Enclosure 3 to E-54844

OAG Water Levels: Empirical and Modeled Relationships between Precipitation and Infiltration, 2011
(Public)

WASTE CONTROL SPECIALISTS LLC

RADIOACTIVE MATERIALS DIVISION

2011 FEB 22 PM 4 4

February 22, 2011

VIA HAND DELIVERY

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Uranium and Technical Assessments Section
Radioactive Materials Division
Texas Commission on Environmental Quality
P.O. Box 13087, MC-233
Austin, Texas 78711-3087

References: (1) Radioactive Material License No. R05807, Amendment 04 CN600616890, RN101702439

(2) Letter from Gary L. Smith, Ph.D. (TCEQ), to Scott Kirk, CHP (WCS), re: "Radioactive Material License No. R05807, Log No. 2009-12-0003, Surface Water Management Plan," dated January 7, 2010 [sic]

Subject: Response to Request for Additional Information Regarding Surface Water Management at the Waste Control Specialists LLC Site, Andrews County, Texas

Dear Dr. Smith:

Your letter of January 7, 2011 (Reference 2), requests submittal of information that includes quantitative models which show that WCS' surface improvements minimize infiltration. Enclosed is a report *OAG Water Levels: Empirical and Modeled Relationships between Precipitation and Infiltration* that addresses infiltration of precipitation and surface water into the Ogallala/Antlers/Gatuña (OAG) formation, including a numerical model analysis of the effects of infrastructure developments such as roads, railways, and ditches. The report provides empirical observations of the response of the OAG wells to precipitation, both under natural circumstances and in the vicinity of ditches and other drainage interruptions such as roads. Also included in the report is a numerical model analysis that illustrates the potential impacts of surface water management on groundwater conditions in the OAG and illuminates the mechanism of recharge to the OAG.

Waste Control Specialists LLC (WCS) submits this report to completely fulfill the requirements of License Condition 97.A of Radioactive Material License No. R05807.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

WCS requests that a copy of all correspondence regarding this matter be directly emailed (skirk@valhi.net) to my attention as soon as possible after issuance. If you have any questions or need additional information, please call me at 432-525-8500.

Sincerely,

Scott Kirk

J. Scott Kirk, CHP
Vice-President, Licensing, Corporate Compliance and Radiation Safety Officer

Enclosure

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OAG Water Levels: Empirical and Modeled Relationships between Precipitation and Infiltration

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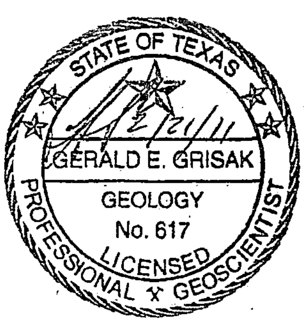

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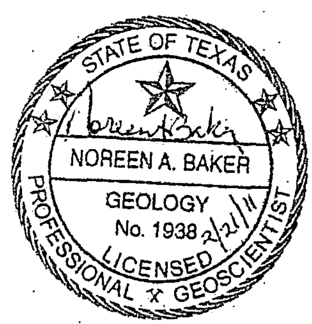


Noreen A. Baker

February 21, 2011

Table of Contents

List of Figures

List of Appendices

1.0 Introduction

The purpose of this report is to respond primarily to the January 7, 2011 letter from the Texas Commission on Environmental Quality (TECQ) regarding Radioactive Materials License (RML) No. R05807, License Condition (LC) 97.A. The report also provides documentation requested by TCEQ in a letter dated December 10, 2009, of continued water level monitoring in TP-42 and TP-43, as well as additional observations in water levels around the Byproduct landfill and documentation of the effect of infiltration from the ditches and drainages in the vicinity of the Byproduct landfill, as requested in a letter from TCEQ dated May 11, 2010. The observations and qualitative analyses in Section 2.0 are provided as the empirical observations of the infiltration processes at the WCS site. Generic numerical modeling of infiltration processes at the site are summarized in Section 3.0, and the modeling results are presented in Appendix II.

The January 7, 2011 letter from TCEQ requests a submission that completely fulfills the requirements of LC 97.A.

License Condition 97.A states:

Within 60 days of issuance of Amendment 03 of this license, the licensee shall submit for review by the Executive Director, a comprehensive plan to manage surface water within an 800-foot perimeter of the by-product material disposal landfill that will minimize infiltration, evaluate run-off from adjacent facilities and evaluate impacts of run-off from all current and planned facilities for the WCS complex. The plan shall also include, at a minimum, installation of continuous water level monitors at TP-142, TP-143, TP-146, TP-148, TP-167, and TP-171 (see Figure 1 OAG Groundwater Occurrence – Facilities Area, July 2009, received August 10, 2009).

WCS contends that the requirements of LC 97.A have been met. As noted by TCEQ in the January 7, 2011 letter, WCS submitted a document entitled 'Surface Water Management Plan' on December 1, 2009, as well as additional supporting information regarding surface water management in a report entitled 'Engineering Design and related Construction Plans to Maintain the Drainage Ditch for the Red Bed Bench in the Byproduct Material Landfill', submitted pursuant to provision 9.B of the compliance agreement effective August 27, 2010. WCS installed the continuous water level monitors at the wells identified in License Condition 97.A and at several other wells around the Byproduct landfill, for a current total of 18 wells with continuous water level monitors in the vicinity of the Byproduct landfill and one continuous monitor in TP-14 north of the Federal Waste Facility/Compact Waste Facility (FWF/CWF). The reports and actions stated above are the basis of WCS' contention that the requirements of License Condition 97.A have been met.

In the January 7, 2011 letter, TCEQ references additional discussions and correspondence wherein WCS agreed to provide an assessment of infiltration to the OAG that included both observations of the response of the OAG to precipitation as well as generic modeling of potential infiltration scenarios. The observations and modeling are to demonstrate the response or lack of response of the OAG to precipitation. The observations and modeled scenarios are meant to account for variability in subsurface geology and proximity to probable sources of infiltration such as playas or other topographically low areas with a tendency to develop standing water following precipitation events. Man-made influences on surface water runoff and potential infiltration scenarios include drainage ditches and drainage interruptions by roads, railroads or other surface facilities.

Therefore, although WCS contends that the requirements of LC 97.A have been met by previous submissions and site activities undertaken pursuant to the license condition, this report provides information in response to additional requests that have been made by the TCEQ.

The report is presented in two parts. The first part provides historical observations from wells in the OAG unit. There are currently 254 OAG wells on the WCS site, of which 152 are dry and 102 contain some measureable thickness of water in the OAG. Most of the OAG in the vicinity of the WCS landfill facilities is dry. The second part of the report presents generic modeling of infiltration representative of the site hydrogeologic conditions, demonstrating the mechanisms of infiltration at the site under various geologic sequence scenarios and under undisturbed and current conditions. Current conditions at the site include infrastructure development such as roads, ditches, railroads, buildings or other man-made features that impact runoff and infiltration.

2.0 Empirical Observations

The WCS site comprises the Flying W Ranch, approximately 23 sections which includes the facilities area, the 1338 acres of the Flying W Ranch within which the WCS hazardous and radioactive waste permitted facilities are located. The thickness of the OAG on the WCS site ranges from zero, where the caliche that developed on and in the OAG sediments extends from ground surface to the top of Dockum, to about 30 feet. The OAG occurs at depths of a few feet to 80 feet or more in the extreme southern and northern parts of the Flying W Ranch.

The OAG, which has some saturated thickness on a somewhat laterally continuous basis in the northern and eastern parts of the WCS site, is generally dry on the western and southern parts of the site. The saturated thickness feathers out to zero as the WCS landfill facilities are approached from the north and east, leaving a few isolated areas of thin OAG saturation in low spots on the top of the Dockum. There are currently 254 OAG wells on the WCS site, of which 152 are dry and 102 contain some measureable thickness of water in the OAG. Most of the OAG in the vicinity of the WCS landfill facilities is dry. There are a limited number of areas, such as playas or undisturbed topographic lows, where recharge to the OAG occurs under natural conditions. There are also some areas where previously dry wells or wells with minimal saturated thicknesses have shown some response to precipitation over the past several years. Instances where wells have gone from dry to wet, or shown significant increases in water levels, are generally related to localized infiltration in the vicinity of ditches, roads and other landfill construction activities. These instances will be detailed in the following sections.

A series of 34 OAG wells, termed PZ-1 through PZ-34, were installed in 1999 throughout the Flying W Ranch (Lehman and Rainwater, 2000) and outside the then-undesignated facilities area. Water levels in these wells were periodically monitored, with quarterly monitoring commencing in December, 2003. A-16 was also installed in 1999. The PM series of wells were installed in 2001 along with TP-12 and TP-13 and TP-14 was installed in 2004. The remainder of the 254 OAG wells on the WCS site were installed since about October, 2005. With a few exceptions, wells outside the facilities area are labeled PZ-XX, and wells inside or immediately adjacent to the facilities area are labeled either TP-XX, OAG-XX, CWF-XX, FWF-XX, or PM-XX. A series of OAG wells labeled TMW-XX were installed as temporary monitoring wells under the RCRA regulatory program in the southwestern quadrant of the facilities area. Three monitor wells labeled GW-X were installed in December, 2009 and January, 2010 pursuant to RML No. R04100, Attachment A; GW-1A and GW-3 are outside the facilities area while GW-5 is inside. All OAG wells were monitored periodically after installation. Commencing November, 2006 all existing wells within the facilities area began monthly monitoring and wells outside the facilities area began quarterly (or more frequent) monitoring. Monthly monitoring of all OAG wells on the WCS site commenced in September, 2008.

Precipitation records are available since approximately 2000 from a meteorological station designated Tower 1, located near the entrance to the WCS Facility. Three additional weather stations were installed in February, 2009. The WeatherHawk west station is located about 1000 feet northwest of the Byproduct landfill west of State Line road, the ER Tower station is about 500 feet north of the north-central boundary of the FWF, and the WeatherHawk East station is about 2000 feet east-southeast of the southeast corner of the CWF (Figure 1).

The following sections discuss hydrographs of historic water levels in the OAG at various locations on the site, categorized as to location and water level responses to precipitation. The well locations and associated hydrographs at the site scale are shown in Figure 2 and at the facilities scale in Figure 3. Figures 2 and 3 are taken from the December, 2010 OAG quarterly monitoring report (WCS, 2011). Although the site currently has three weather stations, the longest precipitation record is from Tower 1, therefore Tower I precipitation data are plotted on each of the hydrographs discussed in the following sections. The hydrographs illustrated on Figures 2 and 3 and in the following discussions extend through December, 2010.

The categories of wells discussed below are:

1) Wells outside the facilities area with no response to precipitation.

2) Wells outside the facilities area with some response to precipitation.

3) Wells inside and outside the facilities area that show a response to infiltration from the large playa north of the FWF/CWF.

4) Wells inside the facilities area with no response to precipitation.

5) Wells inside the facilities area with some response to precipitation.

6) Wells in areas of localized recharge related to ditches, roads or other infrastructure development affecting surface drainage.

2.1 Wells outside the Facilities Area with no Response to Precipitation

This section briefly discusses wells outside the facilities area that show virtually no response to precipitation. The location of the wells discussed in this section starts in the northwest corner of the WCS site and continues in a clockwise direction. Most of the wells outside the facilities area in the northern half of the site have some saturated thickness of OAG sediments above the top of the Dockum. Wells along the southern part of the eastern WCS site boundary, along the southern and southwestern boundaries, and all wells on the site south of the WCS facilities area are dry. The first water level elevations on the hydrographs of wells PZ-1 through PZ-34 are based on GPS-measured elevations taken when the wells were installed. Subsequent water levels are based on depth to water measured from surveyed top of casing (TOC) elevations.

PZ-1, in the extreme northwest corner of the site, shows virtually no response to precipitation, including the relatively high periods of precipitation in 2004 and 2005. PZ-16, located about 3000 feet south of PZ-1, exhibits similar behavior over the ten year record. The lack of response to precipitation of these and many other wells on the WCS site is due to the arid climate and the return of infiltration to the atmosphere. Barring localized recharge in nearby playas or in low, poorly-drained areas, the majority of wells outside the facilities area that are not dry show little response to precipitation, indicating very little infiltration. In addition, the long-term trend of most of the wells that show no response to precipitation is essentially flat, suggesting that what little recharge does occur in playas and low areas has very little influence on nearby long term water levels. This observation is consistent with the relatively long-term water level records in Andrews County included in the WCS permit applications. The water level records in the permit applications show very little variability and no significant or consistent long term trends over the 40-year period of record.

Numerous additional wells with 10 year records outside the facilities area show no apparent response to precipitation including PZ-3, PZ-18, PZ-17, PZ-10, PZ-32, PZ-33 and PZ-34.

2.2 Wells outside the Facilities Area with Some Response to Precipitation

There are six wells outside the facilities area that show some response to precipitation: PZ-6, PZ-11, PZ-12 and PZ-26 located on the far eastern and southeastern part of the WCS site, PZ-9 located about 2000 feet east of the southeastern boundary of the facilities area, and PZ-2 in the extreme north-central part of the site. PZ-6, which responded to precipitation in 2004/2005 and 2007 is located about 9000 feet east of the northeast corner of the facilities area near a well-defined topographically low area in the sand dunes that contains abundant mesquite and other vegetation (Figure 4). The topographic low is most likely a blowout in the dune field which has developed into a playa-like depression. The infiltration evident in the water level record of PZ-6 is most likely due to infiltration in this low area.

Other wells on the eastern extreme of the WCS site that show some response to precipitation are PZ-11, PZ-12 and PZ-26 (Figure 4). PZ-11 is located about 4500 feet southeast of PZ-6, south of the dune field on which PZ-6 is located. PZ-11 is not situated in the near vicinity of a topographic low; however it is about 400 feet east of a draw that empties in the vicinity of a closed topographic low, probably a constructed stock tank, which appears to contain water occasionally. The very minor recharge apparent in the hydrograph of PZ-11 is probably the result of infiltration from the draw after significant precipitation, such as the wet years 2004/2005.

PZ-12 is located immediately south of an area of sand dunes where the caprock or younger caliche is reasonably near ground surface. As seen in Figure 4, a significant tonal change from brown to light grey from north to south is observed in the vicinity of this well. Although there is not an obvious playa or depression in the immediate vicinity of PZ-12, the minor recharge apparent in the hydrograph following the wet years of 2004/2005 may be the result of infiltration in the minor lows, aligned just south of and parallel to the road on which PZ-12 is located. These lows are defined by the enhanced vegetation seen in Figure 4.

PZ-26 is located about 3750 feet south directly south of PZ-12, adjacent to a depression that is well defined by enhanced vegetation (see Figure 4). The depression is the most likely source for the 2004/2005 recharge evident in the hydrograph of PZ-26.

PZ-9, about 2000 feet east of the facilities area southeastern boundary, shows some response to precipitation although there is no obvious source of recharge in its immediate vicinity. It is possible that surface drainage collects in a minor topographic saddle along the ranch road where PZ-9 is located, or the playas located within about 1000 to 1500 feet of PZ-9 may be the source of the recharge.

PZ-2, near the extreme north-central boundary of the WCS site, is the only other well outside the facilities area that shows evidence of direct response to precipitation. PZ-2 is located in the immediate vicinity of a well pad on the southern end of the oil and gas field at the northern boundary of the WCS site. Infiltration occurs in response to precipitation because drainage off the relatively low permeability caliche pad is directed to the adjacent sand dunes, where infiltration overcomes evapotranspiration following extremely wet periods.

2.3 Wells Inside and Outside of the Facilities Area that Show a Response to Infiltration from the Large Playa

Most water-level increases observed in wells are in response to precipitation and the increases occur as a consequence of infiltration in the vicinity of the well. However, there are also instances where upward or downward water-level trends are not necessarily in direct response to precipitation or to infiltration from nearby sources of recharge; rather the levels are changing as an overall trend that is occurring on a broader scale than infiltration in the vicinity of individual wells. One of the reasons for some of the observed upward- and downward-trending water levels is that the only significant source of groundwater recharge on the entire WCS site is from a relatively large playa that contributes recharge to the groundwater system only after very high precipitation. There was significant infiltration from the large playa north of the FWF and CWF following the wet years of 2004/2005. TP-14, located in the large playa, shows an increase of at least 6 feet following the wet period.

Water that infiltrated at the playa in 2004/2005 appears to be slowly migrating northward in the OAG down a broad buried draw on the surface of the red beds (Figure 5). The northward-draining groundwater is evidenced by minor upward-trending water levels in OAG wells situated in the draw. The wells that show this minor upward trend include PZ-58, PZ-38, PZ-60, PZ-5 and PZ-59. Some of these wells only have water in the screened interval below the top of the

Dockum. They are classified as dry until water occurs above the top of the Dockum; however, they are clearly receiving some minor amount of recharge due to the drainage occurring on the top of the Dockum, although there is insufficient water to result in any saturated thickness of OAG at these wells. The buried draw eventually joins the buried paleo Monument Draw on the top of the Dockum approximately 10 miles north of the site.

There is also a well south of the large playa, TP-18, with an upward-trending water level between about 2005 and 2007. The upward trend, which was due to mounding beneath the playa following recharge in 2004/2005, reversed after a couple of years and has been decreasing over the last several years. The water level in TP-18 is currently about 0.1 ft higher than the water level in TP-14, indicating that after the recharge mound beneath the playa dissipates, groundwater in the vicinity of TP-18 eventually migrates to the north down the buried draw.

2.4 Wells inside the Facilities Area with No Response to Precipitation

Wells inside the facilities area generally have a shorter period of record than those outside, with hydrographs ranging from 2 to 5 years. Some wells inside the facilities area that are not dry and show no response to precipitation include several located in the nose of OAG saturation north of the FWF/CWF. These wells are TP-93, TP-94, TP-97, TP-98, TP-99, TP-100, TP-105 and TP-118.

Examples of wells on the eastern and southeastern side of the facilities area wells that show no response to precipitation include TP-67, GW-5 and TP-71 and TP-80. Note that TP-71 was installed as a replacement to PM-07 for water-level monitoring purposes because the top of red bed elevation in PM-07 was uncertain due to poor core recovery. Three wells on the eastern side of the facilities area that show no response to precipitation have water levels in the well screen below the top of red beds and are therefore classified as dry. These are TP-12, TP-48 and TP-49.

To the northeast of the northeast corner of the CWF, TP-111 and TP-122 are two wells with water surrounded by dry wells. These two wells are in one of the localized topographic lows on the surface of the red beds. The water levels in these wells have not responded to precipitation since the first measurements were taken in January, 2009, and have continuously declined over the 2009-2010 time period. The water in these wells is likely due to infiltration from a localized topographic low around TP-111.

2.5 Wells inside the Facilities Area with Some Response to Precipitation

The water levels in a few wells inside the facilities area exhibit a response to precipitation that appears to be the result of recharge from small playas or other local topographic lows with little affect from infrastructure development on the WCS site. These include PM-01 located on the eastern side of the facilities area, which responded to infiltration from an adjacent playa after the 2004/2005 wet years, and TP-68, located near the north-central boundary of the facilities area which appeared to respond to precipitation in 2008 and 2010. The source of infiltration in the vicinity of TP-68 is not obvious, although it is most likely blocked drainage inside the road that comprises the access loop to the well.

Water levels in TP-19 and TP-39, located near the north-central boundary of the CWF appear to have responded to the 2004/2005 precipitation. Both of these wells are located near a well-defined topographic low along the road near the northern CWF boundary. The topographic low collected surface water drainage from precipitation and resulted in localized saturation in the OAG following the wet years of 2004/2005. Since then the water levels in TP-19 and TP-39 have declined and remain below the bottom of the screen slots in the wells.

TP-63 and TP-117 are located in a well defined small playa to the east of the CWF. Water levels in TP-63 responded to precipitation in 2008 and 2010, while TP-117, installed after the precipitation events in 2008, responded to the 2010 precipitation. Both of these wells are in the playa where surface drainage is restricted and water collects and infiltrates following significant precipitation. TP-

117 and TP-63 currently have saturated OAG thicknesses of about 7 and 4 feet, respectively. Road construction around the playa has further restricted runoff.

Water levels in two wells to the south and southeast of the RCRA landfill show some response to precipitation; A-16 responded to the wet years of 2004/2005 and TP-46 appears to have responded to a relatively large rainfall event in early 2007. A-16, located south and east of the RCRA landfill area, is adjacent to Ranch House draw. Surface drainage in Ranch House draw during the wet years of 2004/2005 likely resulted in infiltration in the vicinity of A-16. There are numerous small closed topographic lows within Ranch House draw that occur because the draw is not well-integrated and subject to aggradation by wind deposition between runoff events. Infiltration could occur when runoff is trapped in these lows.

Water levels in TP-46 responded to precipitation in 2007, probably due to temporarily blocked drainage related to construction when the RCRA landfill excavation was expanded to the east. Water levels in TP-46 have since dropped below the bottom of the screen slots and have remained there for the past two years.

Water levels in TP-31, located near Baker Spring northwest of the Byproduct landfill, show responses to precipitation, likely due to infiltration from a southwest trending surface draw that passes within about 100 feet of TP-31 and empties into Baker Spring about 75 feet south of TP-31.

Water levels in PZ-42, located northeast of the well-defined playa west of the Byproduct landfill, show minor responses to precipitation. Note that the water level in PZ-42 is below the top of red beds and the well is considered to be dry. The source of water in PZ-42, and in the recently installed well GW-3 in the playa, is infiltration from the playa following precipitation.

Water levels in FWF-6A, located on the south-central boundary of the FWF, show no apparent response to precipitation. The presence of water in FWF-6A is likely due to its proximity to a local minor topographic low that is well-defined by mesquite and associated vegetation. Water levels in FWF-27A, located on the west-southwest boundary of the FWF, also show little if any response to precipitation. There is a minor increase in water levels in this well over the winter of 2008, which may be related to temporarily blocked drainage during construction of the Byproduct landfill.

2.6 Wells in Areas of Localized Recharge Related to Ditches, Roads or Other Infrastructure Development Affecting Surface Drainage

The infrastructure in the WCS facilities area has developed significantly over the past 5 years. Numerous roads and trails were developed around the Byproduct, FWF and CWF areas during the period 2004 to 2008. The eastward RCRA landfill extension was completed in 2004/2005. The excavated materials from the RCRA extension excavation are stockpiled on the west side of State Line road west of the Byproduct landfill. The LSA storage pad, north of the Byproduct landfill, was constructed in 2005 and the Byproduct landfill was built in 2008/2009. Numerous surface drainage alterations, temporary and permanent, were made in conjunction with these activities, and there are several areas where infiltration to the OAG has occurred that would not have otherwise occurred. Most significantly, the surface drainage alterations around the Byproduct landfill, including the LSA storage pad, have resulted in areas of infiltration and focused recharge that would not exist but for the infrastructure development in this area.

