVC 8 RM (SR) 9 ABS 10 Asbestos-Cement 11 Other (Specify) .... (12) None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot 2 Louvered shutter 3 Mill slot 4 Key punched 5 Guazed wrapped 6 Wire wrapped 7 Torch cut 8 Saw Cut 9 Drilled holes 10 Other (specify) .... (11) None (open hole)

SCREEN-PERFORATED INTERVALS: From.................... ft. to .... ft., From .... ft. to .... ft.
From.................... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From.................... ft. to .... ft., From .... ft. to .... ft.
From.................... ft. to .... ft., From .... ft. to .... ft.

6 GROUT MATERIAL: (1) Neat cement 2 Cement grout 3 Bentonite 4 Other ....
Grout Intervals: From ...515..... ft. to ..0.......... ft., From .... ft. to .... ft., From .... ft. to ....ft.
What is the nearest source of possible contamination: NONE
1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well 16 Other (specify below) ....
Direction from well? .... How many feet? ....

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
		Enclosed and Attached			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) ..3/16/06... and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. ..561....... This Water Well Record was completed on (mo/day/year) ..3/31/06......... under the business name of Evans Energy Dev. Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well. Visit us at http://www.kdhe.state.ks.us/geo/waterwells.

KSA 82a-1212

PITTSBURG #1 MONITORING WELL SAMPLE LOG

Depth (ft)	Cuttings Description/Driller Comments
0-20	03/13/06 No samples collected; surface casing set at 21 ft.
20-30	03/14/06 Gray silty shale and sandy siltstone. Started drilling at 7:45AM
30-40	-do-
40-50	Gray shale
50-60	Do
60-70	-do-
70-80	Gray siltstone; very fine sand
80-90	-do-
90-100	-do-
110-120	-do-
120-130	-do-
130-140	-do-
140-150	-do- carbonaceous or heavy oil?
150-160	-do- smell of petroleum; lots of subangular to angular chert grains; some fine sand; Mississippian top at 158 (driller)
160-170	Gray siltstone, sandstone chert granules, heavy oil globules;
170-180	White, speckled limestone some chert
180-190	Tan to light gray limestone
190-200	-do-
200-210	-do- water wet
210-220	-do- water wet
220-230	-do- dry sample
230-240	Tan fossiliferous limestone
240-250	-do-
250-260	White to light gray limestone
260-270	Light gray and tan limestone; some chert
270-280	Light gray limestone and chert
280-290	Tan and light gray limestone; some chert
290-300	Tan and light gray limestone and abundant chert; wet sample
300-310	Light gray and some tan limestone and white opaque chert abundant
310-320	Dark tan dolostone and abundant white to gray chert
320-330	Brown fine grained dolostone and chert
330-340	Chert dark gray to gray and brown dolostone; disseminated pyrite
340-350	-do-
350-360	-do-
360-370	-do- some red silt; driller notes porosity from 330-380; hole producing water.
370-380	Gray and white chert; dark gray dolostone; rare white limestone?
380-390	Dark gray dolostone some chert; some reddish silt
390-400	Gray chert; brown dolostone
400-410	Light gray and gray chert; brown dolostone; rare fragments of clear quartz

410-420	-do-
420-430	Gray dolomitic limestone and chert
430-440	Dark tan dolostone; some chert
440-450	Tan limestone; some chert
450-460	-do-
460-470	-do- Northview at 463 (driller)
470-480	Soft gray to greenish gray shale with disseminated pyrite
480-490	Gray green shale
490-500	Gray-green shale and tan limestone
500-510	Tan limestone (Top of the Cotter at 510 ft.)
510-520	Tan dolostone. (Casing point at 516 ft.) Stopped drilling at 12:30PM
520-530	03/15/06 Tan and gray dolostone; minor translucent to white chert with oolites. Started drilling at 8:30 AM
530-540	-do- with minor green shale pieces
540-550	Brown dolostone with minor translucent to white opaque chert minor black and green shale
550-560	-do- green shale absent
560-570	Brown dolostone with abundant oolite-bearing brown to white translucent to opaque chert and gray dolostone
570-580	Gray and tan dolostone with minor opaque gray to white chert
580-590	Brown and gray dolostone; sandy dolostone and clear quartz; gray shale
590-600	Light tan dolostone; sandy dolostone; gray shale
600-610	Brown dolostone; chert with oolites; some sandy dolostone
610-620	Tan dolostone, chert, white, more abundant; silicified sandstone
620-630	-do- green shale; pyrite
630-640	Tan dolostone; clear and translucent quartz and some chert
640-650	Tan to brown sandy dolostone; white chert and clear quartz; silicified sandstone; green shale
650-660	Brown dolostone; white silicified sandstone; white opaque chert
660-670	-do-
670-680	Brown dolostone; silicified dolostone; white chert containing silicified oolites
680-690	-do- and brown sandy dolostone; trace amounts of pyrite
690-700	-do-
700-710	-do- silicified oolites more abundant
710-720	Brown dolostone; minor chert and trace of pyrite
720-730	Tan dolostone, translucent to white chert; green shale; pyrite
730-740	Brown dolostone; sandy dolostone; green shale, translucent to white chert
740-750	Brown dolostone; chert with ooids
750-760	Brown dolostone; white silicified sandstone; ooids in chert; white translucent to opaque chert; green shale
760-770	-do- chert abundant
770-780	-do- translucent chert and clear quartz fragments very abundant
780-790	Gray dolostone; white silicified sandstone; green shale. Driller notes increasing water flow into the borehole since the casing point.