Before concentrating on the area around the Byproduct landfill, there are three wells near the south side of the facilities area in which water levels have responded to precipitation. These are TMW-A, TMW-K and TP-62. Almost all the surface runoff from the WCS facilities area is discharged to the sand dunes in this area, and the rising water levels in these three wells are due to this discharge. The surface runoff that does not discharge in this area is that which occurs on the far western side of the facilities area, including the area around the Byproduct landfill and the LSA storage pad.

Most of the wells in the facilities area with water levels that show a response to precipitation are located in the vicinity of the Byproduct landfill. Infiltration from drainage ditches is the primary source of recharge observed in these wells. TP-42, located near the north-central boundary of the Byproduct landfill, and TP-43, located near the south-central boundary, have the longest water level records of all the wells in the Byproduct vicinity. TP-42 was dry for over a year after it was installed in February, 2006. Water began to appear in the well in April, 2007 due to nearby ponding of runoff from the LSA pad which is located about 1500 feet to the north of TP-42.

Infiltration around TP-42, and generally along the northwest boundary of the Byproduct landfill, continued while the Byproduct landfill was constructed and surface drainage was affected by haul roads and temporary ditches. The hydrographs of monthly water level measurements of wells TP-149, TP-167, TP-148, TP-166 and TP-90 are located in this area and show a water level response similar to that of TP-42.

Continuous water level monitors (transducers – called Level TROLLS) are installed in several of these wells. The continuous records for the past year for TP-42, TP-148, TP-166 and TP-167 are provided Appendix I. Water levels in TP-42 show a monotonic increase in water levels in response to the ponding and infiltration of runoff from the LSA pad until approximately mid-summer 2010, when the water levels leveled out for a month or more. Subsequently, relatively large precipitation events again resulted in infiltration that was reflected in the water levels in TP-42. The late 2010 increase in water levels may be partly due to infiltration from the Byproduct run-on diversion ditches constructed in the area over the past several years, as well as the low surface grade in a relatively shallow drainage ditch near TP-42, rather than localized ponding of runoff from the LSA pad.

Similar to TP-42, water levels in TP-148 and TP-167 show minor water level increases following the mid-to-late 2010 precipitation events. On the other hand, water levels in TP-166, located immediately adjacent to the drainage ditch on the north side of the Byproduct landfill, show dramatic increases following both precipitation events. The water level increases observed in TP-166 are also a result of discharge from the Byproduct landfill holding tanks, which are tanks that hold water collected from direct precipitation in the landfill excavation, into the drainage ditch about 100 feet north of the holding tanks. This northwest trending ditch joins the east-west ditch south of the LSA pad in the immediate vicinity of TP-166.

Water levels in TP-90, located along State Line road about 500 feet northwest of the northwest corner of the Byproduct landfill, show a response to precipitation and drainage in the ditches similar to the responses in TP-42, TP-148 and TP-167.

TP-86, TP-147 (dry), TP-146, TP-78 and TP-145 are located adjacent to State Line road, which runs along the western boundary of the Byproduct landfill. TP-86 was dry at the time it was installed in 2008 until water appeared in the well in late 2009. The water level in TP-86 rose above the top of red beds coincident with the mid-year (July/August) precipitation in 2010. The appearance of water and increase in the water levels in this well is due to infiltration from the ditch along State Line road which has been reconstructed, improved and regraded over the past 18 months. Within the last few months of 2010, this ditch and others in the Byproduct landfill area have been coated with Posi-Shell, a spray-applied mineral mortar, to reduce infiltration. Southward from TP-86, TP-147 is dry; water levels in TP-146 show some responses to precipitation, as do water levels in TP-78. TP-145 was dry until late 2009, similar to TP-86. The water level in TP-145 was below the top of Dockum until the mid-year precipitation in 2010, when water rose above the top of the Dockum. Responses to precipitation and the occurrence of water in previously dry wells along State Line road is due to infiltration of runoff which flows in the drainage ditch located along the east side of the road.

Three of the wells along State Line road also have continuous water level monitors: TP-86, TP-146 and TP-78. Water levels in TP-86 and TP-146 show minor but obvious responses to infiltration from the ditch, with the responses directly coinciding with runoff from precipitation or drainage of the holding tanks. Water levels in TP-78 did not respond to precipitation from installation in early 2008 until mid-2010. The response of water levels in TP-78 to mid-year 2010 precipitation is likely due to infiltration from the reconstructed and regraded ditch along State Line road. As indicated above, this ditch was not lined with Posi-Shell until the last few months of 2010.

TP-43, TP-141, TP-88 TP-140, TP-171 and FWF-1A are located along the southern boundary of the Byproduct landfill. Water levels in TP-43 appear to respond to significant precipitation periods, most likely due to infiltration from the drainage ditch located about 50 feet south of the well. The drainage ditch separates the RCRA landfill area to the south from the Byproduct landfill area to the north and receives runoff from both directions. This ditch is not lined with Posi-Shell. Water levels in TP-141, TP-88 and TP-140 also appear to show some responses to precipitation, similar to that observed in TP-43. Again, these responses are likely due to infiltration from the same drainage ditch. The water level in TP-140 has never risen above the top of the Dockum. Water levels in TP-171 show a minor response to precipitation and infiltration from the ditch, with the mid-year 2010 precipitation quite evident. Water levels in FWF-1A show a very little response to precipitation and drainage from the ditch.

The continuous monitors in the wells located along the southern boundary of the Byproduct landfill (i.e., TP-43, TP-141, TP-88, TP-171 and FWF-1A) show in detail the nature of the water-level responses discussed above. The responses to drainage of the Byproduct holding tanks evident in some of the wells located on the northern and western sides of the landfill are noticeably lacking in the wells located along the southern boundary of the landfill. The water drained from the holding tanks does not flow in ditches in the vicinity of these wells.

Further south from the southern boundary of the Byproduct landfill are TP-169, TP-143 and TP-142. Water levels in TP-169 and TP-143 appear to have a residual response to precipitation events prior to their installation in early 2009.

The water levels in these two wells clearly responded to the mid-year 2010 precipitation events, with the response due to infiltration from the drainage ditch along State Line road as well as infiltration from a localized topographic low in which both wells are located. Water levels in TP-142 show slightly more response to precipitation over the 2-year period of record, likely due to infiltration from the adjacent drainage ditch separating the Byproduct and RCRA landfills. The continuous recorders in TP-142 and TP-143 show that water levels in TP-142 appear to respond to most precipitation events, probably due to its proximity to the drainage ditch, while water levels in TP-143 appear to respond only to the more significant precipitation events, perhaps reflecting its location in the localized topographic low.

Further south of the Byproduct landfill along State Line road are the TMW wells (TMW-B, TMW-H, TMW-J, TMW-I and TMW-D), which were installed to investigate the former septic drain field west of the WCS administration buildings. The water level in most of these wells shows some response to precipitation due to their proximity to the drainage ditch along State Line road.

In summary, the response to precipitation in wells away from the Byproduct landfill are, for the most part, much smaller than responses near the landfill because there is little or no effect of facilities-related activities in the far away wells. The response in wells near the Byproduct landfill changed significantly after construction-related activities and continued infrastructure development altered surface drainage, creating significant sources of infiltration such as the ditches in the Byproduct vicinity. Prior to construction-related activities there was likely little or no infiltration in these areas, evidenced by the lack of continuous OAG saturation and by the wells that were dry on installation and only later developed water.

3.0 Infiltration Modeling

Generic infiltration modeling was conducted as part of the analysis of infiltration for the WCS site. This modeling is meant to be generally representative of the site hydrogeologic conditions and to demonstrate the mechanisms of infiltration at the site under natural conditions and as affected by infrastructure development. Current conditions at the site include roads, ditches, railroads, buildings or other man-made features that impact runoff and infiltration. Infiltration modeling results are presented in detail in Appendix II and are summarized here. It is important to note that these modeling efforts are for illustrative purposes only and no efforts have been made to calibrate the models to site-specific hydrologic responses or conditions

Three infiltration scenarios were developed and simulated. In Scenario 1, the land surface is undisturbed, and surface water is not allowed to pond during precipitation events. This scenario represents the case of undisturbed surface conditions at the WCS site. In Scenario 2, surface water is allowed to pond in two locations, reflecting ditches or other anthropogenic disturbances, during precipitation events. It is assumed that the surface water freely drains away from the ponding locations after precipitation events. In Scenario 3, surface water is allowed to pond in the same two locations as Scenario 2 during precipitation events; however, surface water ponds are allowed to remain up to seven days after a rainfall event. This scenario represents the case where surface water is allowed to pond in ditches and depressions following rainfall events. All three scenarios are identical except for changes in boundary conditions that reflect ponding conditions.

Model results show behavior similar to that observed at the WCS site (e.g., Section 2). In Scenario 1, infiltration occurs during precipitation events, saturated conditions do not develop in the OAG, and infiltrating water is quickly redistributed and removed by evapotranspiration.

In Scenario 2, rapid infiltration occurs beneath ditch/pond locations. A single large infiltration event (following ~ 2 in./day of rainfall), is insufficient to cause saturated conditions in the OAG, because water is quickly redistributed laterally into the relatively dry caliche and OAG units and evapotranspiration quickly begins to return much of the precipitation to the atmosphere. Saturated conditions do develop in the OAG following a sustained rainfall event consisting of four days of precipitation at rate of ~0.4 in./day and two days of precipitation at a rate of ~ 2 in./day. Groundwater mounds develop beneath the ditch/pond locations and quickly spread laterally across the Dockum-OAG contact, and lateral flow redistributes the water down dipping Dockum surfaces. Following the precipitation events, lateral flow along the Dockum surface, redistribution of water into the unsaturated zone, and evapotranspiration quickly eliminates saturated conditions in the OAG.

Scenario 3 is similar to Scenario 2, except ponding after precipitation events allows much more water to infiltrate, leading to the development of larger groundwater mounds and allowing saturated conditions to remain in the OAG for longer time periods.

While no effort has been made to calibrate this model to specific well observations or locations at the WCS site, the model results illustrate potential impacts of surface water management on groundwater conditions in the OAG and illuminate the mechanism of recharge to the OAG. The following conclusions can be drawn from this modeling effort:

1) Under natural conditions at the WCS site, recharge to the site only occurs in local depressions or playas where water is allowed to pond.

2) Water in unlined ditches and ponds can quickly infiltrate to the OAG causing saturated conditions.

3) OAG monitoring wells are likely to show complicated responses to anthropogenically-induced infiltration, as water levels data will be impacted by the distance of the well from the recharge point(s) (likely influenced by the location of vertical fast paths) and lateral flow along the OAG-Dockum surface.

4) Once saturated conditions have developed in the OAG, OAG groundwater is redistributed in the subsurface by lateral flow along the topography of the Dockum surface and evapotranspiration.

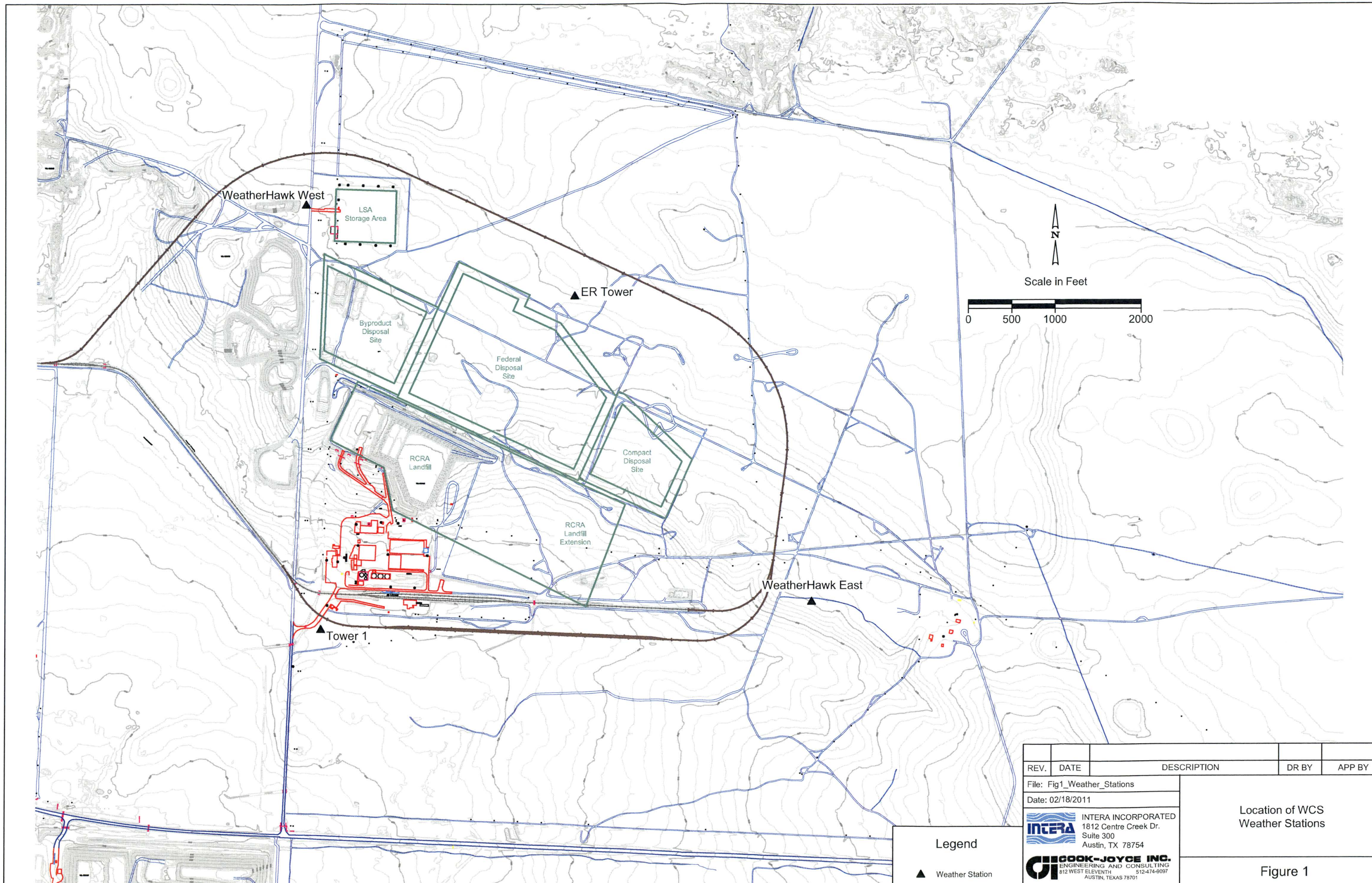
Effective lining of ditches and the removal of areas where surface water ponds and the maintenance of plant communities capable of providing high evapotranspiration rates are critical elements of the surface water management plan at the WCS site and will eliminate anthropogenically-induced recharge to the OAG.

4.0 References

Lehman, T.M. and K. Rainwater, 2000. Geology of the WCS-Flying "W" Ranch, Andrews County, Texas. Texas Tech University Water Resources Center. November, 2000.

Waste Control Specialists (WCS), 2011. December 2010 OAG Water Level Report. January 10, 2011.

FIGURES



REV.	DATE	DESCRIPTION	DR BY	APP BY

File: Fig1_Weather_Stations

Date: 02/18/2011

INTERA INCORPORATED
1812 Centre Creek Dr.
Suite 300
Austin, TX 78754

COOK-JOYCE INC.
ENGINEERING AND CONSULTING
812 WEST ELEVENTH 512-474-9097
AUSTIN, TEXAS 78701

Location of WCS Weather Stations

Figure 1

Legend

▲ Weather Station

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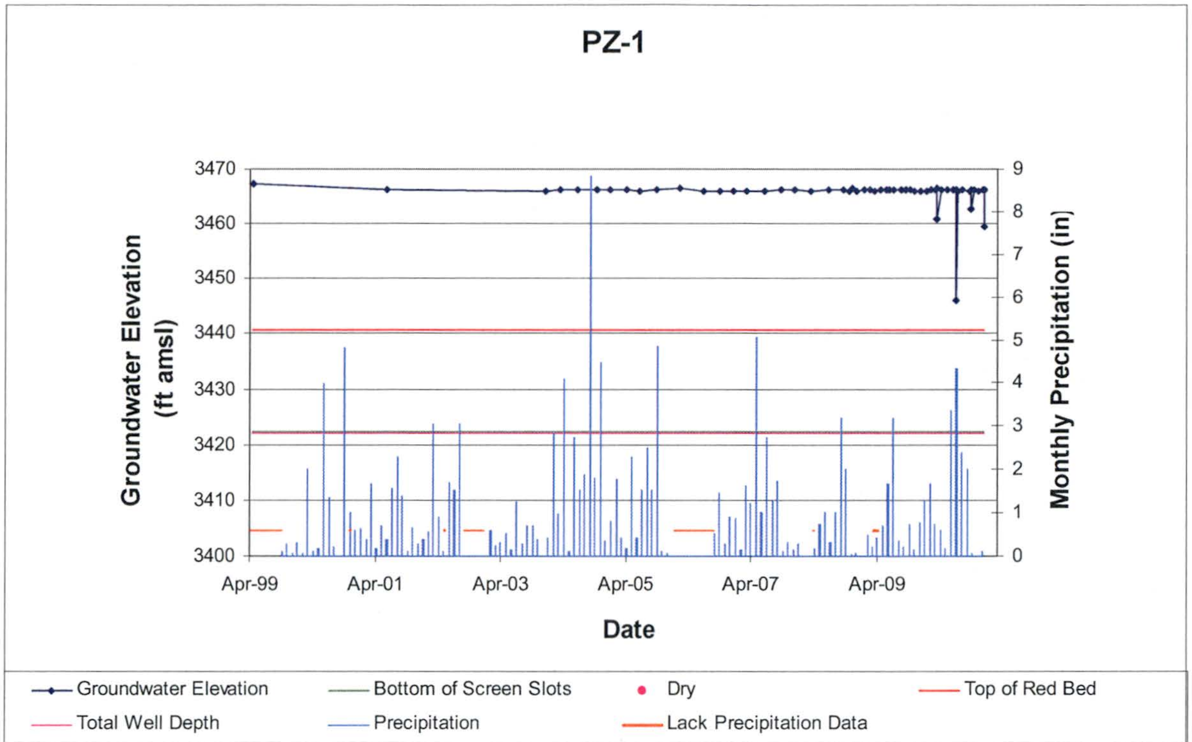
APPENDIX I

Hydrographs of OAG Wells (in order of discussion)

APPENDIX I

Hydrographs of OAG Wells (in order of discussion)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3430
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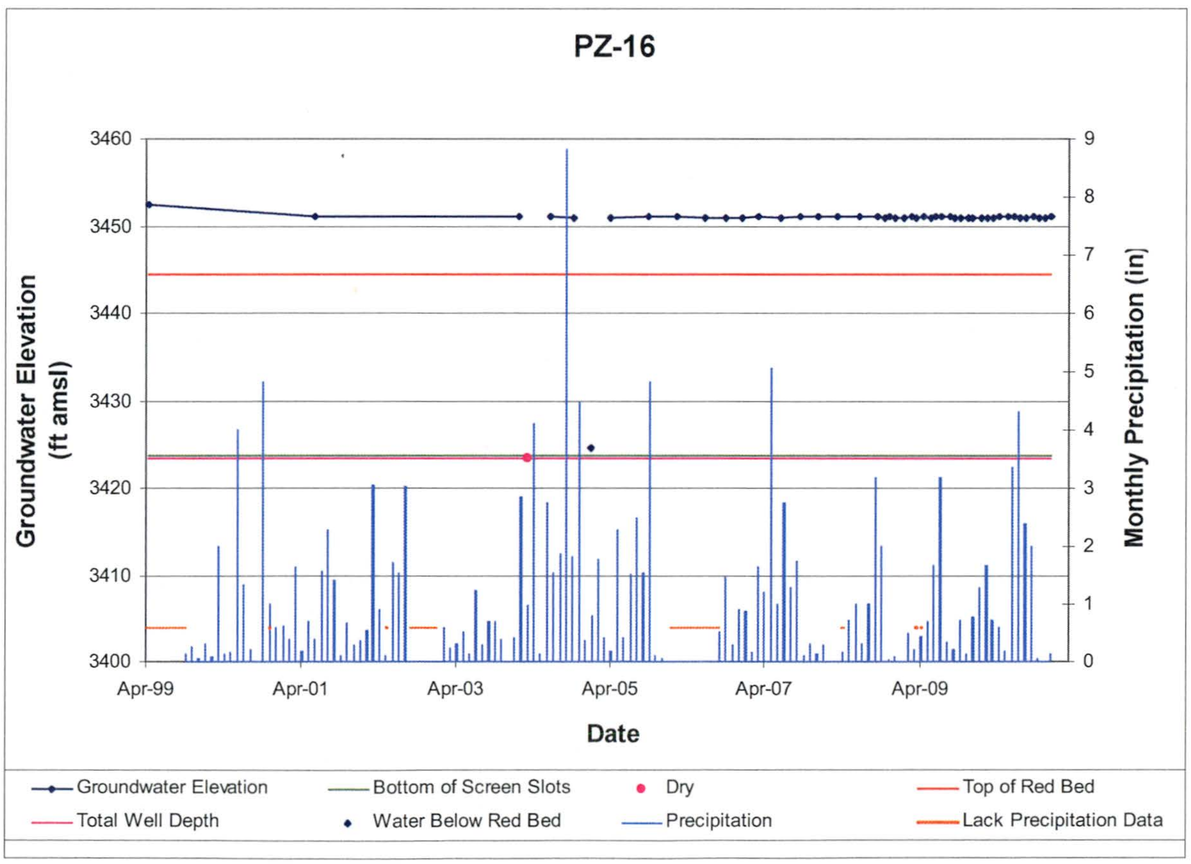
9
8
7
6
5
4
3
2
1
0
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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2
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Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
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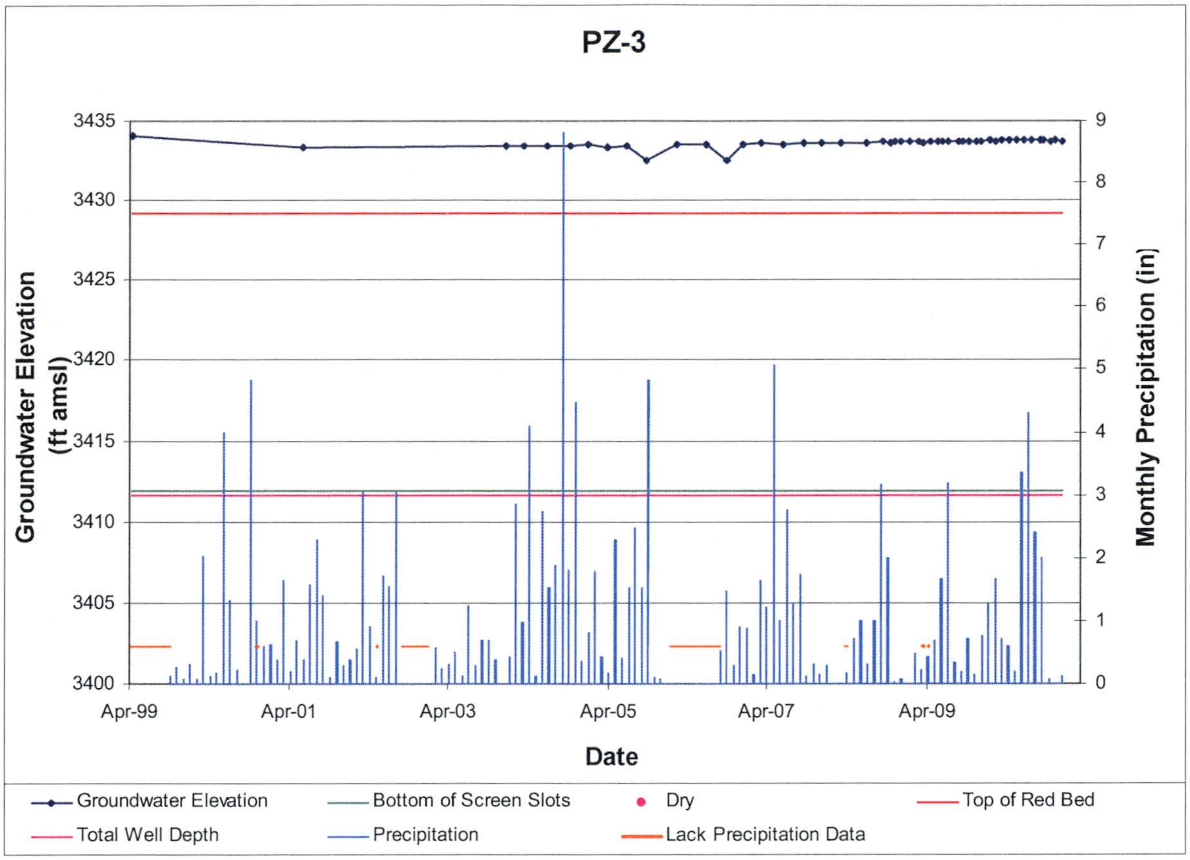
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data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3405
3400
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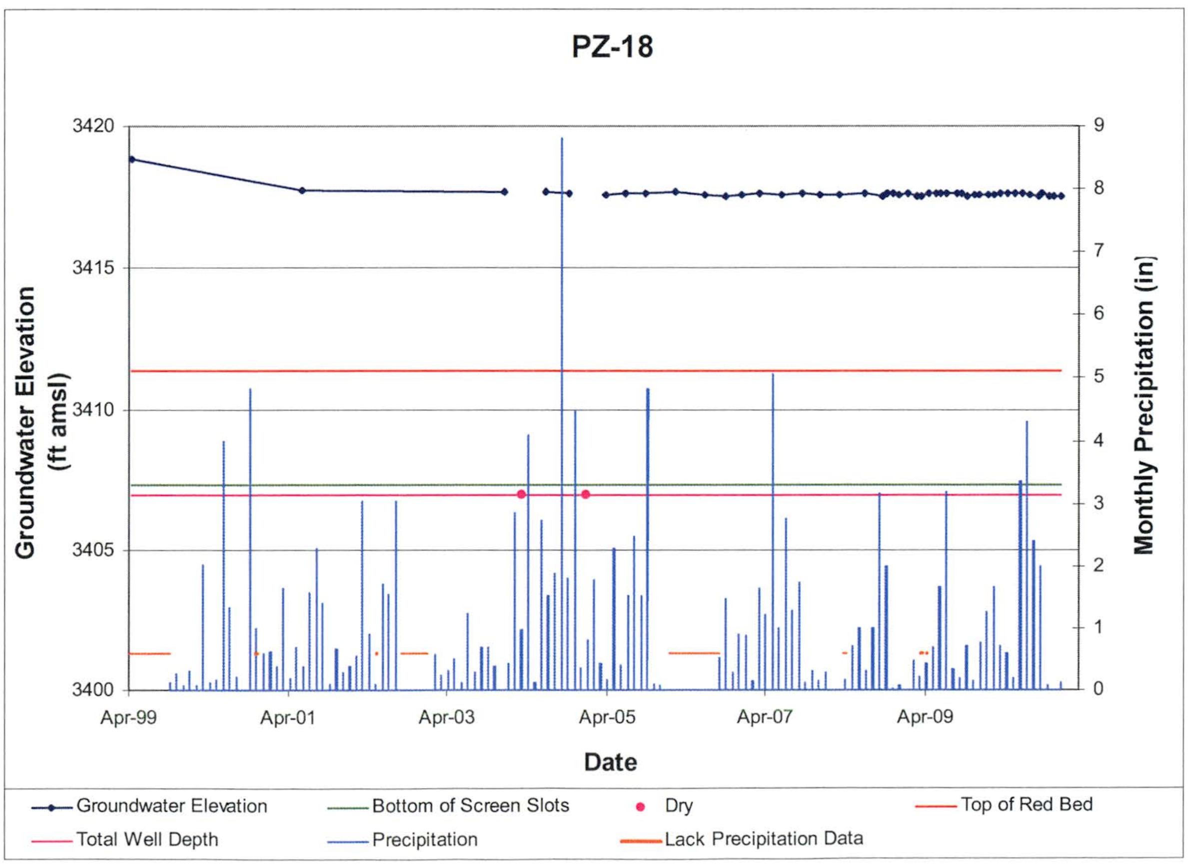
5
4
3
2
1
0
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
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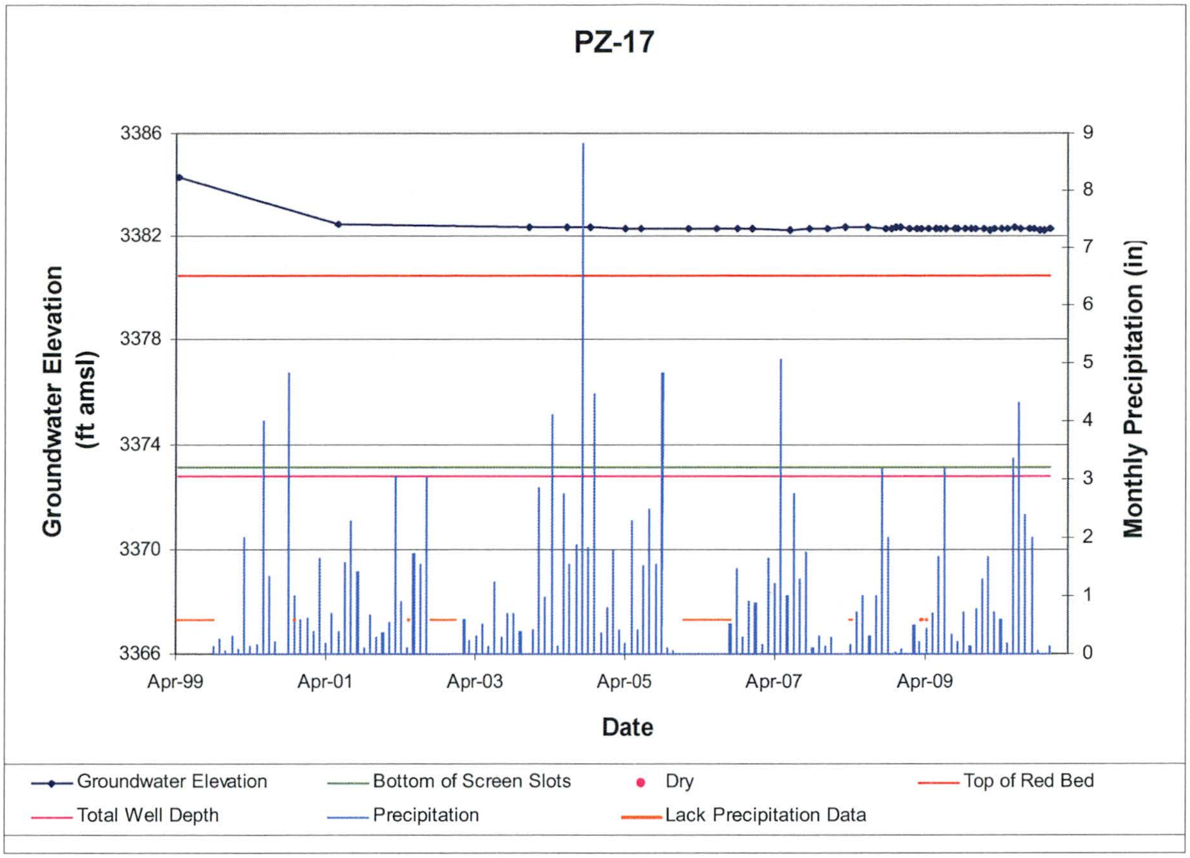
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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Apr-03
Apr-05
Apr-07
Apr-09
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
Groundwater Elevation
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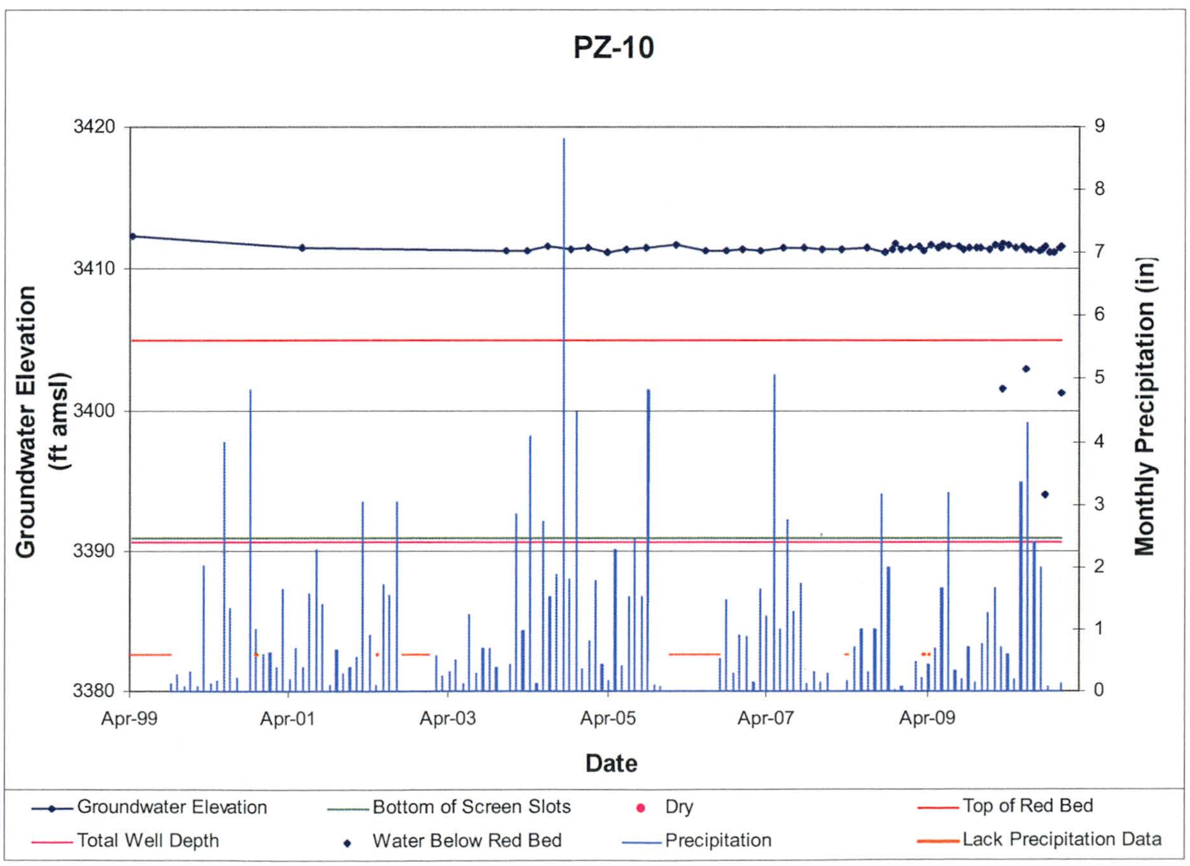
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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Apr-03
Apr-05
Apr-07
Apr-09
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
Groundwater Elevation
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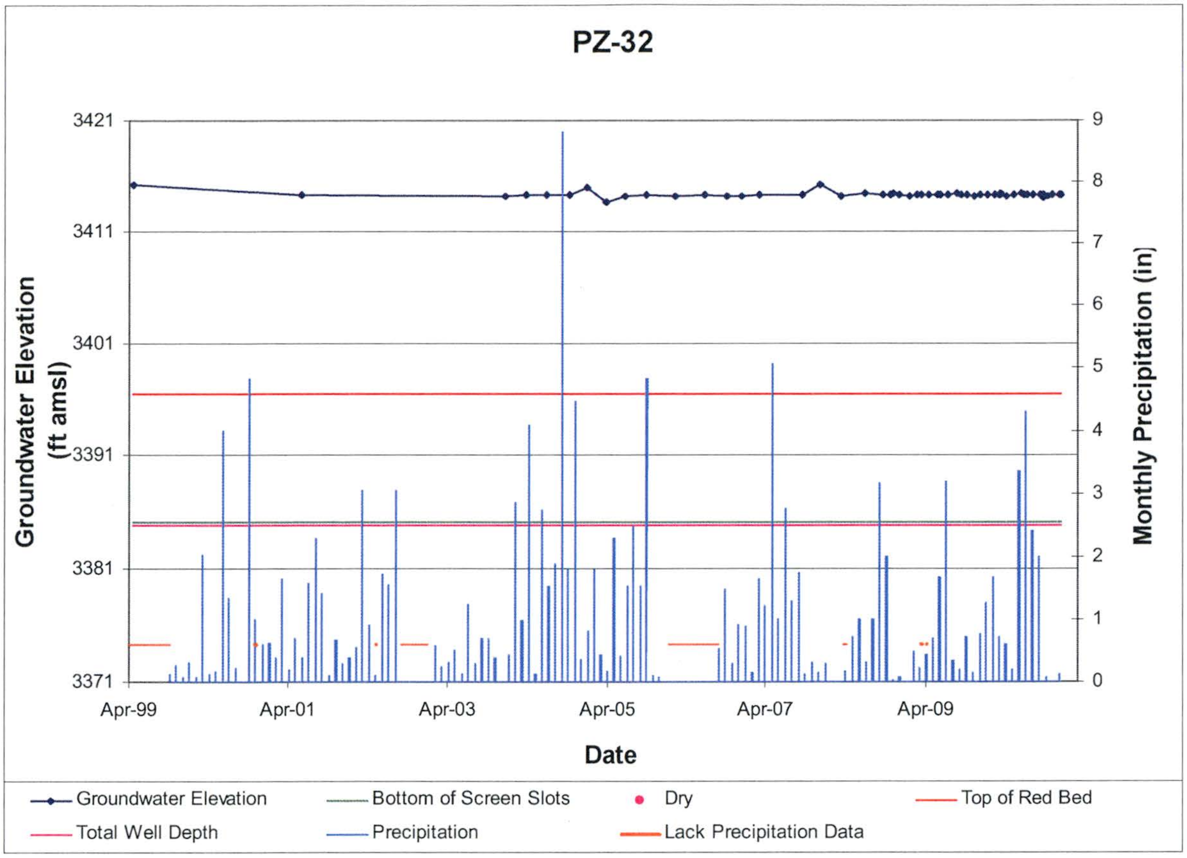
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data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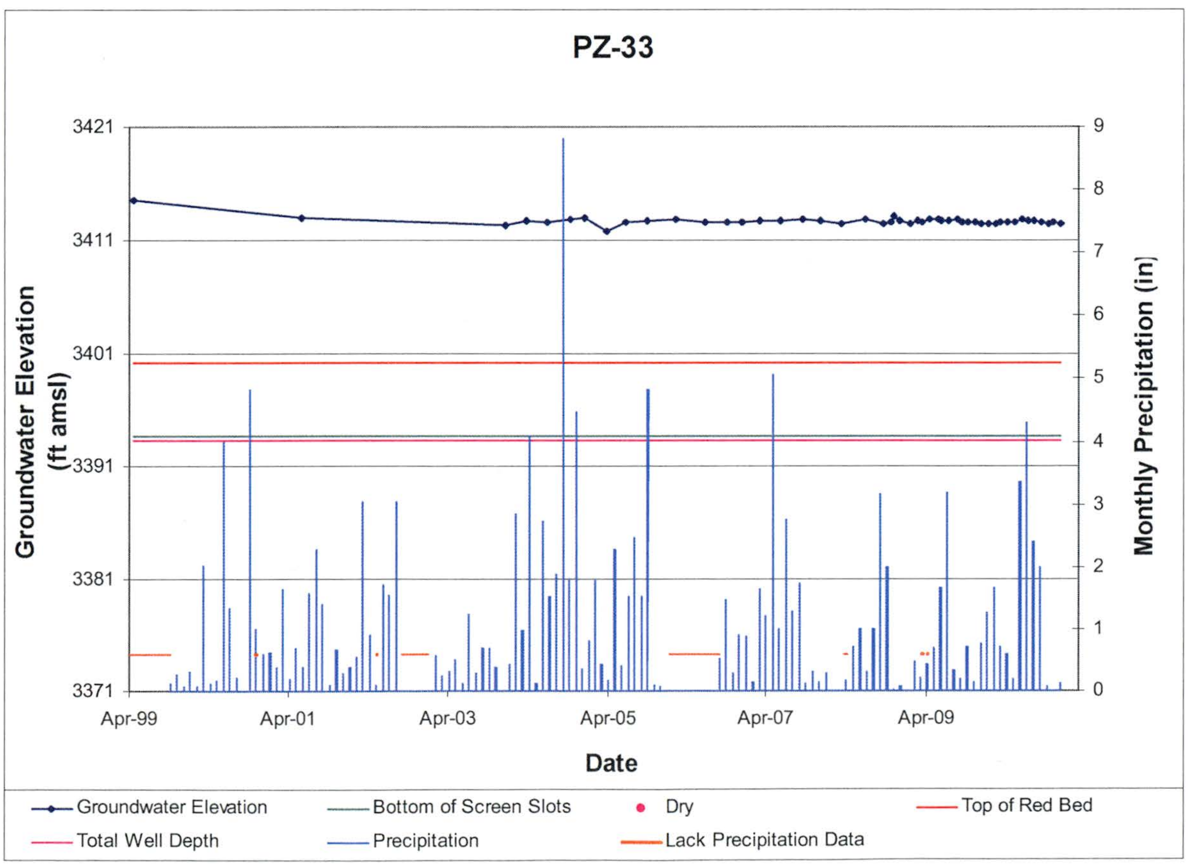
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
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Apr-09
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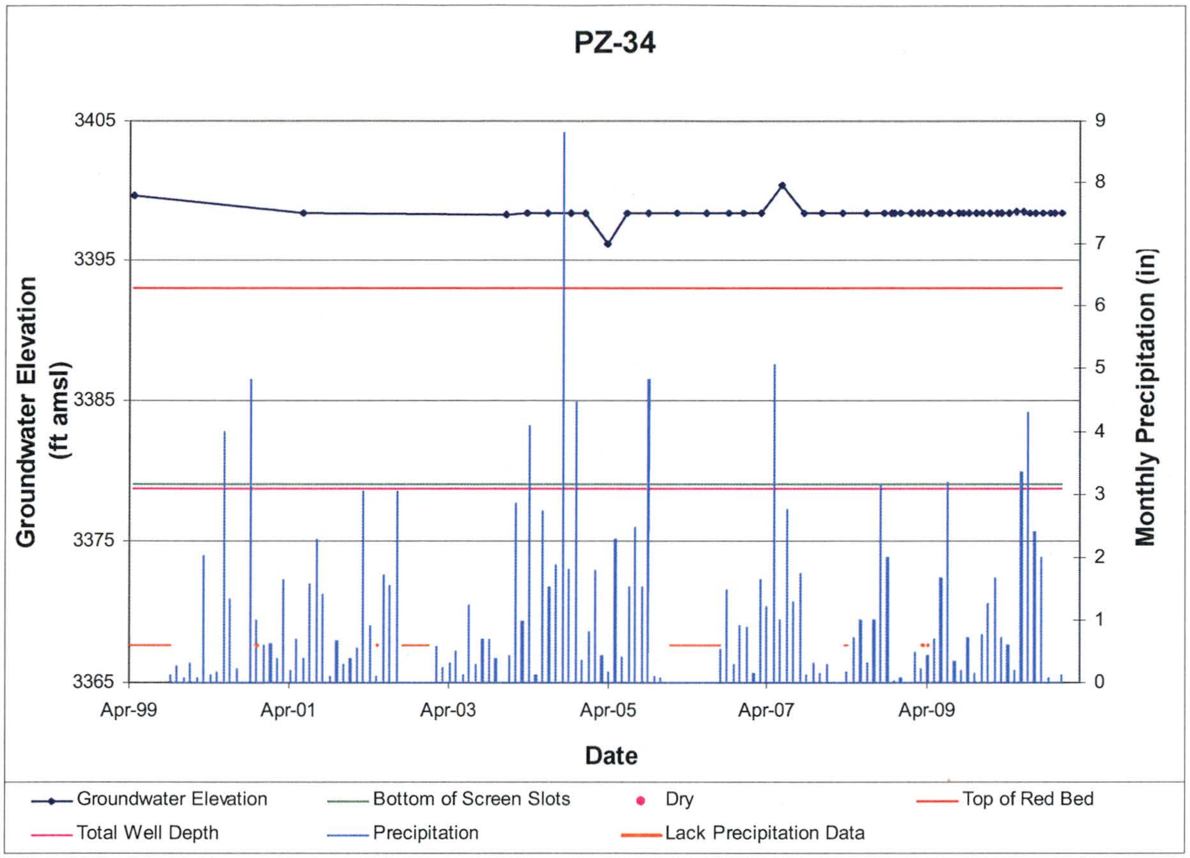
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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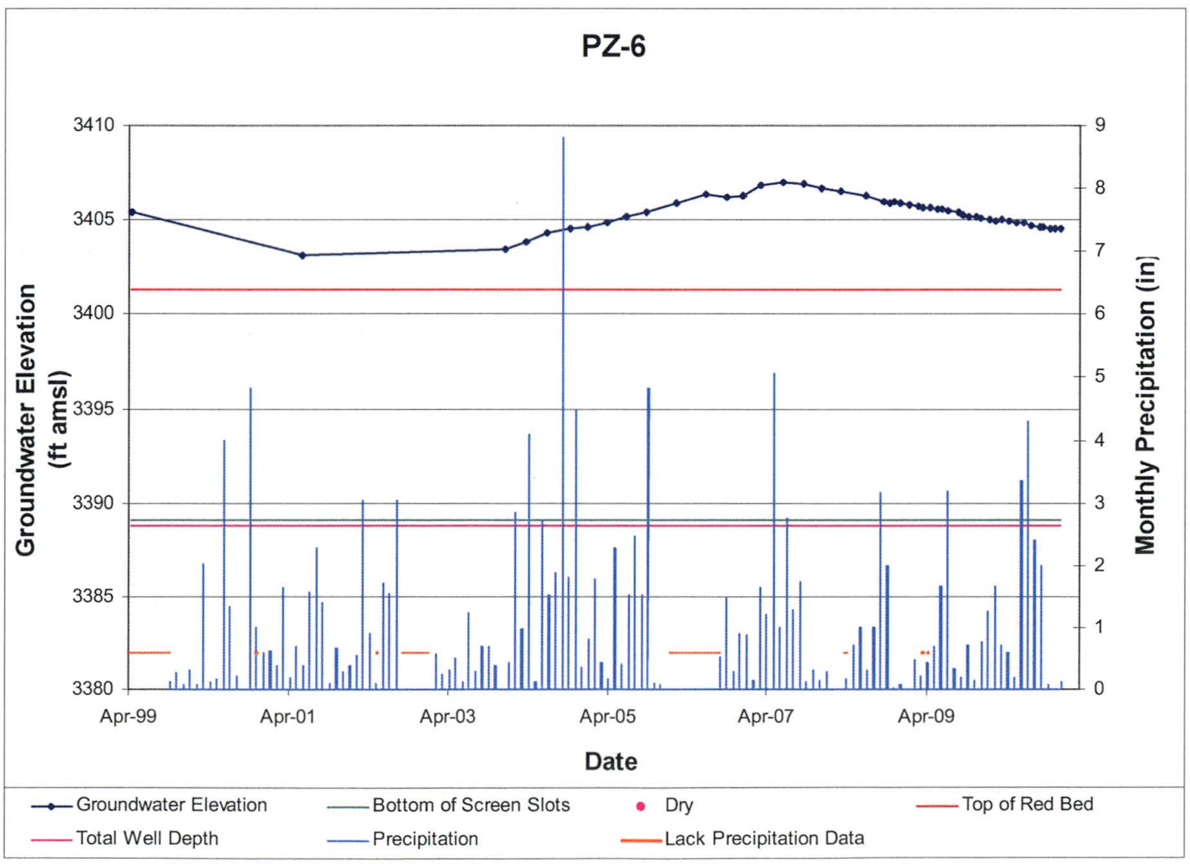
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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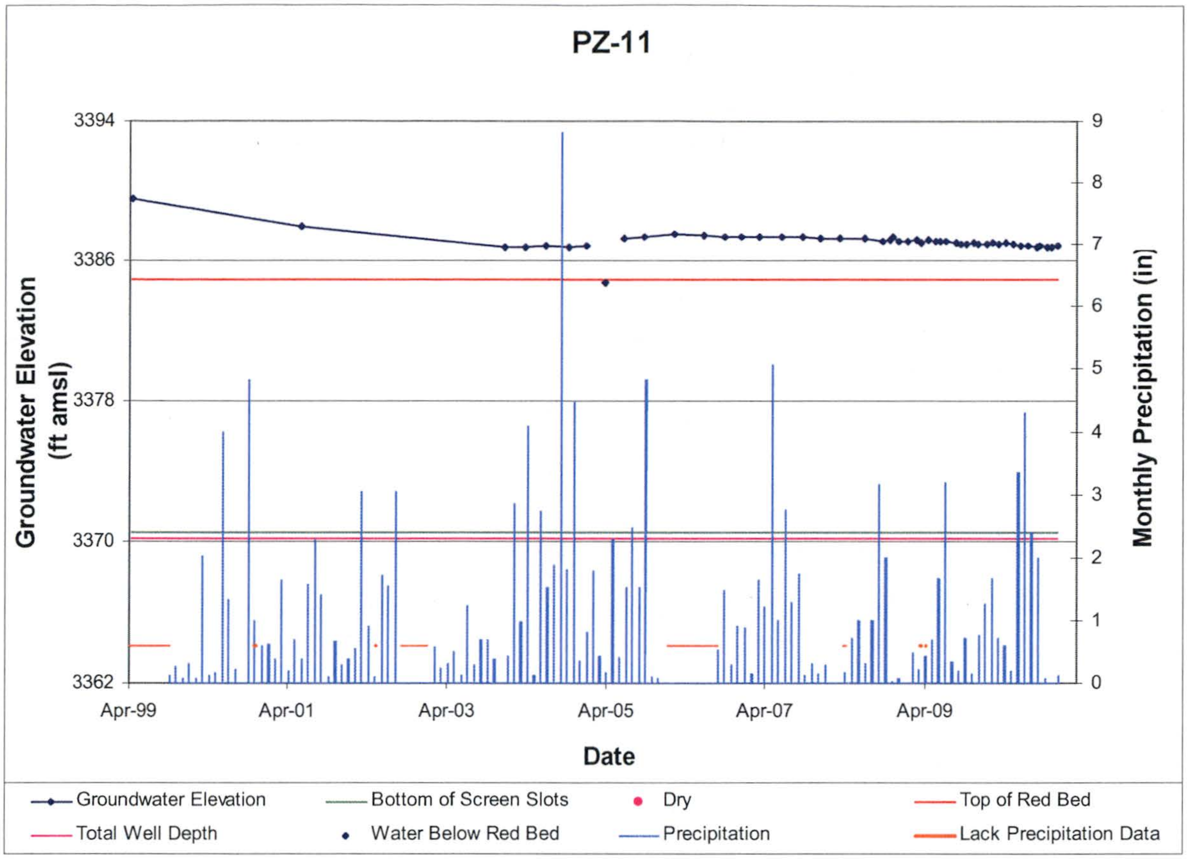
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data