790-800	Gray dolostone; white to gray sandstone with minor glauconite and pyrite; trace green shale
800-810	Tan dolostone; light gray sandy dolomite with sand grains set in a matrix of fine grained carbonate; glauconite
810-820	Light gray and white sandy dolostone; green shale; pyrite.
820-830	Gray to tan gray medium grained dolostone medium. Stopped drilling at about 830+. Potential drilling bit problems. 11PM
830-840	03/16/06 Pulled stem out of the hole and changed bits at 9:30AM. Started drilling from 833 at 10:23 AM Tan dolostone with what appear to be oolites; sandy dolostone
840-850	-do- trace of green shale; white chert and clear quartz
850-860	Tan sandy dolomite; free sand grains fine to medium grained
860-870	Gray dolostone
870-880	Gray to light tan dolostone; white quartz sandstone; trace amounts of pyrite disseminated in dolomite and sandstone
880-890	Fine to very fine quartz sand; no sample collected
890-900	Fine to very fine quartz sand; no sample collected. Harder to drill than the previous 10 ft. Drilling ended at 12:30PM

WATER WELL RECORD **Form WWC-5** Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Crawford | Fraction: SE ¼ NE ¼ SE ¼ | Section Number: 28 | Township Number: T 30 S | Range Number: R 25 (E)W

Distance and direction from nearest town or city street address of well if located within city?
602 S. Free King Hwy Pittsburg, KS 66762

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude:
Longitude:
Elevation:
Datum:
Data Collection Method:

2 WATER WELL OWNER: KS. Dept of Agriculture
RR#, St. Address, Box # : 901 KS Ave
City, State, ZIP Code : Topeka, KS 66612

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

N / W / E / S — NW, NE (X), SW, SE

4 DEPTH OF COMPLETED WELL ..375.......................... ft.

Depth(s) Groundwater Encountered (1) 281-336 ft. (2)................ ft. (3)................ ft.
WELL'S STATIC WATER LEVEL.....251..... ft. below land surface measured on mo/day/yr 3/27/06...
Pump test data: Well water was.................ft. after.................. hours pumping.................. gpm
Est. Yield. 30.....gpm: Well water was.................ft. after.................. hours pumping.................. gpm
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) (10) Monitoring well ....

Was a chemical/bacteriological sample submitted to Department? Yes .... No .X.....; If yes, mo/day/yrs Sample was submitted.... NO.................. Water well disinfected? Yes .... No ..X.....

5 TYPE OF CASING USED: 1 Steel 3 RMP (SR) 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below) (2) PVC 4 ABS
CASING JOINTS: Glued..X.... Clamped........ Welded.......................... Threaded......................
Blank casing diameter ......5...... in. to ..200....... ft., Diameter. .... in. to .... ft., Diameter .... in. to ....ft.
Casing height above land surface...........18......... in., Weight..200..PSI...lbs./ft. Wall thickness or guage No. .SDR21............

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 3 Stainless Steel 5 Fiberglass 7 PVC 9 ABS 11 Other (Specify) ....
2 Brass 4 Galvanized Steal 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement (12) None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot 3 Mill slot 5 Guazed wrapped 7 Torch cut 9 Drilled holes (11) None (open hole)
2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (specify) ....

SCREEN-PERFORATED INTERVALS: From.................. ft. to .... ft., From .... ft. to .... ft.
From.................. ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From.170.............. ft. to ...30.............. ft., From .... ft. to .... ft.
From.................. ft. to .... ft., From .... ft. to .... ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout (3) Bentonite 4 Other ....
Grout Intervals: From ..200....... ft. to ..170....... ft., From ..30......... ft. to ....0......... ft., From .... ft. to ....ft.
What is the nearest source of possible contamination: NONE
1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well 16 Other (specify below) ....
Direction from well? .... How many feet? ....

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
		Enclosed and attached			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 3/17/06..... and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. ...561...... This Water Well Record was completed on (mo/day/year) 3/31/06........... under the business name of Evans Energy Dev. Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well. Visit us at http://www.kdhe.state.ks.us/geo/waterwells.

KSA 82a-1212

ATTACHMENT 3:

WWC-5 RECORD FOR THE McCUNE MONITORING WELL

WATER WELL RECORD **Form WWC-5** Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Crawford | Fraction SE ¼ SE ¼ SW ¼ | Section Number 16 | Township Number T 31 S | Range Number R 22 (E)W

Distance and direction from nearest town or city street address of well if located within city? 1 miles South and ½ East of McCune KS

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude:
Longitude:
Elevation:
Datum:
Data Collection Method:

2 WATER WELL OWNER: Center for Research Inc.
RR#, St. Address, Box # : University of Kansas
City, State, ZIP Code : Lawrence, KS 66045-7583

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N / NW / NE / W / E / SW / SE / S

4 DEPTH OF COMPLETED WELL 1206 ft.
Depth(s) Groundwater Encountered (1) 589-605 ft. (2) 900-1206 ft. (3)........ ft.
WELL'S STATIC WATER LEVEL 199 ft. below land surface measured on mo/day/yr........
Pump test data: Well water was........ft. after........ hours pumping........ gpm
Est. Yield 200+ gpm: Well water was........ft. after........ hours pumping........ gpm

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) (10) Monitoring well - Observation

Was a chemical/bacteriological sample submitted to Department? Yes ...... No X; If yes, mo/day/yrs Sample was submitted........ Water well disinfected? Yes ...... No X

5 TYPE OF CASING USED: (1) Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued........ Clamped........ Welded........ Threaded X

Blank casing diameter 5" in. to 830' ft., Diameter 8 5/8" in. to 22 ft., Diameter .... in. to ....ft.
Casing height above land surface 18 in., Weight 15.5 lbs./ft. Wall thickness or guage No. ....

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 3 Stainless Steel 5 Fiberglass 7 PVC 9 ABS 11 Other (Specify) ....
2 Brass 4 Galvanized Steal 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement (12) None used (open hole) OPEN 830' - 1206'

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot 3 Mill slot 5 Guazed wrapped 7 Torch cut 9 Drilled holes (11) None (open hole)
2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (specify) ....

SCREEN-PERFORATED INTERVALS: From........ ft. to .... ft., From .... ft. to .... ft.
From........ ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From........ ft. to .... ft., From .... ft. to .... ft.
From........ ft. to .... ft., From .... ft. to .... ft.

6 GROUT MATERIAL: (1) Neat cement 2 Cement grout 3 Bentonite 4 Other ....
Grout Intervals: From 22 ft. to 0-8" ft., From 830 ft. to 0-5' ft., From .... ft. to ....ft.

What is the nearest source of possible contamination:
1 Septic tank 4 Lateral lines 7 Pit privy 10 Livestock pens 13 Insecticide Storage 16 Other (specify below)
2 Sewer lines 5 Cess pool 8 Sewage lagoon 11 Fuel storage 14 Abandoned water well
3 Watertight sewer lines 6 Seepage pit 9 Feedyard 12 Fertilizer Storage 15 Oil well/gas well
Direction from well? .... How many feet? ....

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
		SEE Attached Log			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 11-8-06 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 561 This Water Well Record was completed on (mo/day/year) 11-27-06 under the business name of Evans Energy Dev. Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well. Visit us at http://www.kdhe.state.ks.us/geo/waterwells.

KSA 82a-1212

EVANS ENERGY DEVELOPMENT INC.

11 Lewis Drive Paola, KS 66071

Oil & Gas Well Drilling
Water Wells
Geo-Loop Installation

Phone: 913-557-9083
Fax: 913-557-9084

WELL LOG
Center for Research, Inc.
McCune Observation

Thickness of Strata	Formation	Total
14	soil and clay	14
21	shale	35
2	coal	37
9	shale	46
4	lime	50
9	shale	59
1	coal	60
35	shale	95
2	coal	97
20	shale	117
1	lime	118
1	coal	119
51	shale	170
1	coal	171
160	shale	331
2	coal	333
54	shale	387
2	coal	389
11	shale	400