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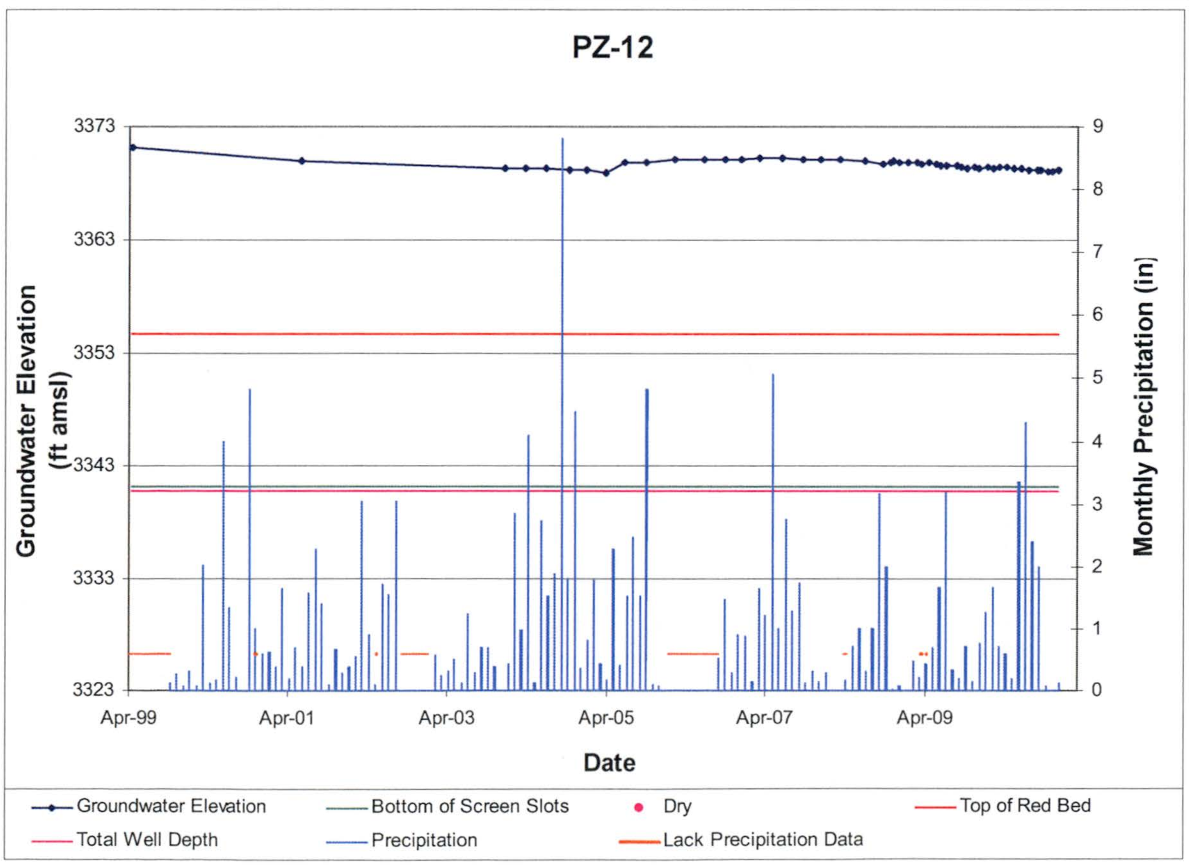
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data



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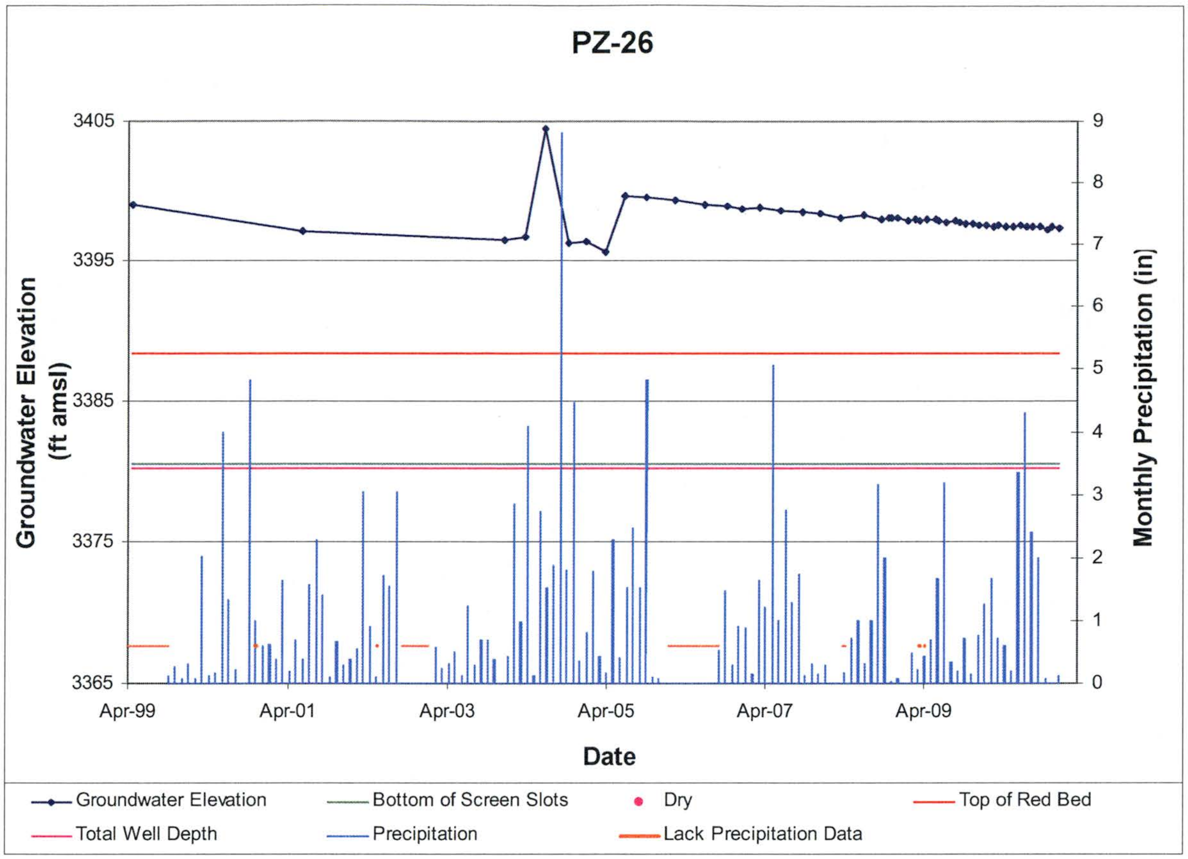
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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3385
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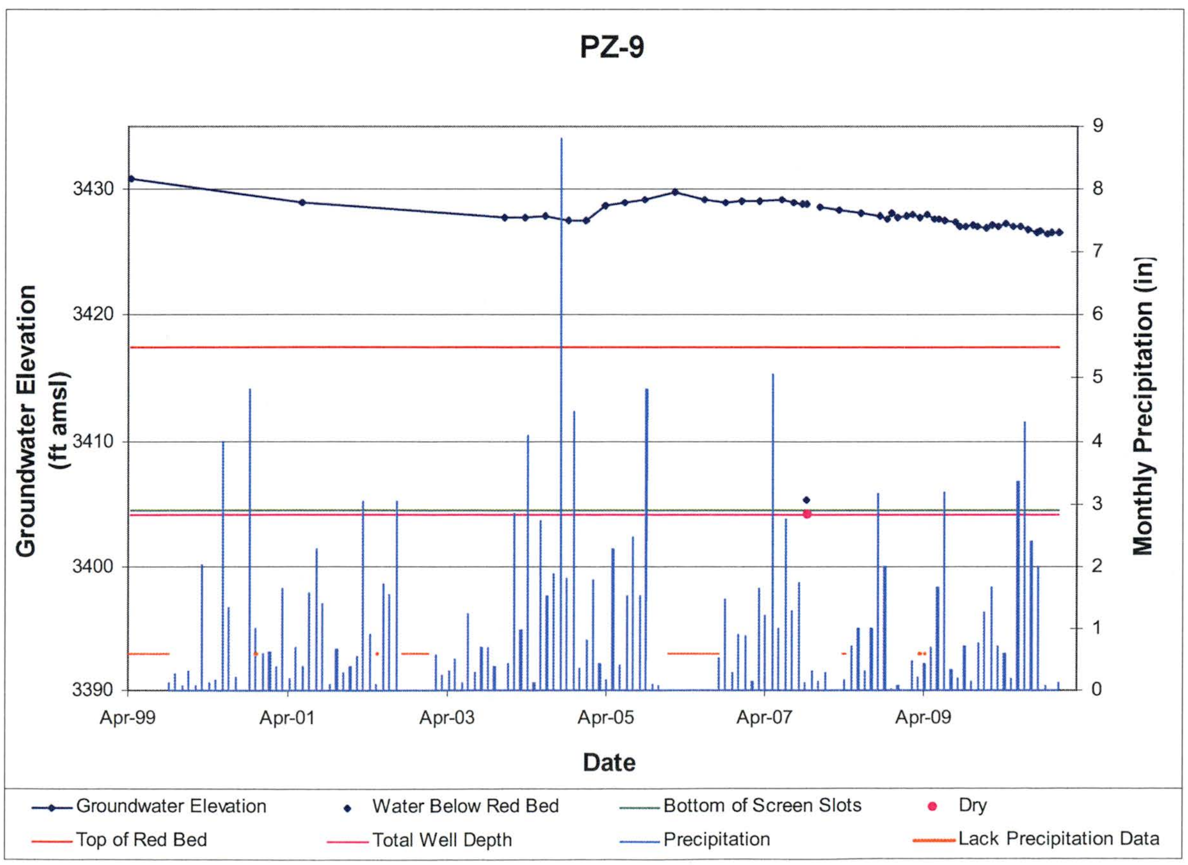
9
8
7
6
5
4
3
2
1
0
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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3410
3400
3390
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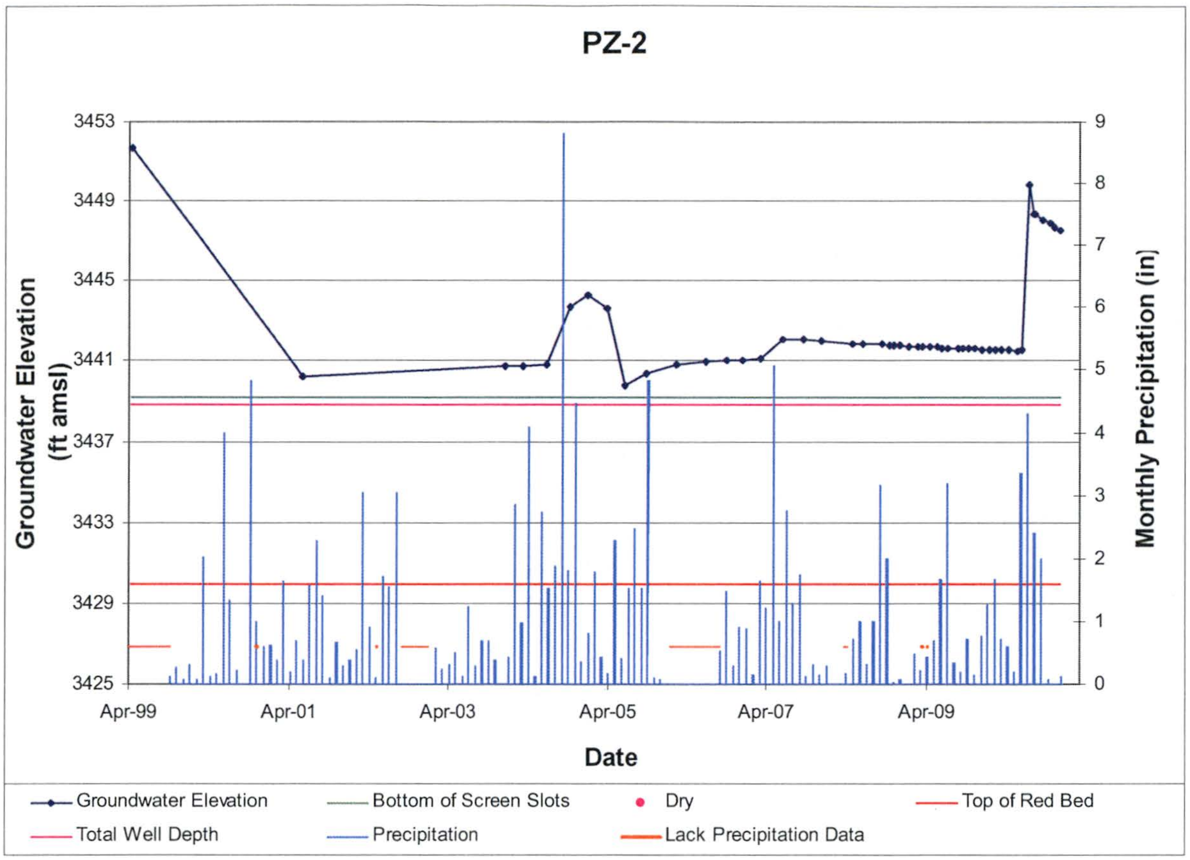
6
5
4
3
2
1
0
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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9
8
7
6
5
4
3
2
1
0
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Apr-01
Apr-03
Apr-05
Apr-07
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Date
Groundwater Elevation
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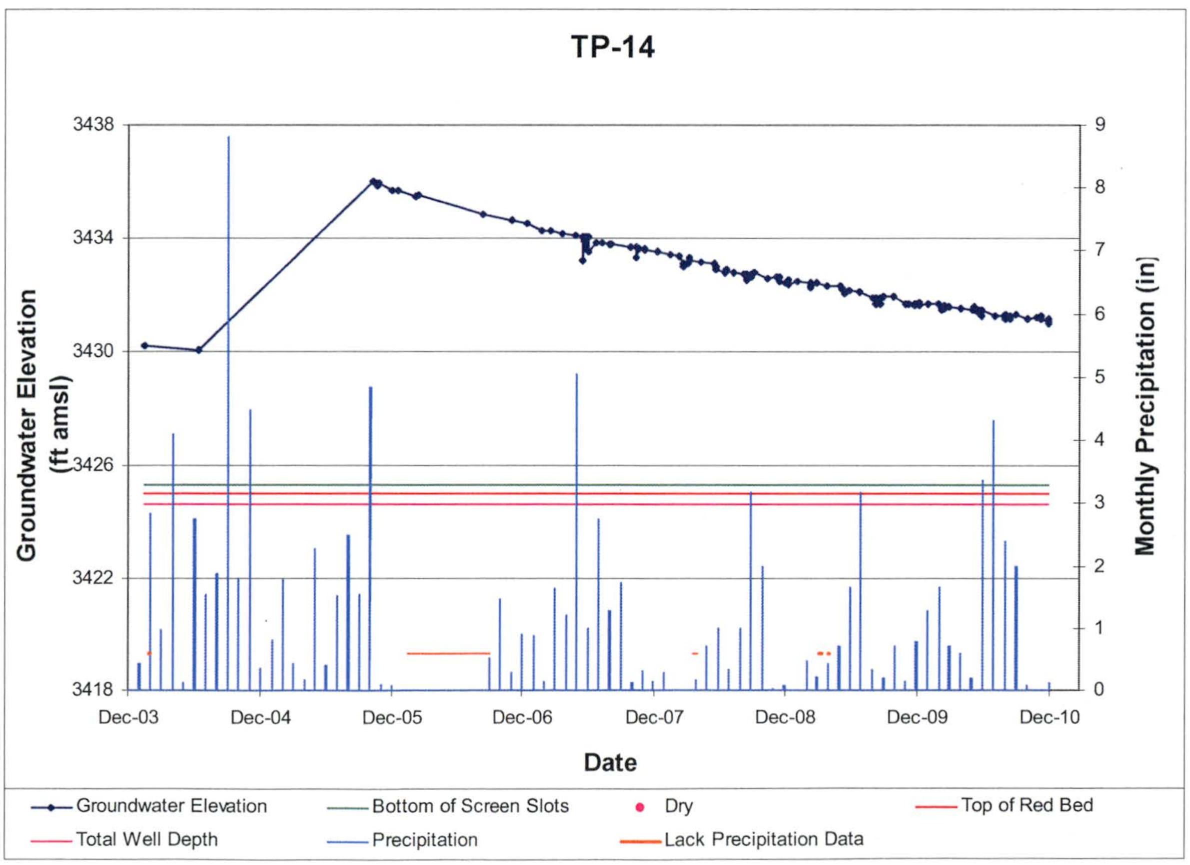
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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3430
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3418
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5
4
3
2
1
0
Dec-03
Dec-04
Dec-05
Dec-06
Dec-07
Dec-08
Dec-09
Dec-10
Date
Groundwater Elevation
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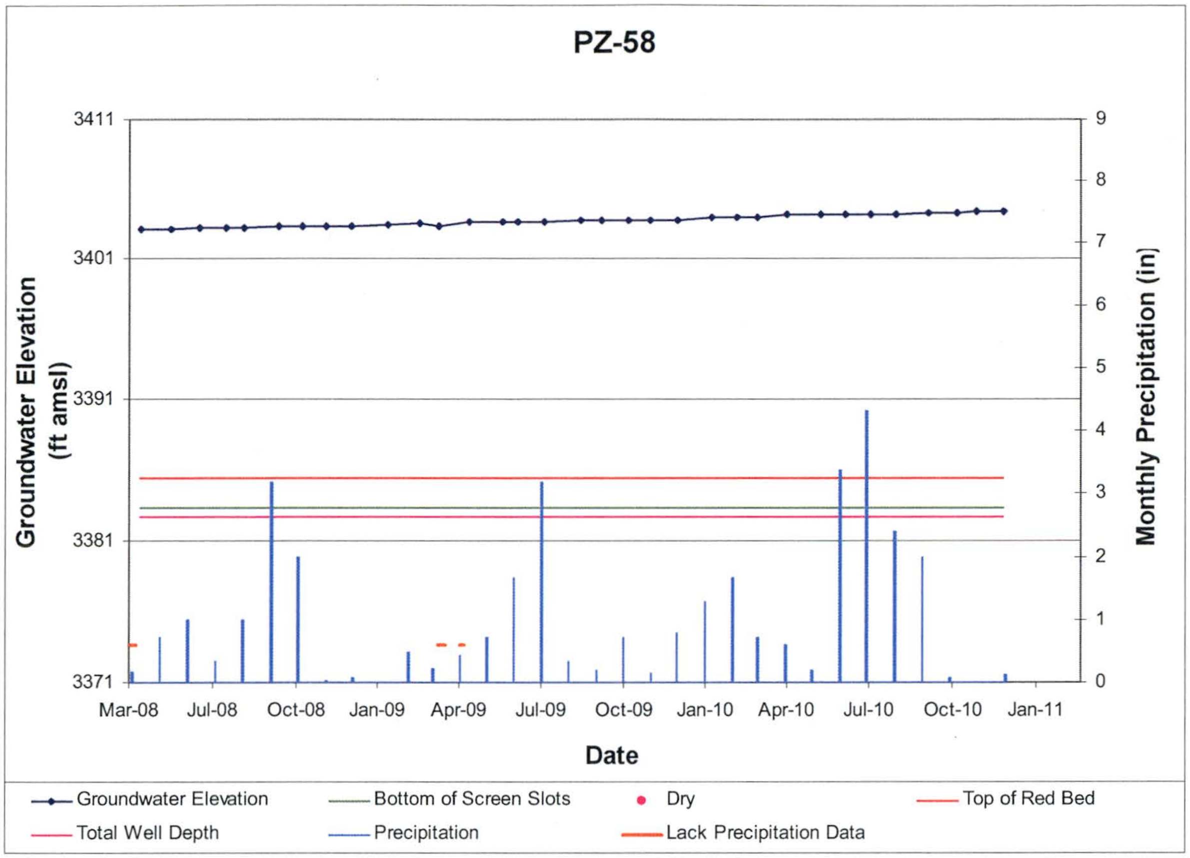
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data