MCCUNE WELL SAMPLE LOG

Depth Below Surface (Feet)	Description
400 – 410	Gray limestone; Mississippian top at 400 feet
410 – 420	-do- plus chert
420 – 430	-do-
430 – 440	Gray-tan limestone and chert
440 – 450	Medium gray limestone with glauconite; no chert
450 – 460	Light gray cherty limestone; samples damp from 450 feet
460 – 470	Line gray fine crystalline limestone
470 – 480	-do-
480 – 490	-do- trace of black shale, possibly from uphole
490 – 500	-do- plus crystalline brown limestone
500 – 510	Light gray very fine grained limestone and fine grained brown limestone and chert
510 – 520	Brown crystalline limestone, chert, and fine crystalline limestone
520 – 530	Gray and brown crystalline fossiliferous limestone and chert
530 – 540	-do-
540 – 550	Light gray limestone and translucent chert, quartz
550 – 560	-do-
560 – 570	Light gray crystalline limestone and chert some iron-stained
570 – 580	-do-
580 – 590	Light gray and gray limestone with pyrite and chert; Water at 590; making mud.
600 – 610	-do- brown limestone more prevalent
610 – 620	Light gray limestone and chert
620 – 630	Tan to light gray fossiliferous limestone and chert
630 – 640	Tan crystalline fossiliferous limestone an chert some blue-gray in color
640 – 650	Gray and tan fossiliferous limestone
650 – 660	Gray and tan limestone, gray opaque chert, and pyrite
660 – 670	Gray and tan gray limestone and gray and blue-gray fossiliferous chert
670 – 680	Gray crystalline limestone with little cchert
680 – 690	Gray-tan crystalline limestone with little chert
690 – 700	Gray to gray-green limestone and shaly limestone and pyrite; little if any chert
700 – 710	Tan limestone with green shaly limestone no chert
710 – 720	-do-
720 – 730	Gray and gray tan fosssiliferous limestone
730 – 740	Greenish gray, slightly calcareuous shale with disseminated pyrite and pyrite masses. Beginning at 732 some clear to translucent chert.
740 – 750	-do-
750 – 760	Green shale and brown dolostone. Top of the Ordovician at 755 feet
760 – 770	Gray to gray brown dolostone
770 – 780	Gray to tan gray dolostone with translucent chert containing ooids
780 – 790	-do- whit porcelaneous and gray translucent chert and pyrite
790 – 800	Brown and tan dolostone and sandy dolostone

800 – 810	Brown medium to fine crystalline dolostone showing some porosity and gray fine dolostone.
810 – 820	-do- plus green laminated shale
820 – 830	Gray dolostone and translucent chert
830 – 840	Gray dolostone, black shale, and chert
840 – 850	Light gray tan dolostone, oolitic chert silicified white sandstone
850 – 860	Gray to gray tan dolostone with pyrite and blue gray translucent chert
860 – 870	No sample collected
870 – 880	-do- some sandstone and clear quartz. Hole making water
880 – 890	Tan dolostone sandstone and chert
890 – 900	-do- oolitic chert
900 – 910	Tan dolostone and sandstone
910 – 920	Tan dolostone
920 – 930	-do-
930 – 940	-do- Black shale; gray dolostone, oolitic chert and very abundant and unconsolidated sandstone
940 – 950	-do- trace of pyrite
950 – 960	Tan and gray dolostone with some sandstone
960 – 970	Lost circulation; no sample from this interval
970 – 980	Gray tan dolostone some of it silicified by chert replacement
980 – 990	Tan dolostone with a trace of sandstone
990 – 1000	Dark tan brown sandy dolostone
1000 – 1010	Light brown dolostone and minor microcrystalline gray dolostone; abundant translucent blue gray chert
1010 – 1020	-do- minor sandstone
1020 – 1030	-do-
1030 – 1040	Gray tan fine grained dolostone and chert as a matrix infilling
1040 – 1050	-do- gray chert abundant and quartz and pyrite present
1050 – 1060	-do- less chert
1060 – 1070	Sandy dolostone and silicified sandstone
1070 – 1080	Gray tan porous crystalline dolostone
1090 – 1100	-do- gray shale
1100 – 1110	Gray tan fine grained porous dolostone and white sandstone
1110 – 1120	-do- with calcite rhombs filling vugs
1120 – 1130	Fine grained white sandstone
1130 – 1140	Glauconitic sandstone and tan vuggy dolostone
1140 – 1150	Tan fine grained dolostone
1150 – 1160	-do-
1160 – 1170	-do-
1170 – 1180	Gray fine grained dolostone and gray to white sandstone; abundant chert, and pyrite common
1180 – 1190	Tan fine grained dolostone
1190 – 1200	Tan fine grained dolostone and sandy dolostone
1200 - 1206	White to light tan sandstone and white siltstone TD @ 1206

ATTACHMENT 4:

WATER-LEVEL DATA COLLECTED DURING PHASES 1 AND 2

(FROM WATER-LEVEL SURVEYS AND MANUAL DATA COLLECTION FROM PUMPING TESTS)