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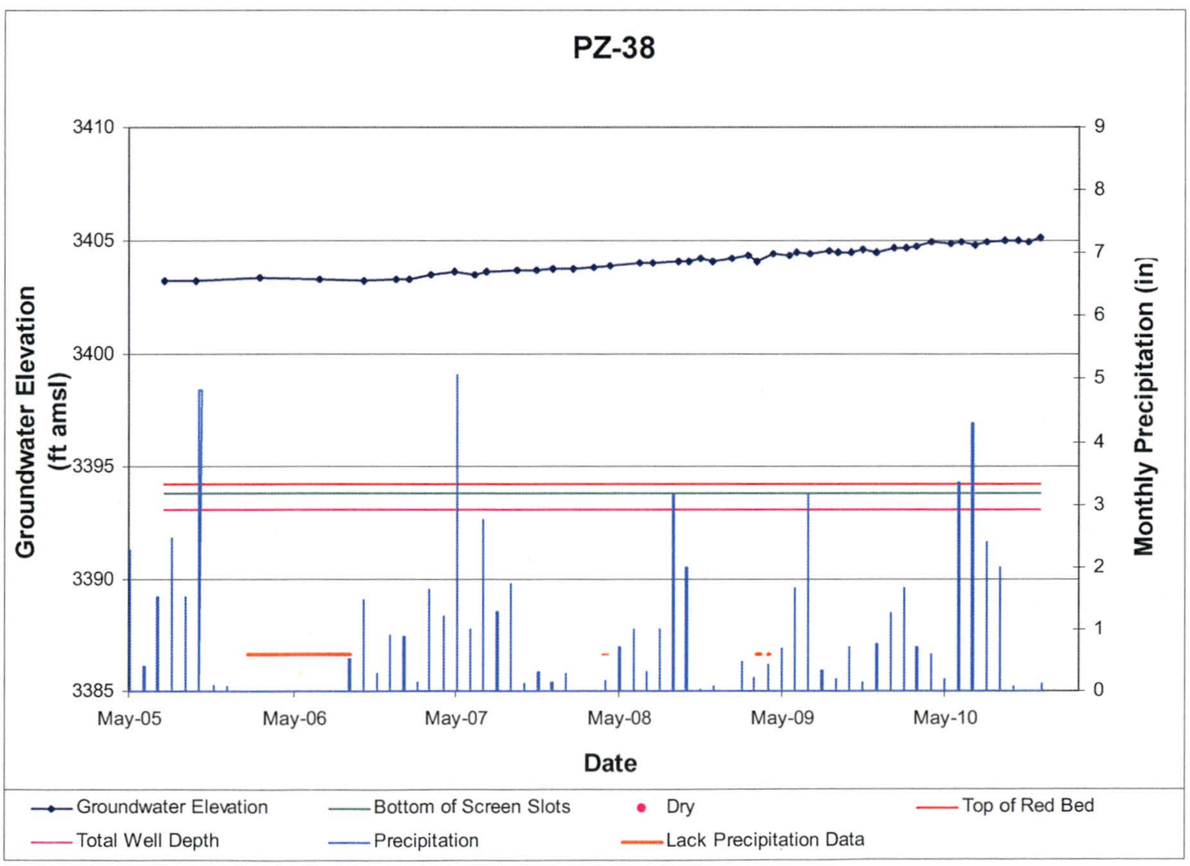
4
3
2
1
0
Mar-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data



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8
7
6
5
4
3
2
1
0
May-05
May-06
May-07
May-08
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Date
Groundwater Elevation
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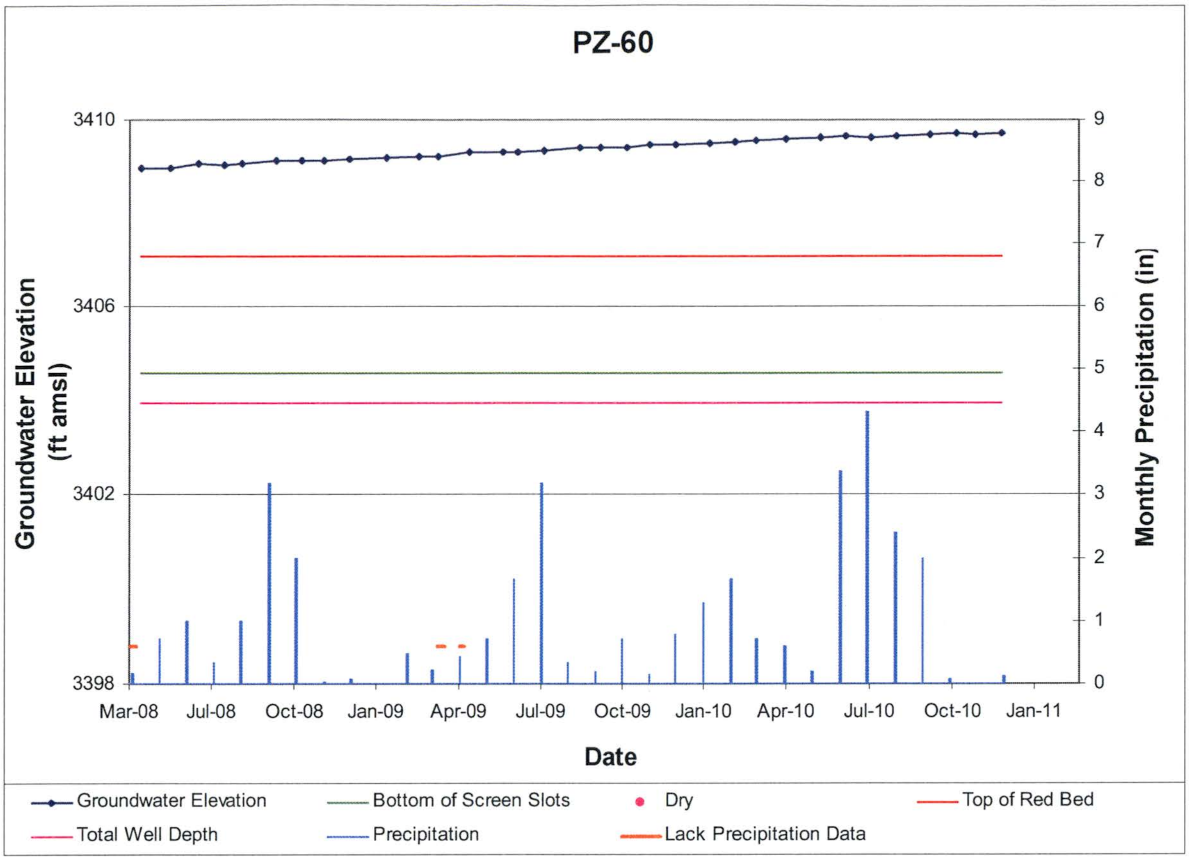
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
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Date
Groundwater Elevation
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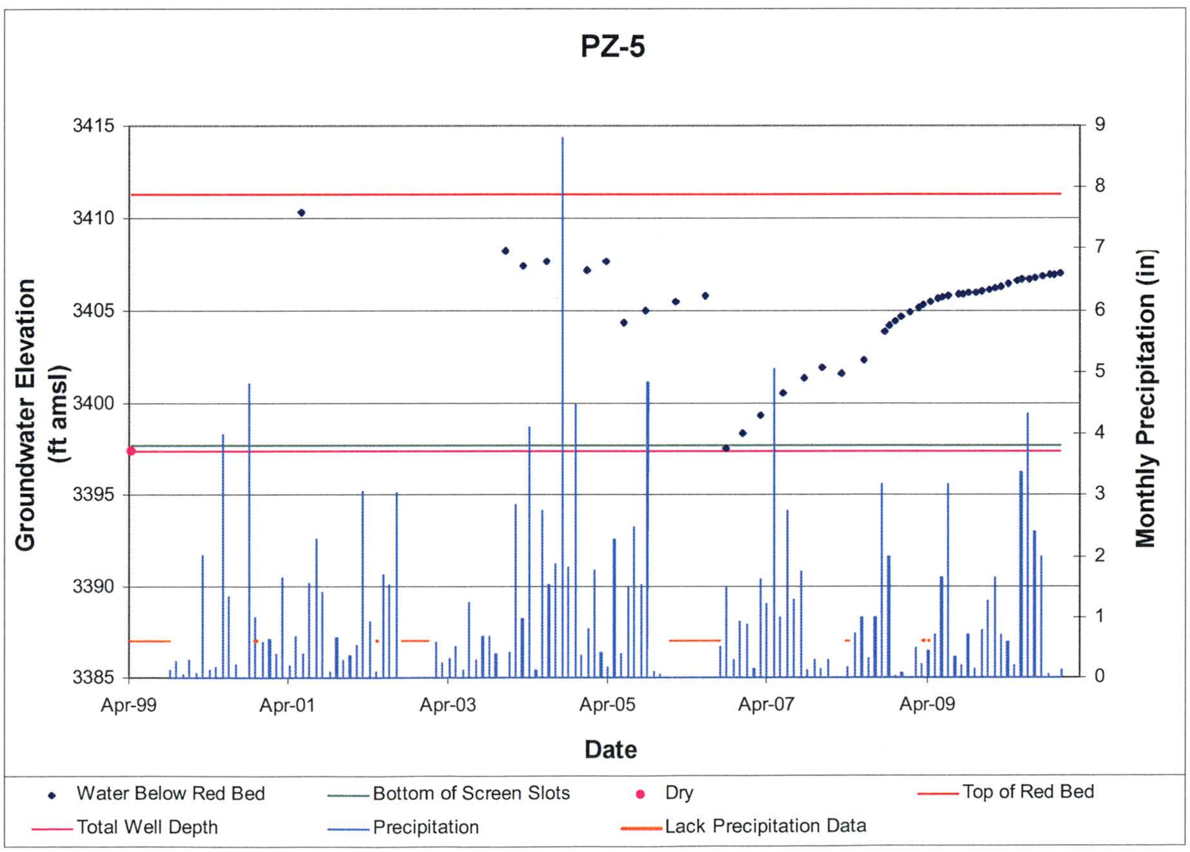
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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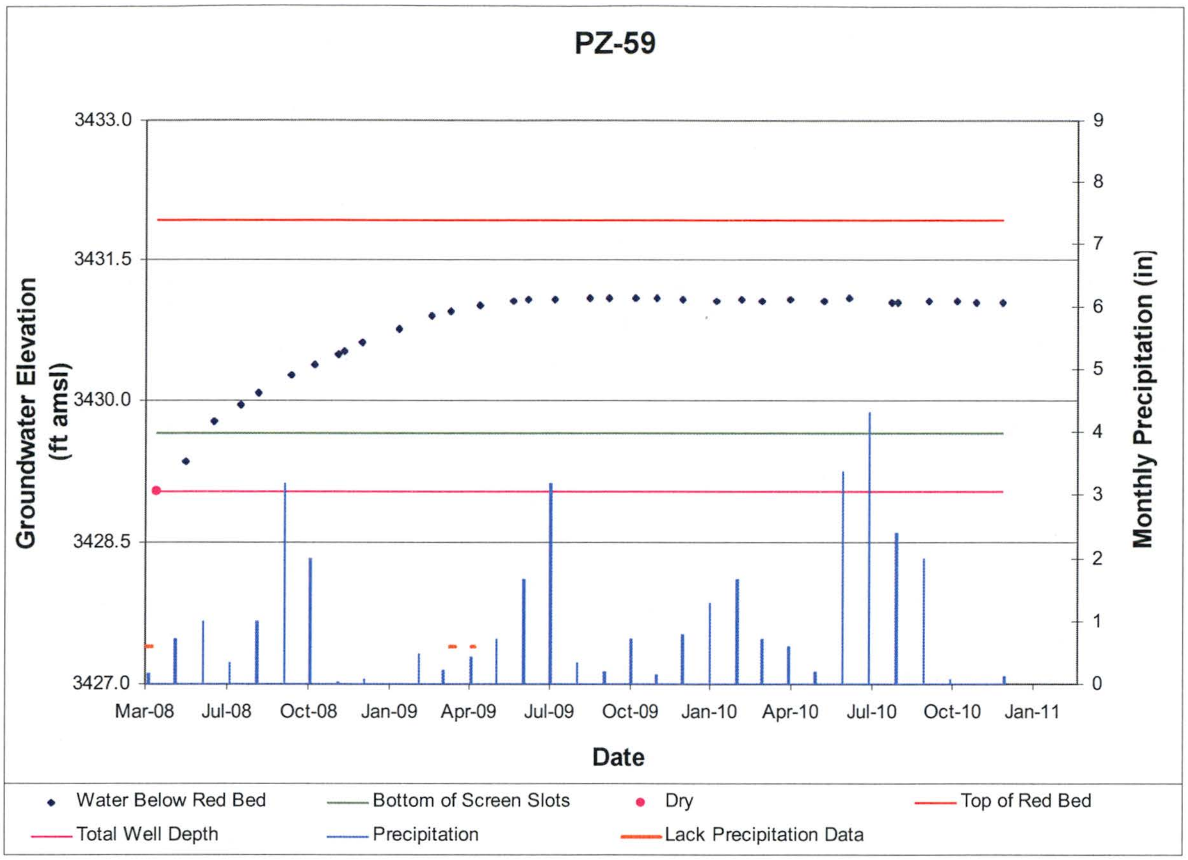
6
5
4
3
2
1
0
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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5
4
3
2
1
0
Monthly Precipitation (in)
Mar-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
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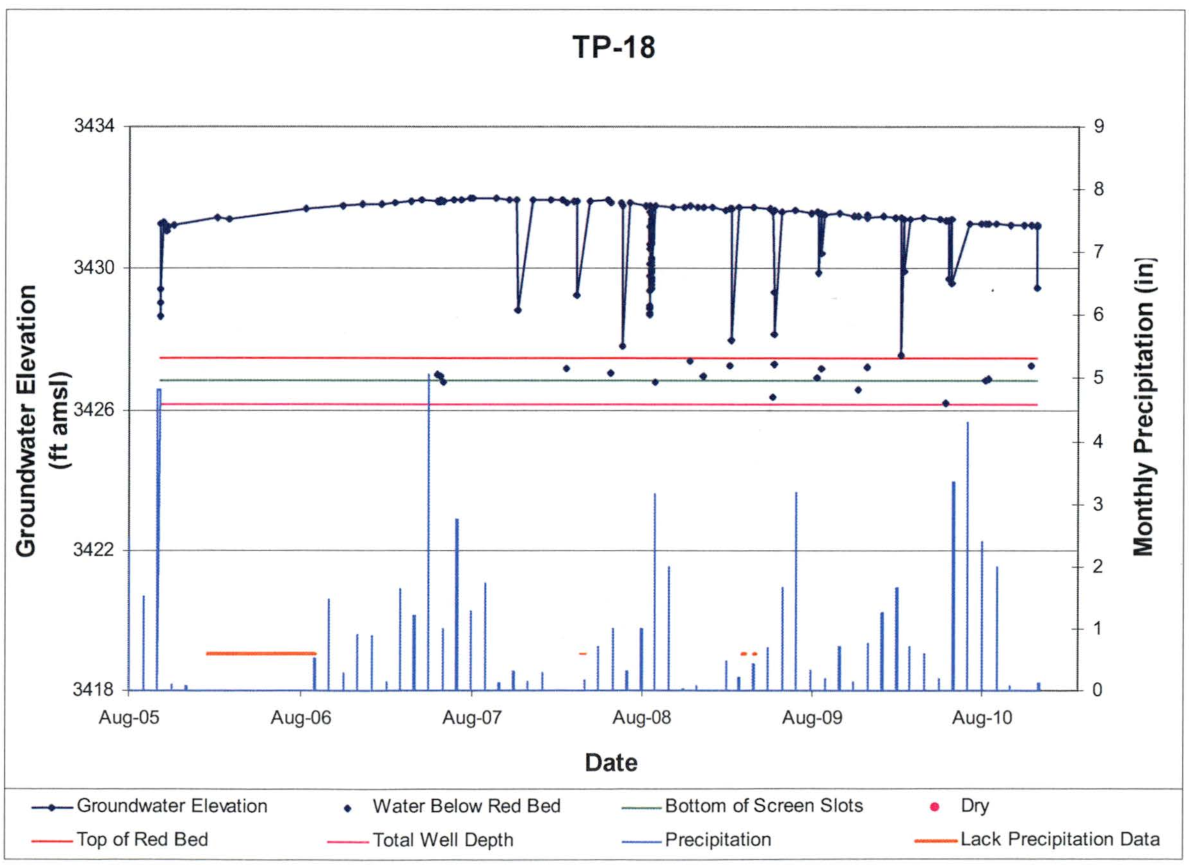
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data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0
Monthly Precipitation (in)
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
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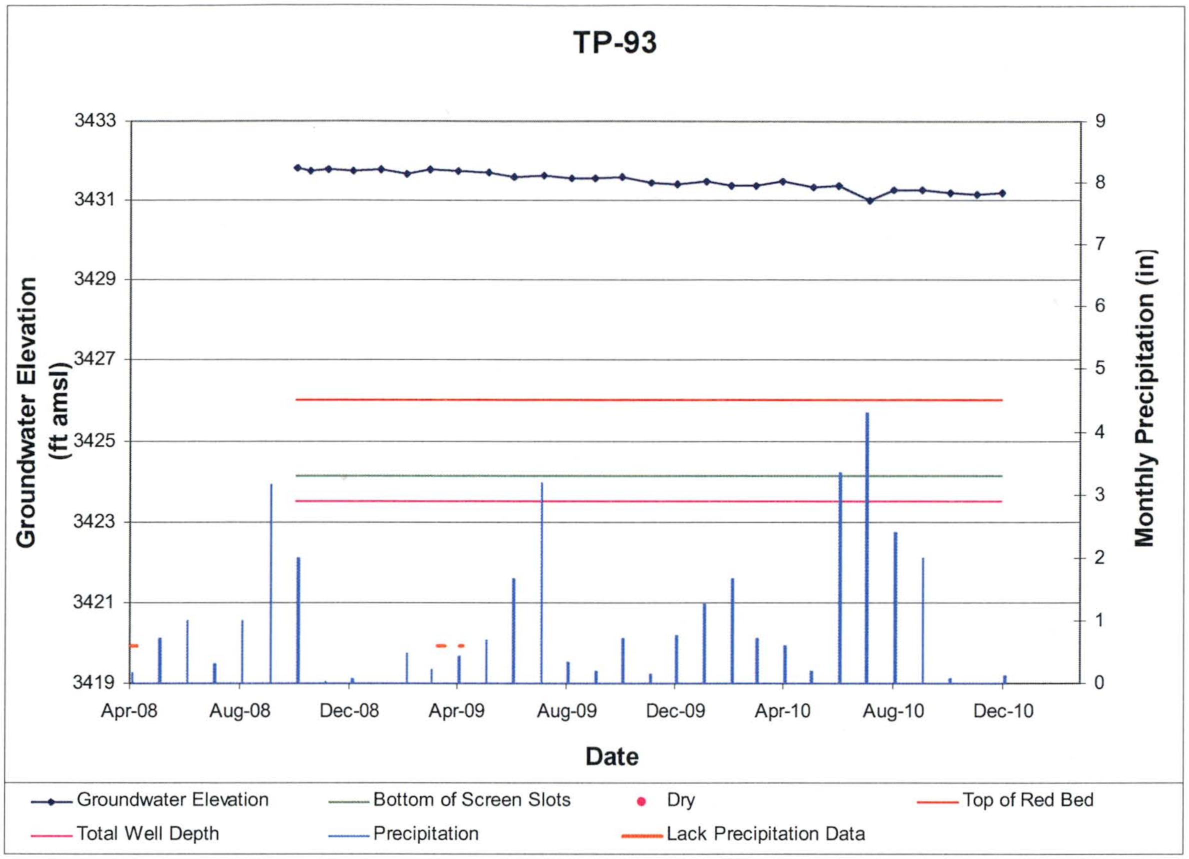
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Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
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Date
Groundwater Elevation
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Dry
Top of Red Bed
Total Well Depth
Precipitation
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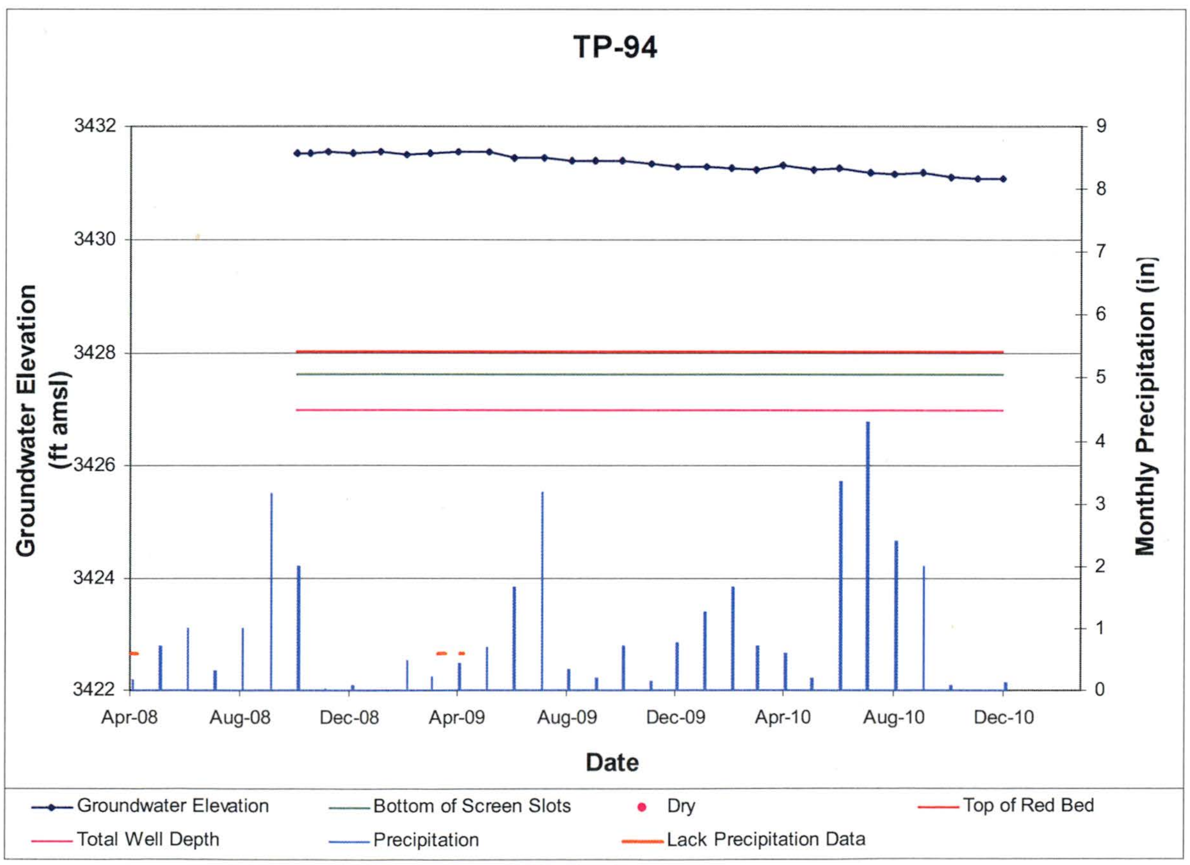
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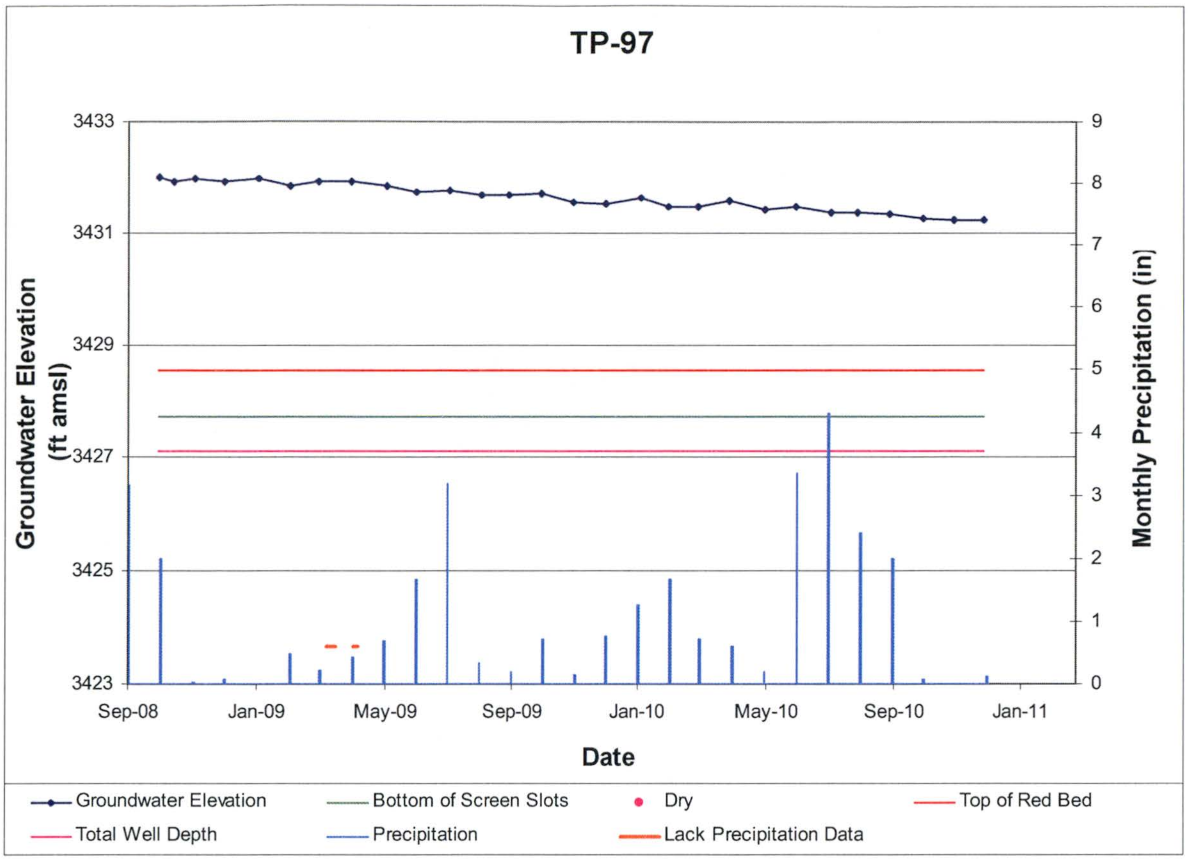
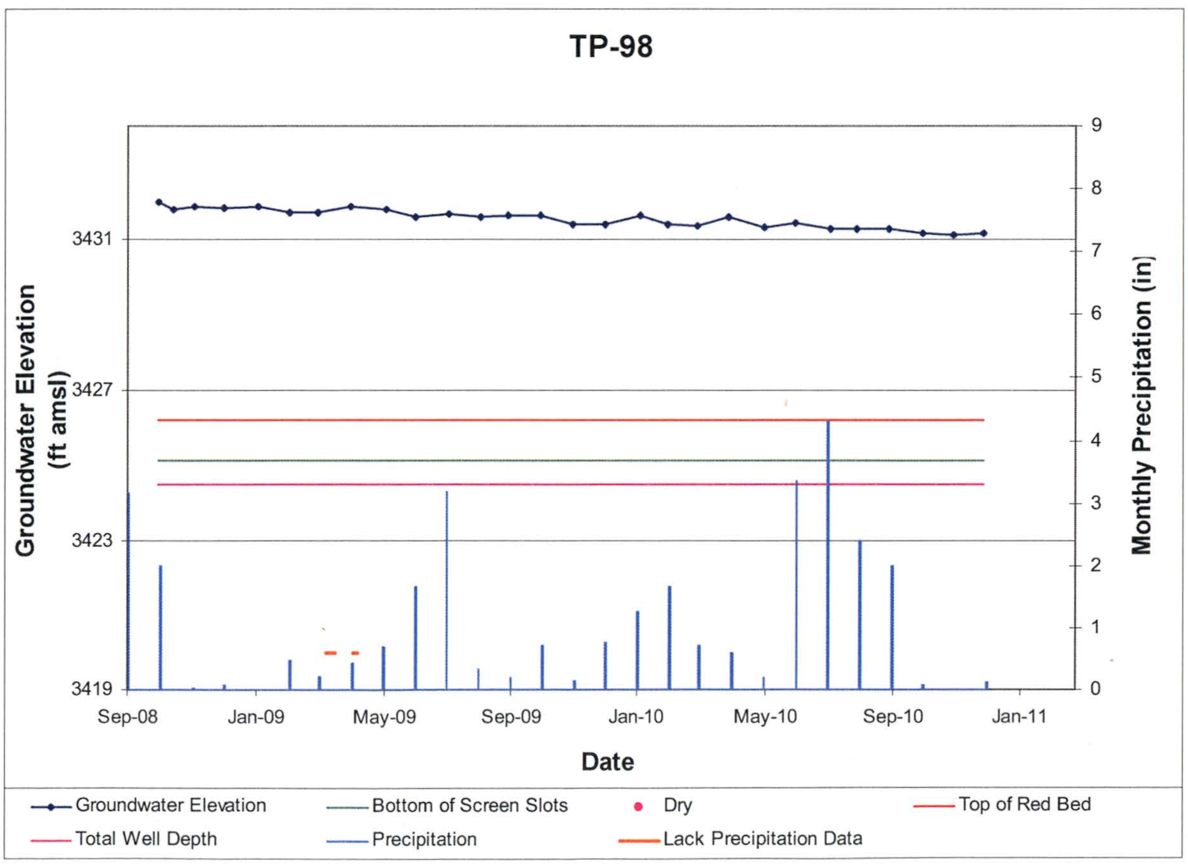
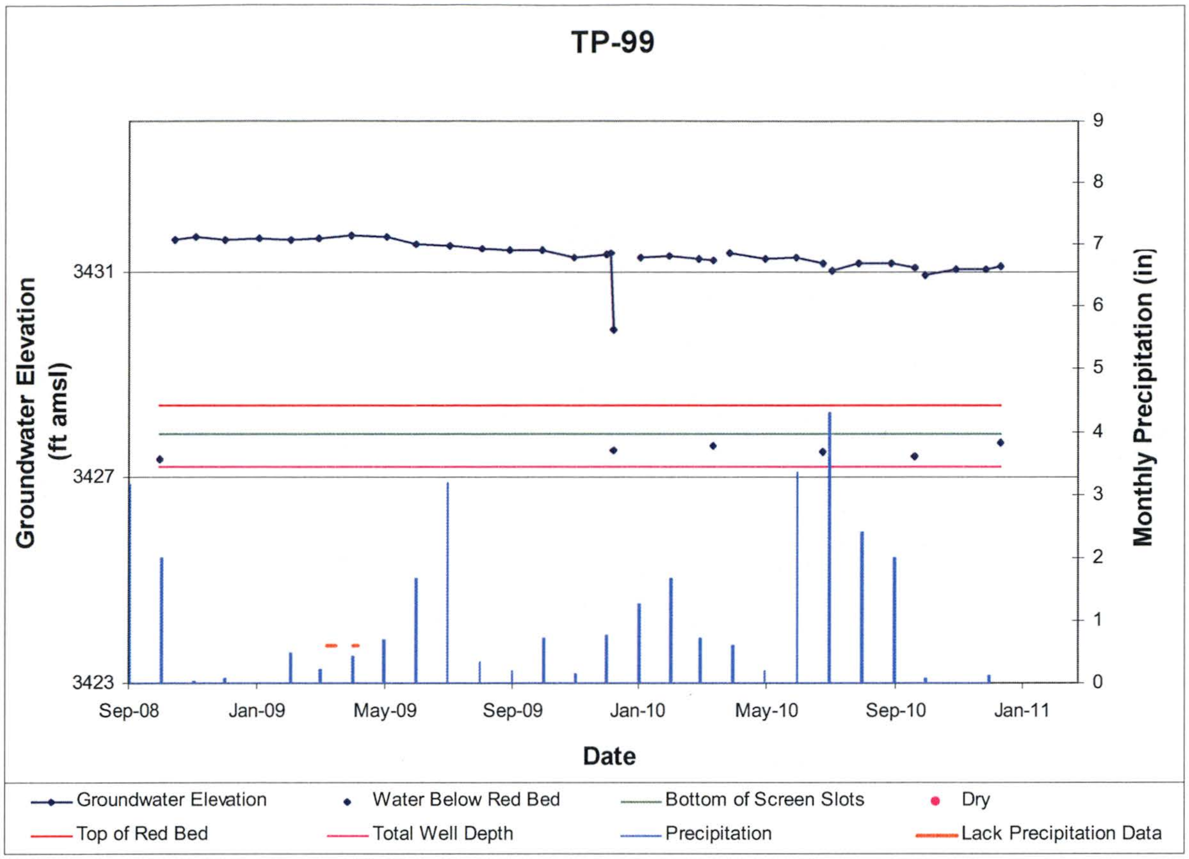
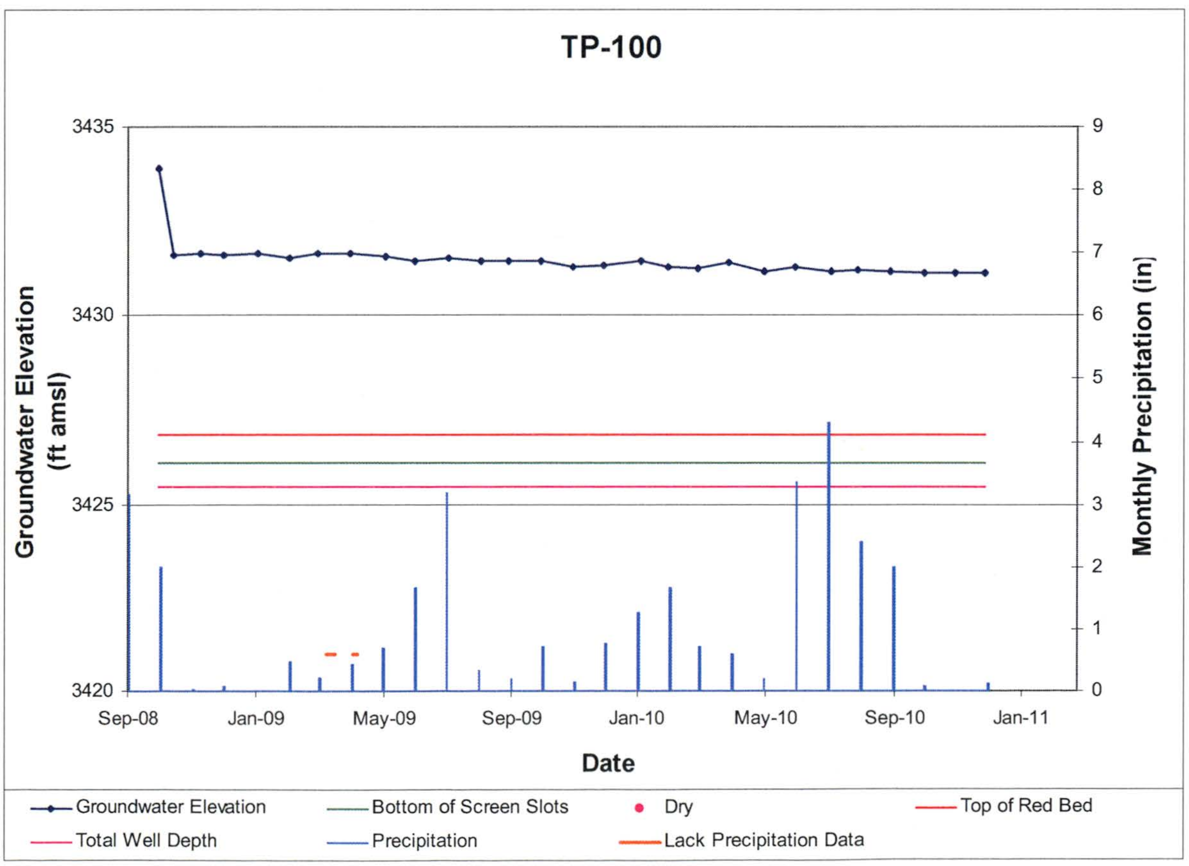
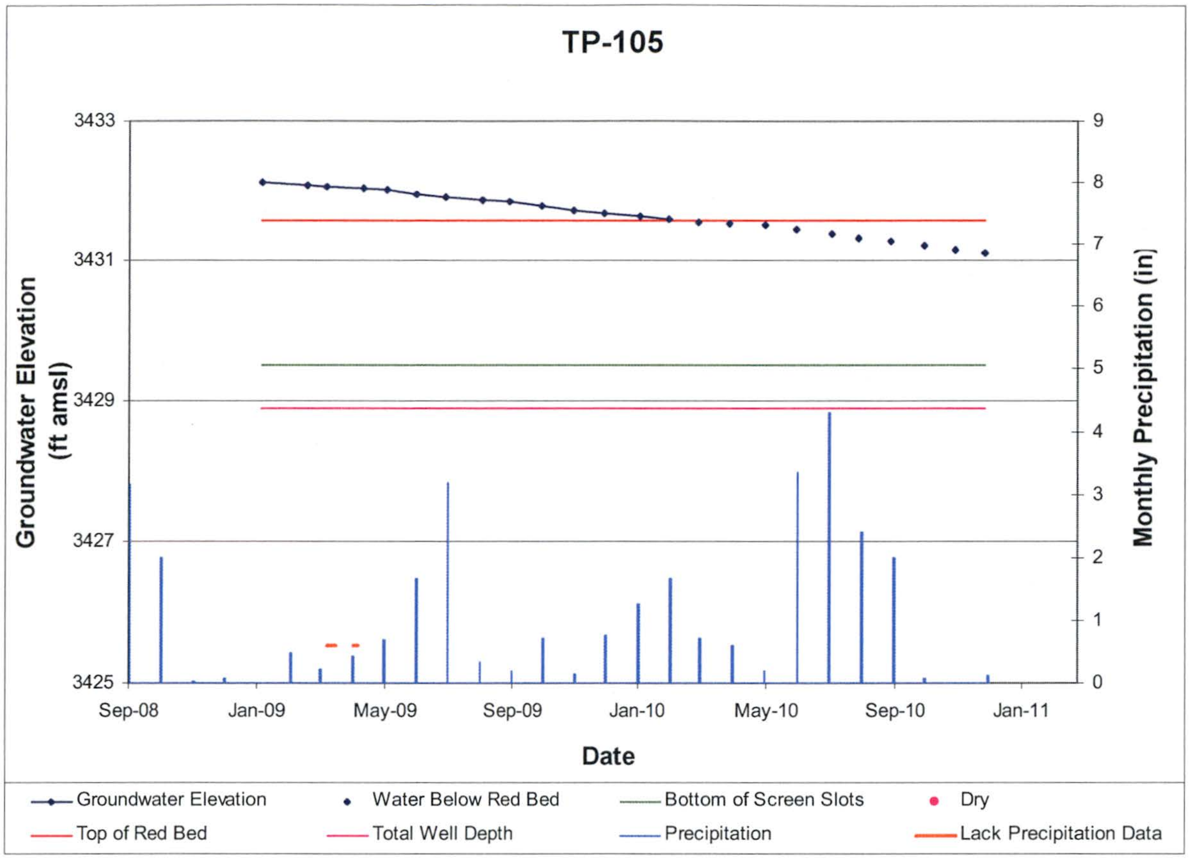
3432
3430
3428
3426
3424
3422
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

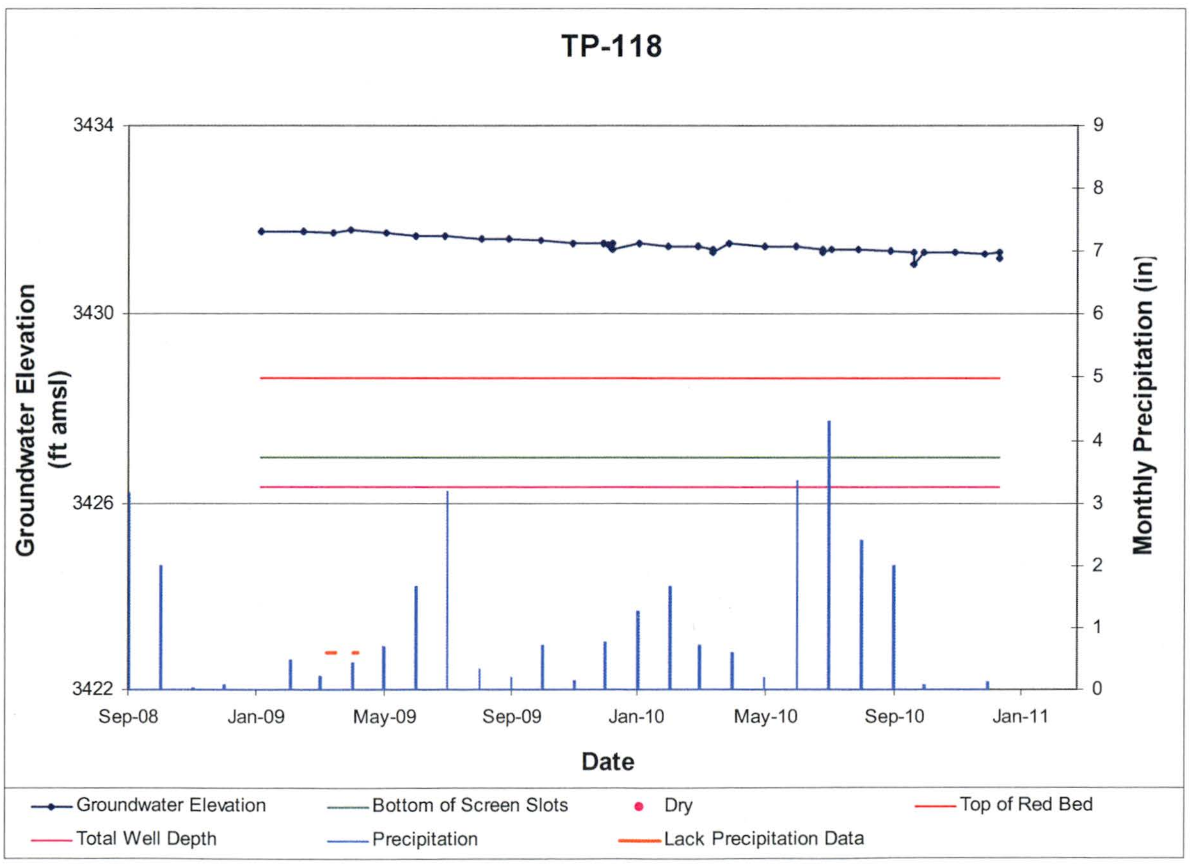

TP-97
3433
3431
3429
3427
3425
3423
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