Well Owner/ Water Supply	Well ID	Township S	Range E	Sec.	Qualifier	GPS Latitude	GPS Longitude	Measurement Point Elevation (feet amsl)
Cherokee Co. RWD 2	1	34	25	8	SWNWSW	37.093 N	94.704 W	848.75
Cherokee Co. RWD 9	1	34	25	20	NWNENW	37.074 N	94.693 W	825.25
Cherokee Co. RWD 8	1	34	25	21	NWNESE	37.064 N	94.669 W	917.71
Cherokee Co. RWD 8	2	34	25	28	NWNWNW	37.060 N	94.677 W	911.71
Galena	1	34	25	23	SENENE	37.072 N	94.632 W	960.75
Galena	4	34	25	13	SWSWSW	37.075 N	94.631 W	962.83
Galena	3	34	25	14	NWNWNE	37.089 N	94.639 W	949
Baxter Springs	6	34	24	36	NENWNW	37.046 N	94.737 W	822.3
Baxter Springs	5	34	24	36	NWNWSW	37.037 N	94.735 W	826.25
Cherokee RWD 3	1	34	24	17	SWSWSE	37.075 N	94.804 W	856.17
Jayhawk Fine Chemicals	PW 1	34	25	4	NENWNE	37.117 N	94.675 W	853
Jayhawk Fine Chemicals	PW2	34	25	4	NENWNE	37.119 N	94.674 W	855.25
Cherokee RWD 1	1	33	25	18	NENESE	37.170 N	94.705 W	870.9
Cherokee RWD 1	2	33	25	9	SENESE	37.180 N	94.669 W	883.00
Columbus	4	32	23	13	NENENW	37.177 N	94.843 W	894.13
Columbus	5	32	23	13	NENENW	37.177 N	94.843 W	892.55
Columbus	6	32	23	13	NWNE	37.176 N	94.839 W	913.5
Cherokee Co. RWD 4	1	32	24	29	NWNWNW	37.237 N	94.813 W	912
Cherokee Co. RWD 4	2	32	24	29	NWNWNW	37.237 N	94.813 W	912.71
Weir	1	31	24	27	NWSESW	37.313 N	94.771 W	924.08
Arma	1	29	25	5	SESESW	37.464 N	94.779 W	1020.5
Arma	2	29	25	5	SESESW	37.464 N	94.779 W	1020.5
Frontenac	North	30	25	9	NENWNE	37.455 N	94.684 W	954.9
Frontenac	South	30	25	9	NENWNE	37.455 N	94.684 W	954.9
Frontenac	1	30	25	4	NESWSW			954.27
KS Dept of Agriculture	OW-O	30	25	28	NENESE			903.00
KS Dept of Agriculture	OW-S	30	25	28	NENESE			903.00
KS Dept of Agriculture	OW-O	31	22	16	SWSESW			879.50
Pittsburg	10	30	25	28	NESESE	37.400 N	94.669 W	898.3

Well Owner/ Water Supply	Well ID	Township S	Range E	Sec.	Qualifier	GPS Latitude	GPS Longitude	Measurement Point Elevation (feet amsl)
Pittsburg	11	30	25	28	SESESE	37.398 N	94.670 W	899.7
Girard	3	30	24	21	NESENE	37.536 N	94.742 W	922
Girard	4	30	24	21	NESENE	37.420 N	94.779 W	925
Arcadia	2	28	25	1	NESWNE	37.398 N	94.670 W	836.45
Crawford Co. RWD 1C	North	30	24	2	SESESE	37.460 N	94.734 W	948.3
Crawford Co. RWD 1C	South	30	24	2	SESESE	37 457 N	94.742 W	948.3
Crawford Co. RWD 4	1	30	24	28	NENENE	37.411 N	94.780 W	928.3
Crawford Co. RWD 4	3	31	24	16	NENENE	37.353 N	94.778 W	909.4
Crawford Co. RWD 5	1	30	25	23	SESWSW	37.461 N	94.645 W	926.4

Well Owner/ Water Supply	Well Num	Aquifer	MP Elev (ft amsl)	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water
Cherokee RWD 2	1	O	848.75	5/24/04	118.38	12/6/04	123.29	8/31/05	129.80	3/21/06	132.82
Cherokee RWD 9	1	O	825.25	5/25/04	143.60	12/6/04	135.72	8/31/05	178.86	3/21/06	141.35
Cherokee RWD 8	1	O	917.71	5/25/04	149.49	12/6/04	150.69	8/31/05	162.50	3/17/06	161.40
Cherokee RWD 8	2	O	911.71	5/25/04	124.99	12/6/04	126.15	8/31/05	149.10	3/21/06	136.72
Galena	1	O	960.75	5/24/04	199.83	12/7/04	193.44	8/31/05	231.25	3/29/06	198.85
Galena	4	O	925.00	5/25/04	222.58	12/7/04	214.15	8/31/05	250.20	3/13/06	281.33
Galena	3	O	949.00	5/25/04	138.69	12/7/04	139.13	8/31/05	143.40	3/13/06	145.20
Baxter Springs	6	O	822.30	5/24/04	180.58	12/7/04		8/31/05	189.34	3/17/06	226.45
Baxter Springs	5	O	826.25	5/24/04	125.29	12/7/04	118.39	8/31/05	129.46	3/17/06	140.72
Cherokee RWD 3	1	O	856.17	5/25/04	173.29	12/6/04	195.13	8/31/05	191.45	3/21/06	183.85
Jayhawk Fine Chemicals	PW 1	O	853.00	5/26/04	107.7	12/8/04	99.43	8/15/05	101.09	-	-
Jayhawk Fine Chemicals	PW-2	O	855.25	5/26/04	209.66	12/8/04	230.07	8/15/05	233.44	-	-
Cherokee RWD 1	1	O	870.90	-	-	-	-	9/1/05	172.85	3/29/06	162.46
Cherokee RWD 1	2	O	883.00	-	-	-	-	9/1/05	110.00	3/29/06	110.19
Columbus	4	O	894.13	5/26/04	203.50	12/7/04	201.58	9/1/05	203.95	3/21/06	203.78
Columbus	5	O	892.55	5/26/04	208.90	12/7/04	203.94	-	-	-	-
Columbus	6	O	913.50	5/25/04	203.63	12/7/04	200.79	-	-	-	-
Cherokee RWD 4	1	OP	912.00	5/25/04	235.12	12/7/04	240.71	9/1/05	240.40	3/21/06	238.58
Cherokee RWD 4	2	OP	912.71	5/25/04	236.53	12/7/04	237.3	-	-	-	-
Weir	1	OP	924.08	5/25/04	242.40	12/8/04	-	9/1/05	238.11	3/21/06	253.10
Arma	1	OP	1020.5	5/24/04	-	-	-	9/1/05	347.07	3/20/06	337.02
Arma	2	OP	1020.5	5/24/04	336.50	12/6/04	338.63	-	-	-	-
Frontenac	1	OP	954.27	-	-	12/7/04	264.60	-	-	-	-
Frontenac	North	O	954.90	-	-	-	-	9/1/05	297.94	3/22/06	291.19
Frontenac	South	O	954.90	5/26/04	283.15	-	-	-	-	-	-
Pittsburg	10	O	898.30	5/29/04	249.90	-	-	-	-	-	-