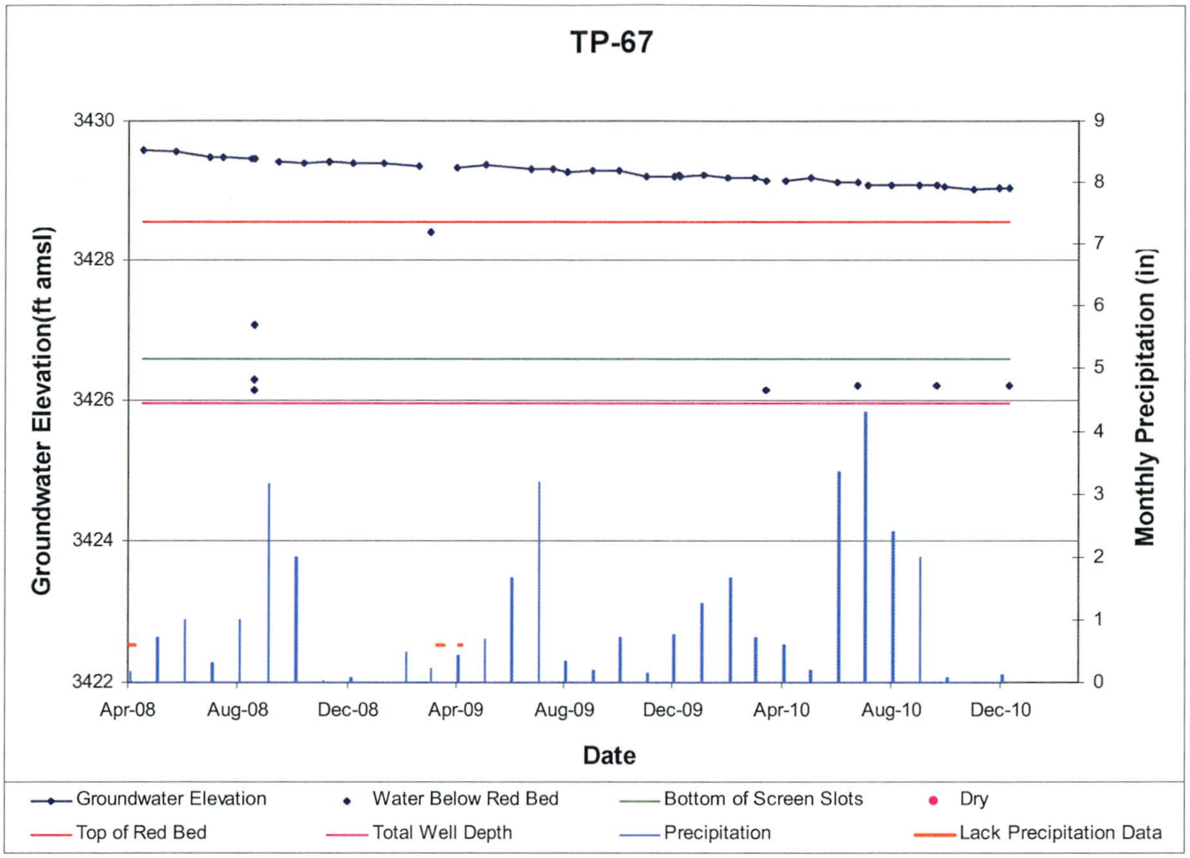

TP-98
3431
3427
3423
3419
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

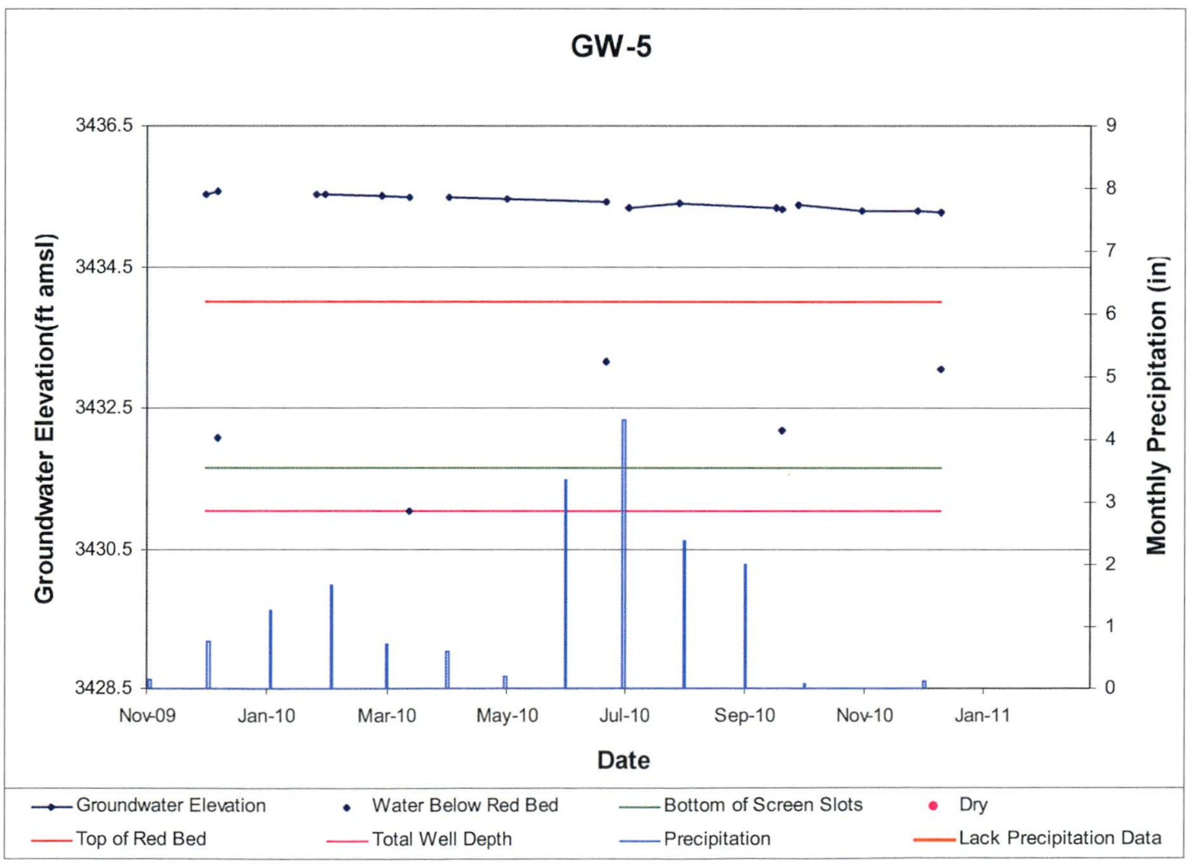

TP-99
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3431
3427
3423
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

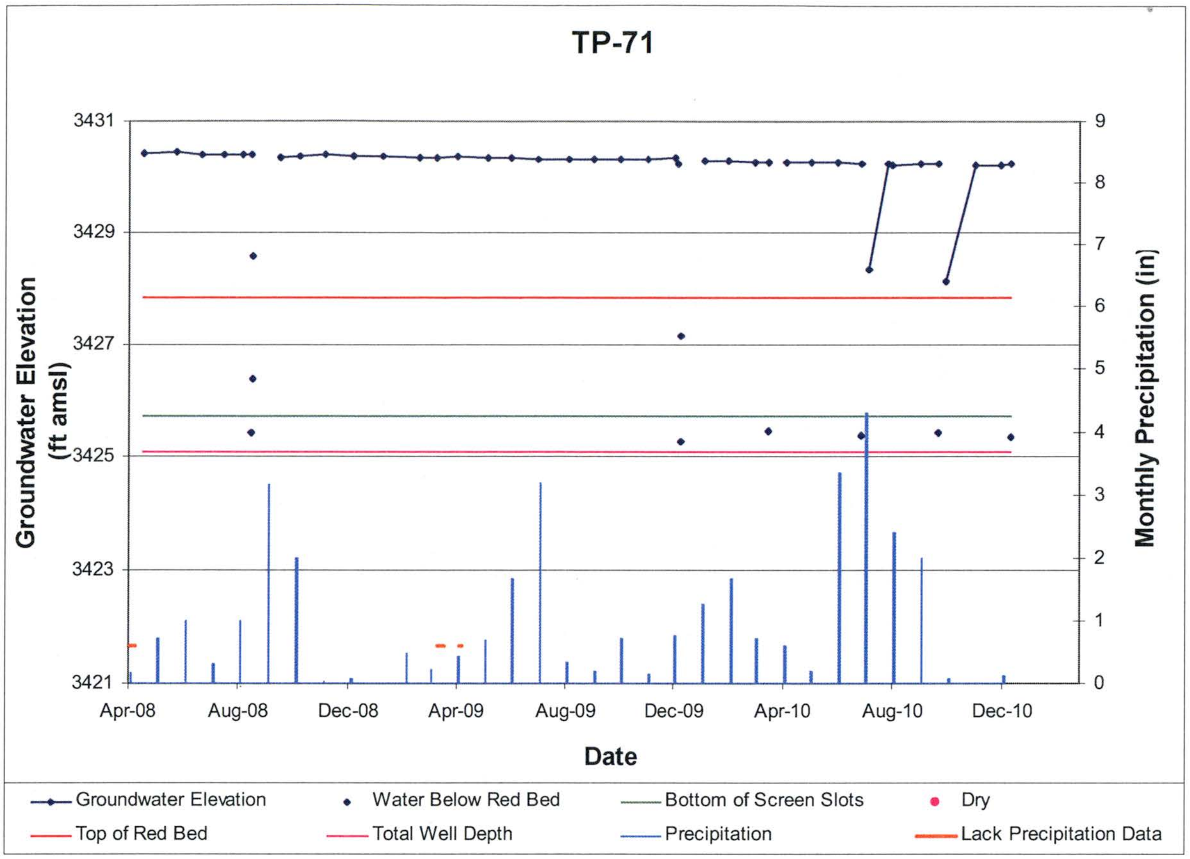

TP-100
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3435
3430
3425
3420
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

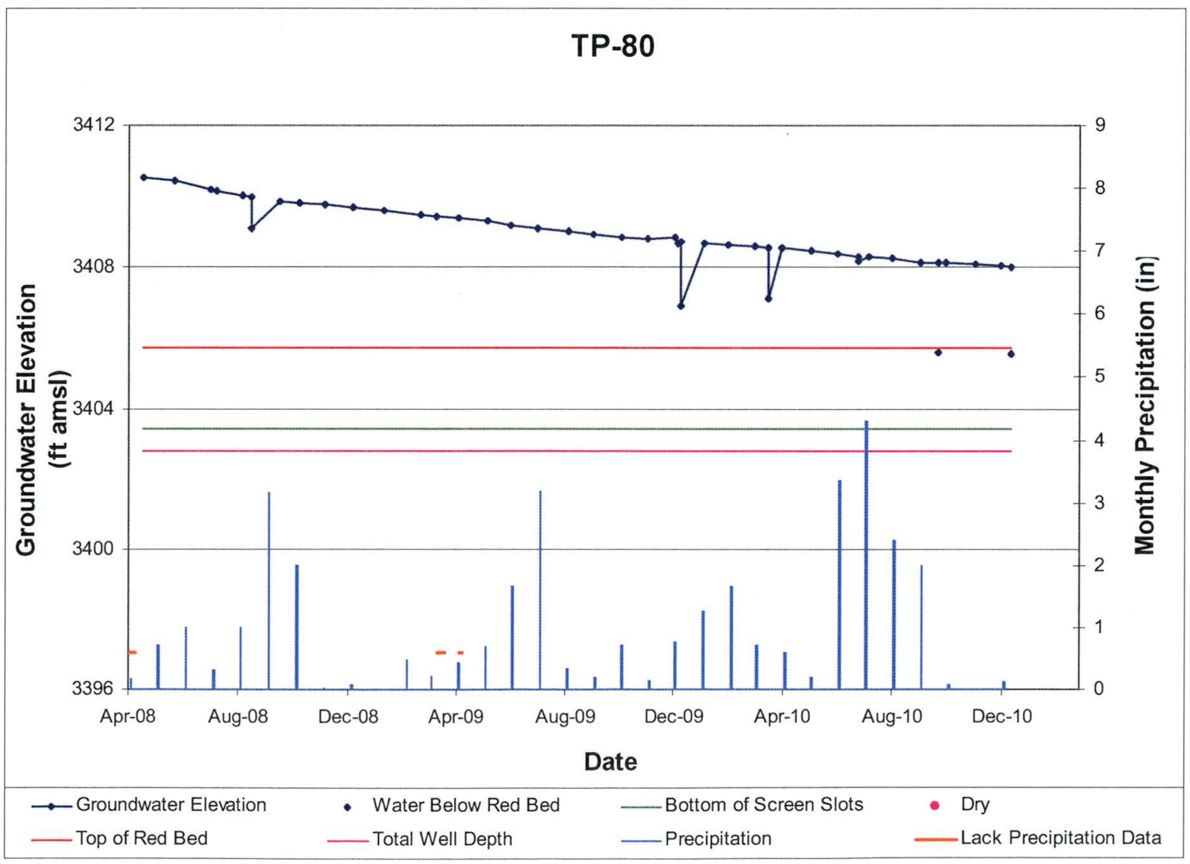

TP-105
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3433
3431
3429
3427
3425
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

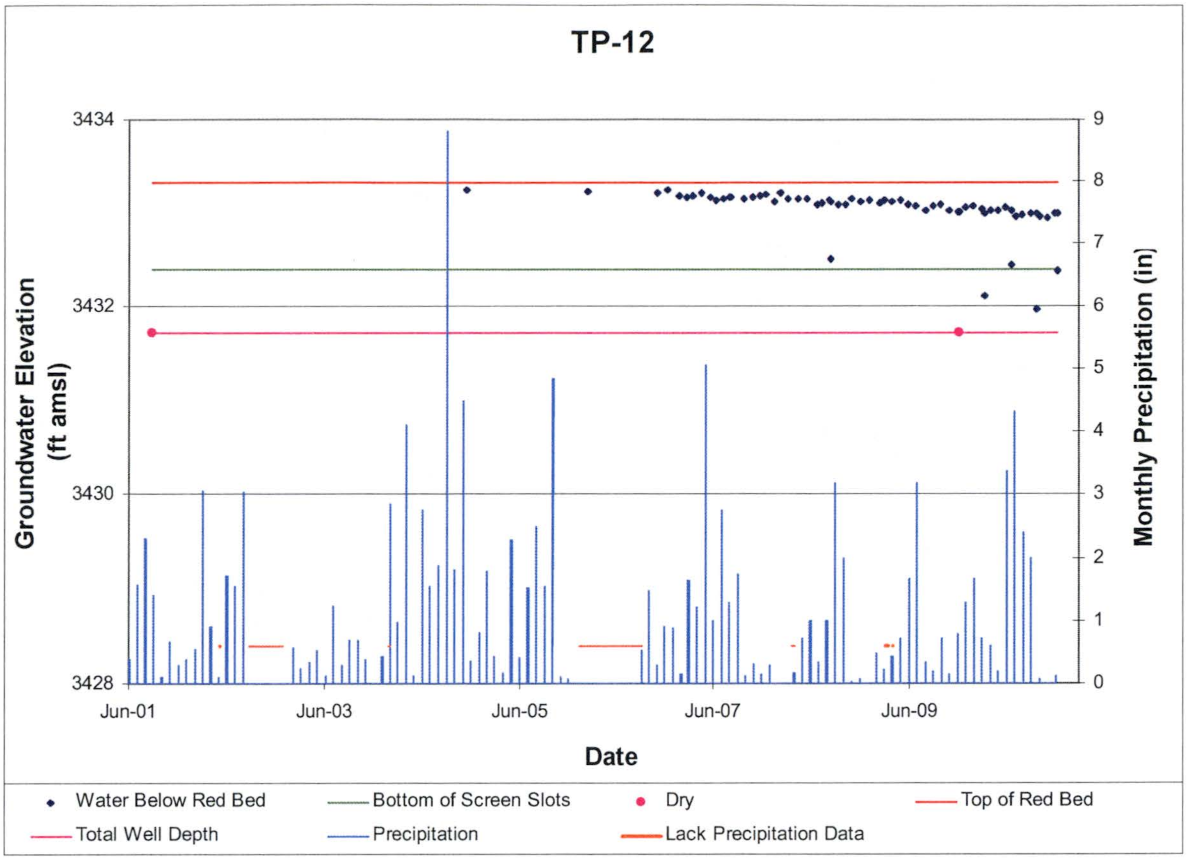

TP-118
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3434
3430
3426
3422
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-67
Groundwater Elevation(ft amsl)
Monthly Precipitation (in)
3430
3428
3426
3424
3422
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

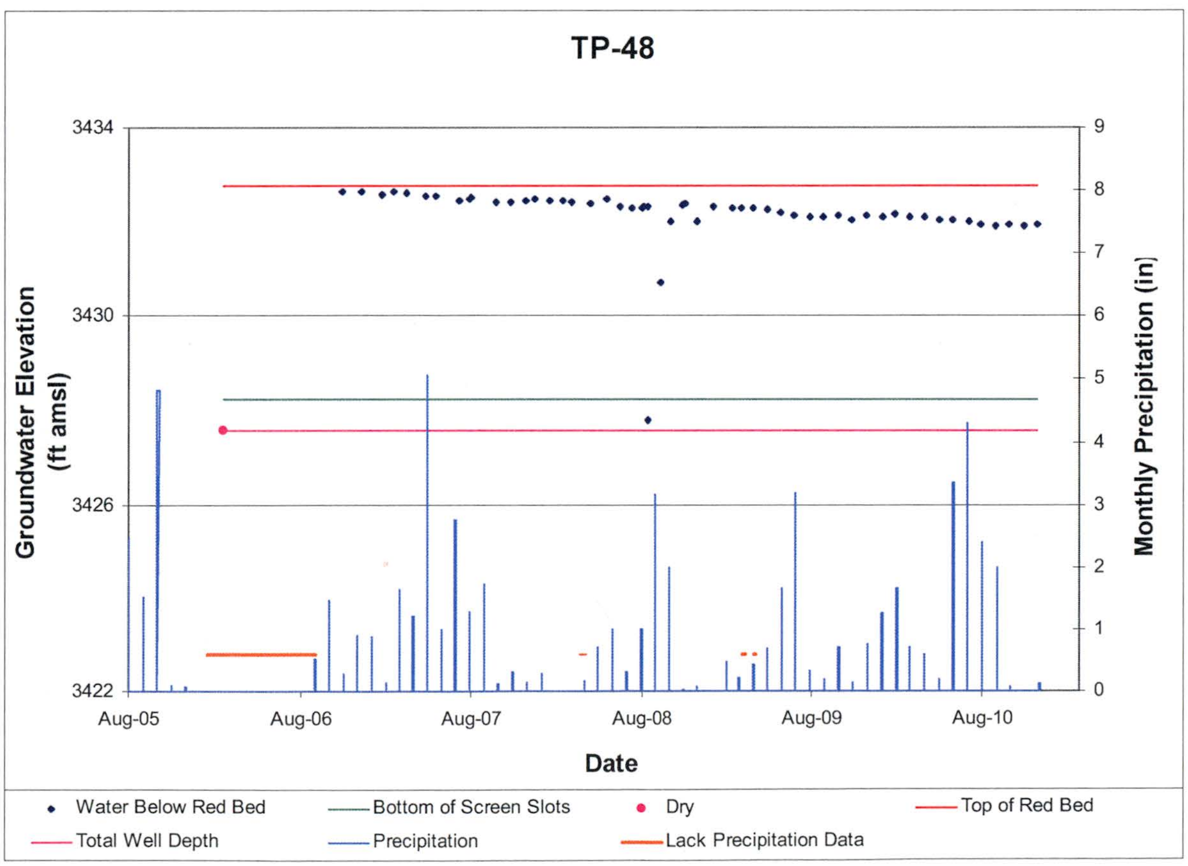

GW-5
Groundwater Elevation(ft amsl)
Monthly Precipitation (in)
3436.5
3434.5
3432.5
3430.5
3428.5
9
8
7
6
5
4
3
2
1
0
Nov-09
Jan-10
Mar-10
May-10
Jul-10
Sep-10
Nov-10
Jan-11
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-71
3431
3429
3427
3425
3423
3421
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

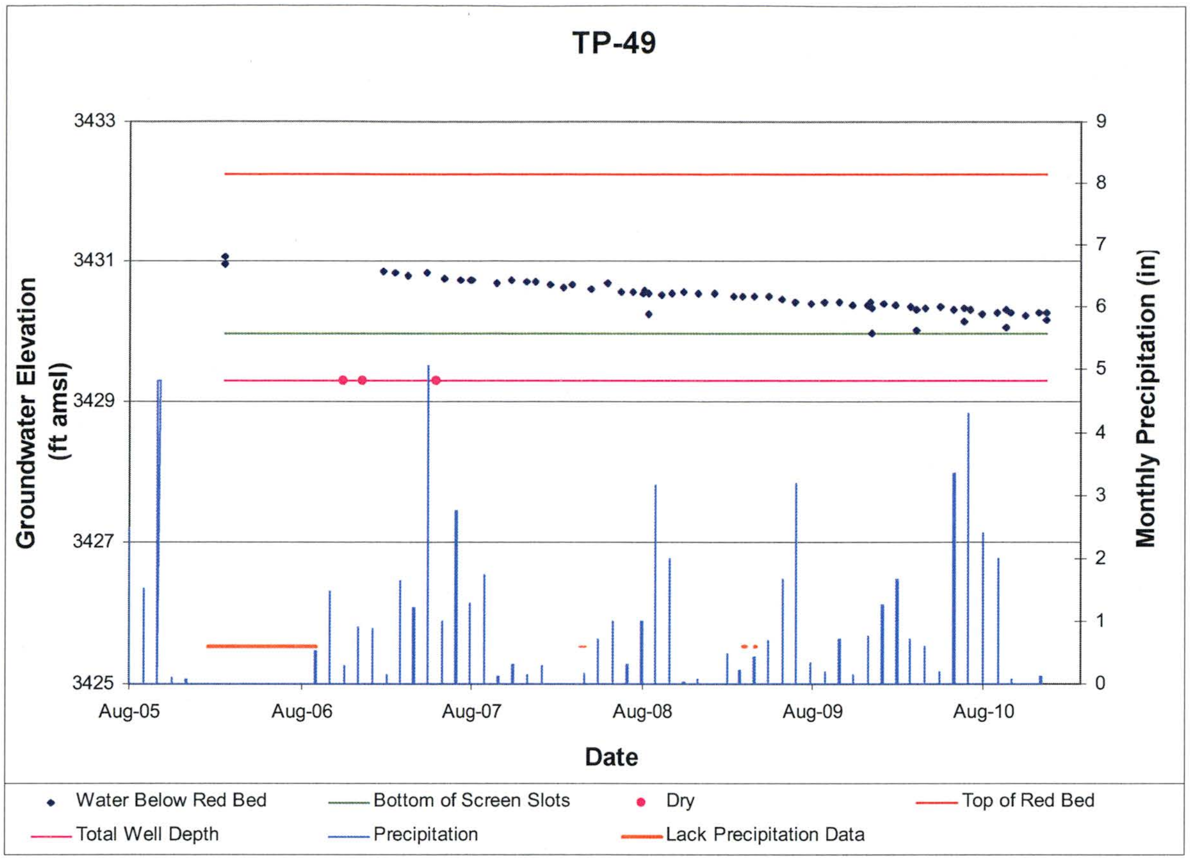

TP-80
3412
3408
3404
3400
3396
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