Well Owner/ Water Supply	Well Num	Aquifer	MP Elev (ft amsl)	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water
Pittsburg	11	O	899.70	5/25/04	257.75	12/07/04	255.27	9/02/05	267.90	-	-
Pittsburg OW	O	O	903.00	-	-	-	-	-	-	3/29/06	261,97
Pittsburg OW	S	SP	903.00	-	-	-	-	-	-	3/29/06	251.05
Girard	3	O	922	-	-	-	-	9/1/05	256.51	3/17/06	248.38
Girard	4	O	925	5/24/04	278.00	12/6/04	247.00	-	-	-	-
Arcadia	2	O	836.45	5/24/04	152.80	12/6/04	155.59	9/1/05	163.17	3/22/06	156.79
Crawford RWD 1C	North	O	948.3	5/24/04	289.90	12/6/04	286.71	9/1/05	298.18	3/22/06	273.50
Crawford RWD 1C	South	O	948.3	5/24/04	290.00	-	-	-	-	-	-
Crawford RWD 4	1	OP	928.3	5/24/04	258.13	12/6/04	237.91	9/1/05	256.75	3/21/06	249.75
Crawford RWD 4	3	OP	909.4	5/24/04	242.53	12/6/04	251.88	9/1/05	243.67	3/21/06	239.01
Crawford RWD 5	1	OP	926.4	5/24/04	280.50	12/6/04	239.29	9/1/05	287.45	3/29/06	282.24

Well Owner/ Water Supply	Well Num	Aquifer	MP Elev (ft amsl)	Date	Depth to Water
Cherokee RWD 2	1	O	848.75	10/2/06	142.33
Cherokee RWD 9	1	O	825.25	10/2/06	154.56
Cherokee RWD 8	1	O	917.71	10/2/06	175.81
Cherokee RWD 8	2	O	911.71	10/2/06	152.74
Galena	1	O	960.75	10/2/06	216.27
Galena	4	O	925.00	10/2/06	257.37
Galena	3	O	949.00	10/2/06	152.84
Baxter Springs	6	O	822.30	9/20/06	293.61
Baxter Springs	5	O	826.25	9/20/06	169.65
Cherokee RWD 3	1	O	856.17	9/21/06	184.28
Jayhawk Fine Chemicals	PW 1	O	853.00	9/21/06	115.60
Jayhawk Fine Chemicals	PW-2	O	855.25	9/21/06	244.61
Cherokee RWD 1	1	O	870.90	10/3/06	173.30
Cherokee RWD 1	2	O	883.00	10/3/06	124.83
Columbus	4	O	894.13	9/21/06	202.83
Columbus	5	O	892.55	-	-
Columbus	6	O	913.50	-	-
Cherokee RWD 4	1	OP	912.00	9/20/06	235.83
Cherokee RWD 4	2	OP	912.71		
Weir	1	OP	924.08	9/20/06	239.30
Arma	1	OP	1020.5	9/19/06	349.90
Arma	2	OP	1020.5	-	-
Frontenac	1	OP	954.27	-	-
Frontenac	North	O	954.90	9/19/06	309.50
Frontenac	South	O	954.90	-	-
Pittsburg	10	O	898.30	-	-

Well Owner/ Water Supply	Well Num	Aquifer	MP Elev (ft amsl)	Date	Depth to Water
Pittsburg OW	O	O	903.00	9/20/06	277.01
Pittsburg OW	S	SP	903.00	-	-
Girard	3	O	922	9/19/06	259.45
Girard	4	O	925	-	-
Arcadia	2	O	836.45	9/19/06	166.20
Crawford RWD 1C	North	O	948.3	9/19/06	290.60
Crawford RWD 1C	South	O	948.3	-	-
Crawford RWD 4	1	OP	928.3	9/20/06	258.11
Crawford RWD 4	3	OP	909.4	9/19/06	244.05
Crawford RWD 5	1	OP	926.4	9/20/06	297.32

Monitoring Well Site	Well	Aquifer	MP Elev (ft amsl)	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water
Pittsburg	OW-O	O	903.00	4/13/06	261.81	5/15/06	261.72	7/13/06	268.05	8/15/06	274.98
Pittsburg	OW-S	SP	903.00	4/13/06	N	5/15/06	N	7/13/06	N	8/15/06	N
McCune	OW-O	O	879.50	-	-	-	-	-	-	-	-

Monitoring Well Site	Well	Aquifer	MP Elev (ft amsl)	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water
Pittsburg	OW-O	O	903.00	9/20/06	277.01	10/3/06	274.04	11/20/06	265.45	12/18/06	268.76
Pittsburg	OW-S	SP	903.00	9/20/06	N	10/3/06	N	11/20/06	N	12/18/06	N
McCune	OW-O	O	879.50	-	-	-	-	-	-	12/18/06	203.12

Monitoring Well Site	Well	Aquifer	MP Elev (ft amsl)	Date	Depth to Water	Date	Depth to Water	Date	Depth to Water
Pittsburg	OW-O	O	903.00	1/25/07	266.64	2/19/07	272.76	-	-
Pittsburg	OW-S	SP	903.00	1/25/07	N	2/19/07	N	-	-
McCune	OW-O	O	879.50	1/25/07	196.85	2/20/07	195.68	3/19/07	195.39

Monitoring Well	Date	Time (24 hour clock)	Depth to Water from MP (ft below land surface)
Pittsburg 11	2/20/07	0847	253.50
Pittsburg 11	2/20/07	0852	257.99
Pittsburg 11	2/20/07	0902	255.60
Pittsburg 11	2/20/07	0912	258.10
Pittsburg 11	2/20/07	0927	258.30
Crawford RWD 5 Well 1	2/20/07	0930	276.35
Pittsburg 11	2/20/07	0947	258.61
Pittsburg 11	2/20/07	1017	259.08
Pittsburg 11	2/20/07	1047	259.41
Pittsburg 11	2/20/07	1117	259.66
Pittsburg 11	2/20/07	1147	259.87
Pittsburg 11	2/20/07	1247	260.19
Pittsburg OW-O	2/20/07	1333	277.69
Pittsburg 11	2/20/07	1347	260.42
Pittsburg 11	2/20/07	1447	260.65
Pittsburg OW-O	2/20/07	1502	261.60
Crawford RWD 5 Well 1	2/20/07	1600	278,45
Pittsburg OW-O	2/20/07	1615	260.70
Pittsburg 11	2/20/07	1647	260.59
Pittsburg 11	2/20/07	1847	261.03
Crawford RWD 5 Well 1	2/20/07	2000	307.87
Pittsburg OW-O	2/20/07	2030	260.95
Crawford RWD 5 Well 1	2/21/07	0615	297.55
Pittsburg OW-O	2/21/07	0630	261.87
Pittsburg 11	2/21/07	0645	261.95
Pittsburg OW-O	2/21/07	0726	261.92
Crawford RWD 5 Well 1	2/21/07	0915	284.34
Pittsburg OW-O	2/21/07	0945	262.03

Monitoring Well	Date	Time (24 hour clock)	Depth to Water from MP (ft below land surface)
Crawford RWD 5 Well 1	2/21/07	1200	279.73
Pittsburg OW-O	2/21/07	1215	262.26
Pittsburg OW-O	2/21/07	1230	263.23
Pittsburg 11	2/21/07	1230	262.23
Pittsburg 11	2/21/07	1530	262.35
Pittsburg OW-O	2/21/07	1551	263.62
Crawford RWD 5 Well 1	2/21/07	1639	269.85
Crawford RWD 5 Well 1	2/22/07	0804	280.45
Pittsburg OW-O	2/22/07	0823	264.12
Pittsburg 11	2/22/07	0904	261.80
Pittsburg 11	2/22/07	0918	261.77
Pittsburg OW-O	2/22/07	1106	263.08
Pittsburg 11	2/22/07	1138	261.86
Crawford RWD 5 Well 1	2/22/07	1154	275.15
Pittsburg OW-O	2/22/07	1224	258.39
Pittsburg OW-O	2/22/07	1237	257.54
Pittsburg OW-O	2/22/07	1250	256.96
Pittsburg OW-O	2/22/07	1305	256.47
Pittsburg OW-O	2/22/07	1402	255.20
Crawford RWD 5 Well 1	2/22/07	1424	280.49
Pittsburg OW-O	2/22/07	1501	255.07
Pittsburg OW-O	2/22/07	1547	254.04

ATTACHMENT 5:

REVISED TABLE 4 FROM MACFARLANE ET AL. (2005)

County	Location	Well Depth	Aquifer(s)	Use	Observation Period (DD/MM/YY – DD/MM/YY)	Number of Observations
Cherokee	35S 23E13BAC	1,210	?	Public supply	01/01/36 – 10/01/71	13
Cherokee	35S 23E 02DCD	206	?	Unknown	13/08/81 – 18/03/82	4
Cherokee	35S 25E 02CC	181	?	Domestic	01/09/64 – 31/07/81	2
Cherokee	35S 23E 02DCDA	1,050	?	Unknown	13/08/81 – 18/03/82	4
Cherokee	34S 24E 36CDB	1,020	?	Unused	01/01/26 – 10/11/75	7
Cherokee	34S 24E 33CAC	1,050	?	Unknown	20/11/81 – 16/03/82	2
Cherokee	34S 24E 36DB	1,090	?	Public supply	01/03/56 – 13/05/65	24
Cherokee	34S 24E 36BBA	1,175	Ozark	Public supply	06/10/87 – 06/27/2003	36
Cherokee	34S 24E 17DCC	1,050	Ozark Plateaus	Unknown	01/01/74 – 13/05/80	3
Cherokee	34S 25E 13BAC	1,150	Ozark	Observation	01/12/32 – 08/09/87	358
Cherokee	34S 25E 04ADB	901	Ozark	Unknown	01/02/42 – 27/09/79	2
Cherokee	34S 23E 02ABA	26	?	Domestic	01/08/42 – 27/10/65	117
Cherokee	33S 25E 18ADD	900	?	Unknown	01/04/64 – 13/05/81	4
Cherokee	33S 25E 09DAD	1,020	?	Domestic	01/9/64 – 06/06/79	24
Cherokee	32S 24E 19CBD	850	?	Unused	03/02/43 – 27/10/65	89
Cherokee	32S 25E 06DAD	25	?	Unused	01/01/51 –09/09/64	81
Cherokee	32S 23E 06DAA	1,280	Ozark	Unknown	01/09/35 – 12/05/80	3
Crawford	31S 22E 08DCD	1,310	Ozark	Public supply	01/05/47 – 15/05/80	3
Crawford	31S 22E 08DC	1,300	?	Unknown	01/08/63 – 09/06/64	3
Crawford	30S 25E 21CCD	49	?	Unknown	27/09/79 – 16/05/80	2
Crawford	30S 24E 24DDD	109	?	Industrial	02/03/87 – 08/09/87	3
Crawford	30S 24E 19ADD	955	?	Unused	12/12/77 – 03/06/86	37
Crawford	29S 23E 24DBA	1,210	Ozark Plateaus	Unused	12/12/77 – 05/12/97	80
Crawford	29S 23E 24ACD	1,190	Ozark Plateaus	Public supply	01/01/45 – 14/05/80	4
Crawford	29S 23E 24ACC	1,200	Ozark Plateaus	Public supply	01/01/52 – 09/06/64	4
Crawford	29S 24E 11ADD	1,145	?	Unused	07/10/87 – 10/09/2003	30
Crawford	28S 22E 21CCD	1,020	?	Public supply	01/06/59 – 14/05/80	3
Bourbon	25S 24E 36ADB	700	?	Unused	13/12/77 – 05/12/97	74
Bourbon	25S 25E 29DDA	1460	?	Unused	01/09/42 – 30/01/56	2

Table 1. Revised Table 4 from Macfarlane et al. (2005)

ATTACHMENT 6:

SUMMARY OF COSTS FOR CONDUCTING PHASE II

Budgeted Item	Cost
Personnel & Fringe Benefits[1]	$14,054.00
Monitoring Well Installation & Geophysical Logging[2]	105,057.00
Monitoring Equipment & Related Supplies[3]	1,848.80
Travel (per diem & mileage)[4]	4,888.71
Total	$125,848.51
KWO Funds Allotted	$126,630.00
Remaining in the Project Account[5]	$781.49

Notes

[1] PI salary originally estimated at 2.25 months FTE. The actual time spent on the project by the PI is estimated to have been on the order of 3.5 months FTE.

[2] Includes the cost of materials and labor for the installation of both monitoring wells as specified in Attachment 1. Geophysical logging includes only the travel expenses charged to the project by KGS Exploration Services personnel and this is charged under the Travel budget category. The expense associated with operating the logging equipment was donated by KGS to the project.

[3] Monitoring equipment includes a Solinst pressure transducer and cable purchased for installation in PW-2 at the Jayhawk Fine Chemicals plant.

[4] Travel includes all travel for monitoring well siting and installation, geophysical logging, installation, servicing, and downloading of data from the pressure transducers, water level surveys, and attendance at out of town TAC meetings and events.

The per diem rate in 2004-2006 = $10 per quarter and in 2007 = $11 per quarter; Lodging cost is actual. Mileage cost was calculated at the prevailing state rate for each year of the project.

[5] Remaining funds will be used to continue participation in the Ozark WISP meetings, attendance at TAC meetings, and other related activities.