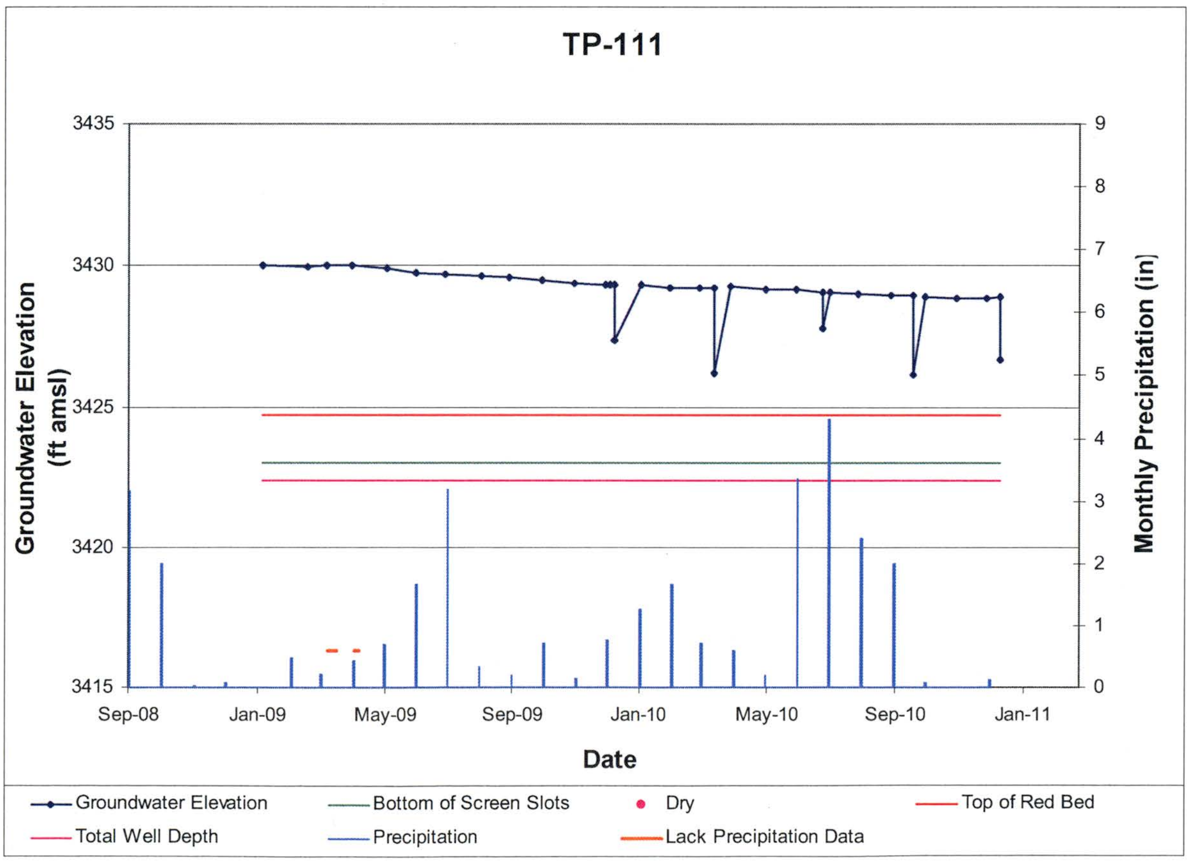


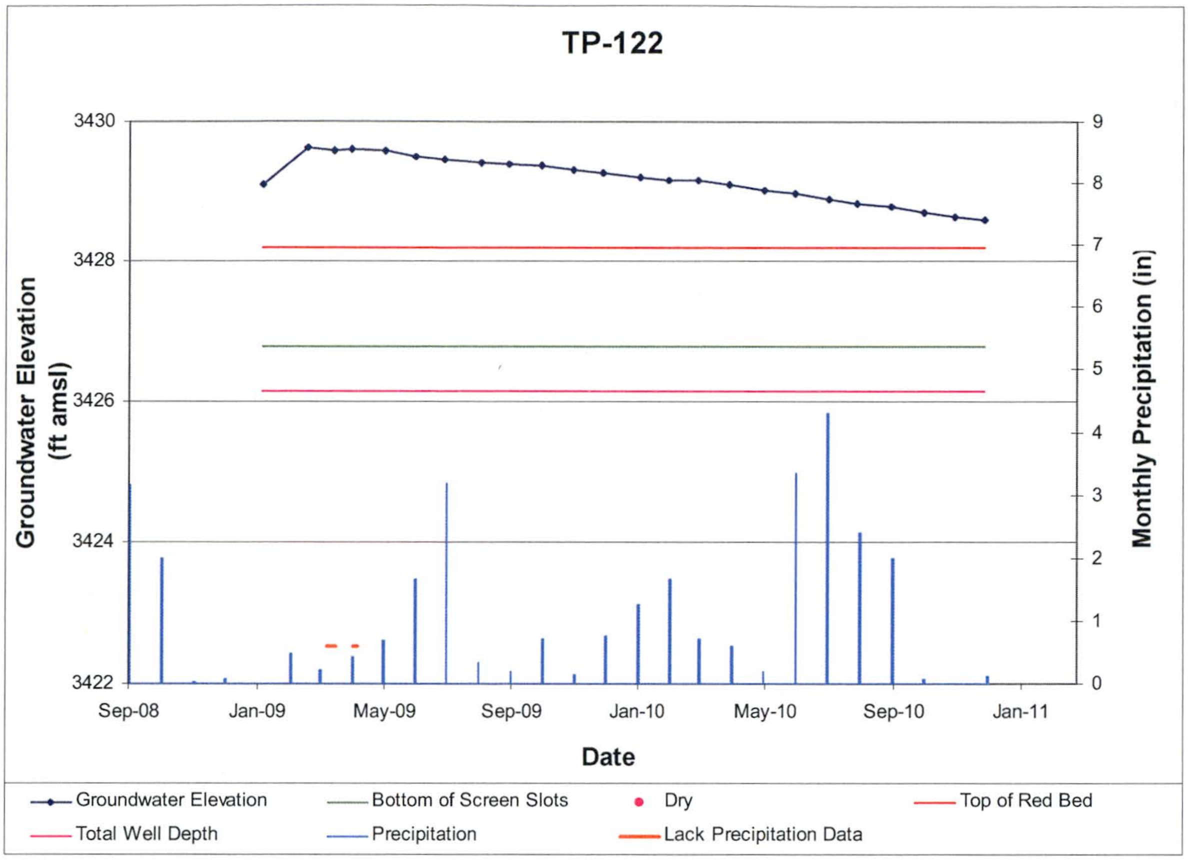
TP-12
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3434
3432
3430
3428
9
8
7
6
5
4
3
2
1
0
Jun-01
Jun-03
Jun-05
Jun-07
Jun-09
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

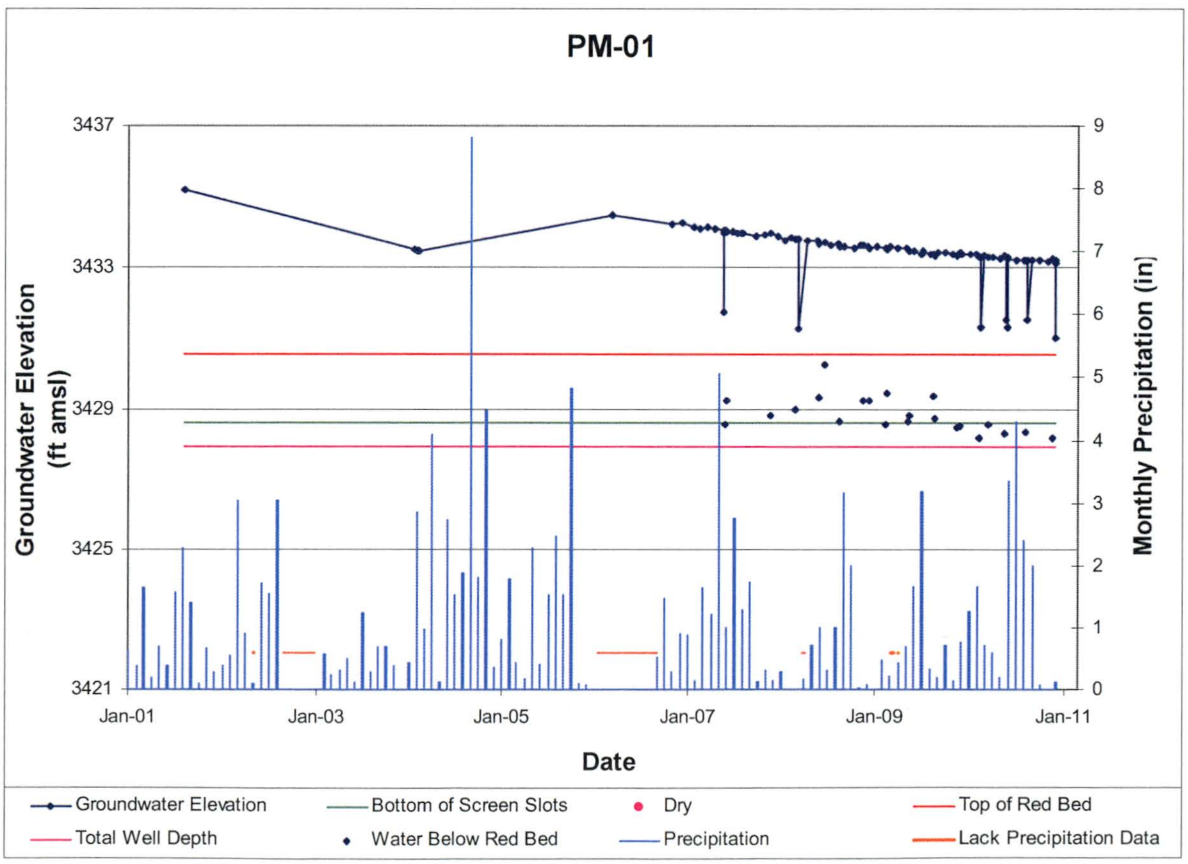


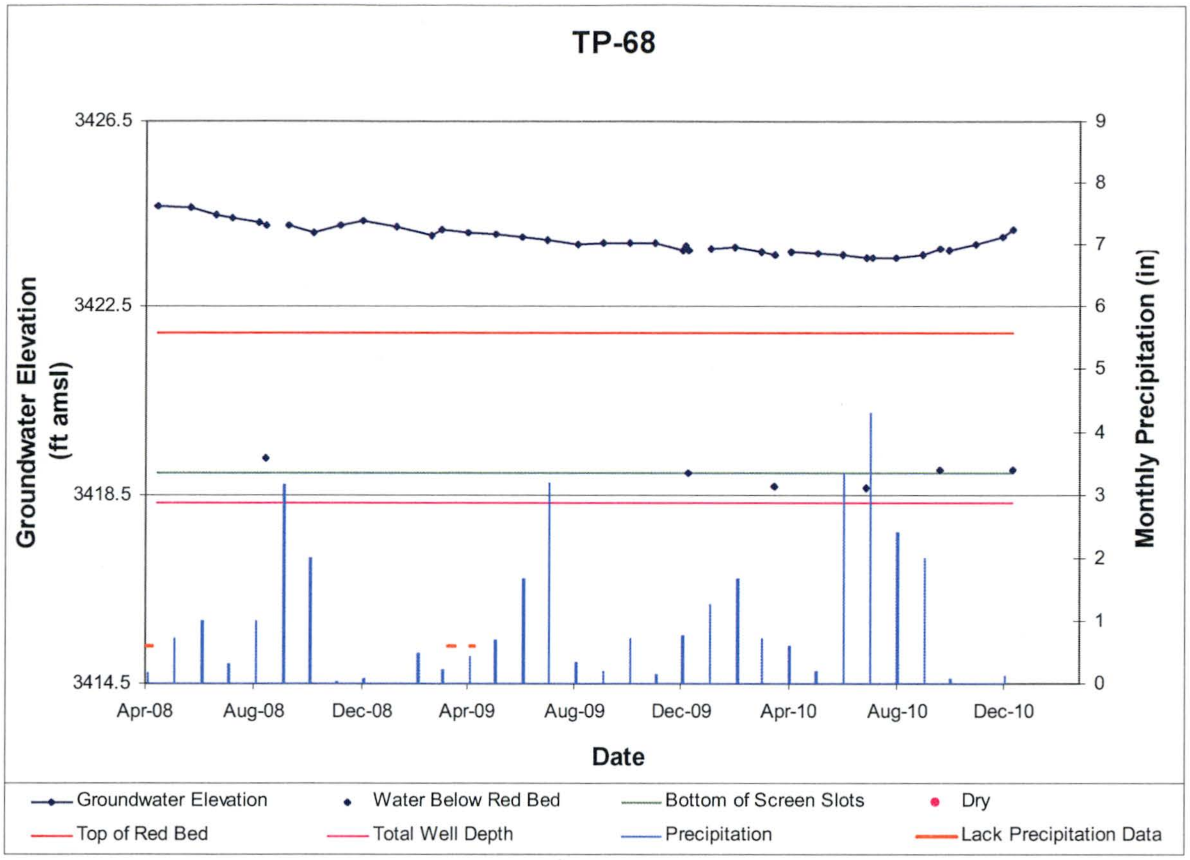
TP-48
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3434
3430
3426
3422
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

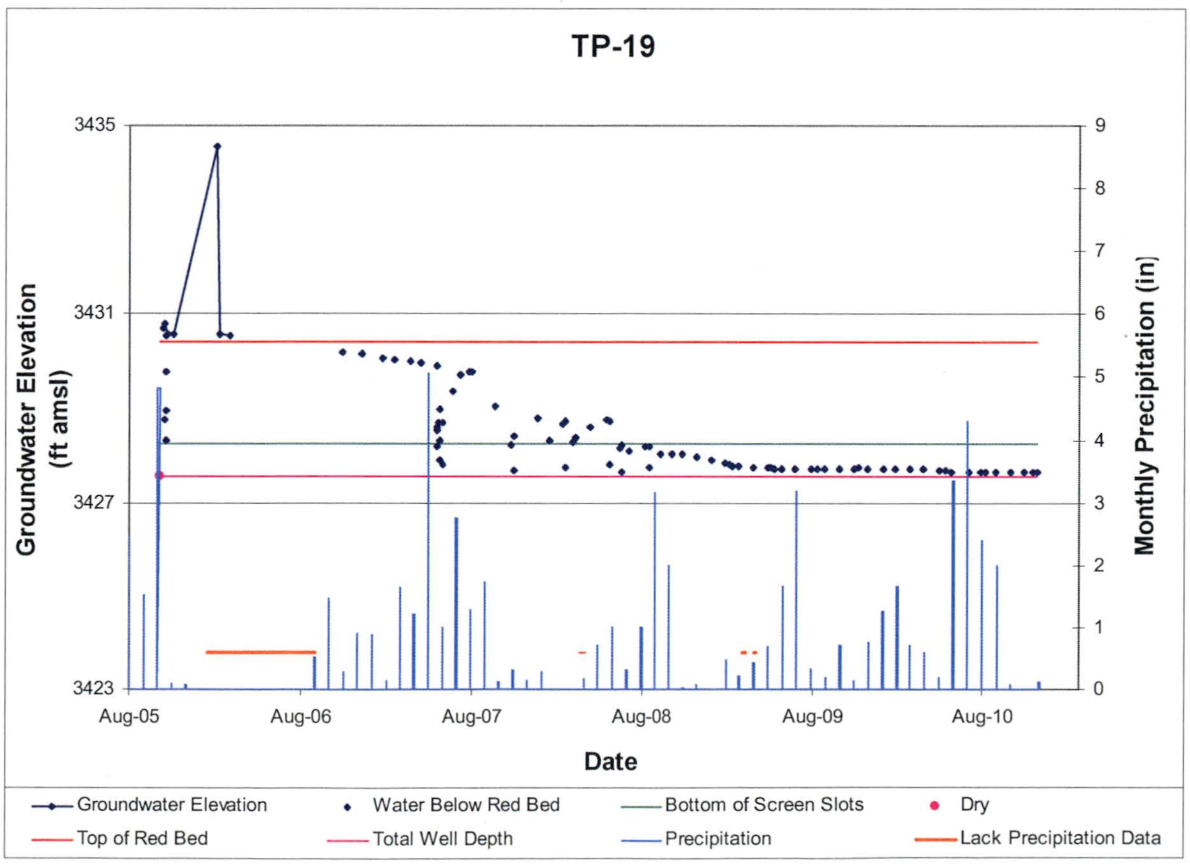

TP-49
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3433
3431
3429
3427
3425
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

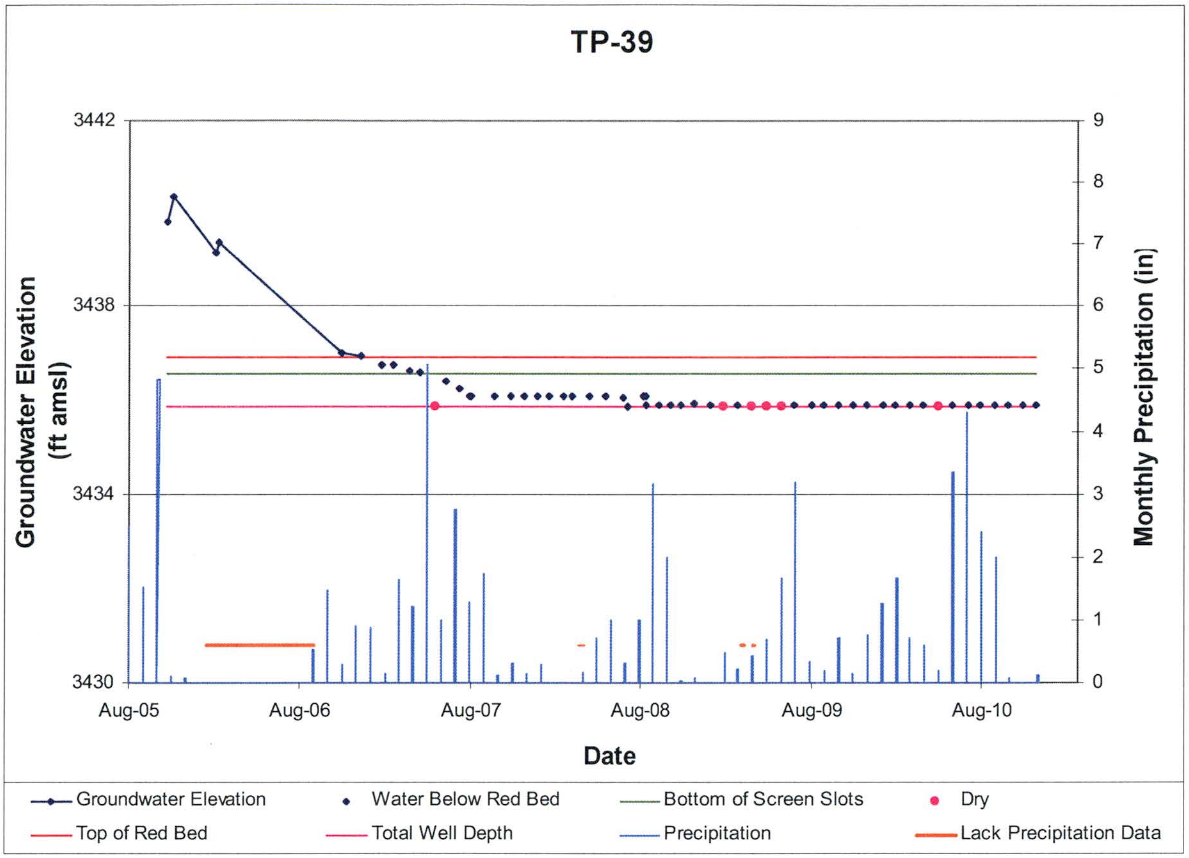

TP-111
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3435
3430
3425
3420
3415
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

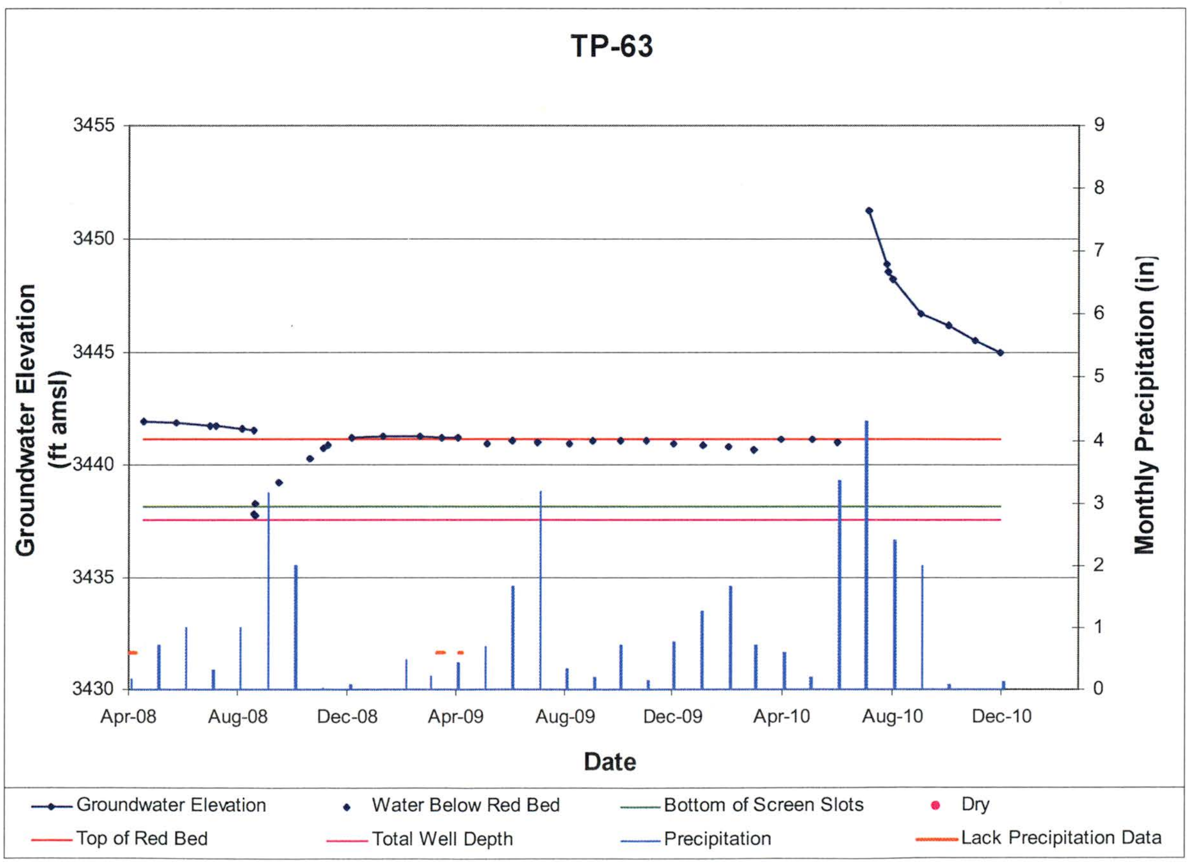

TP-122
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3430
3428
3426
3424
3422
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

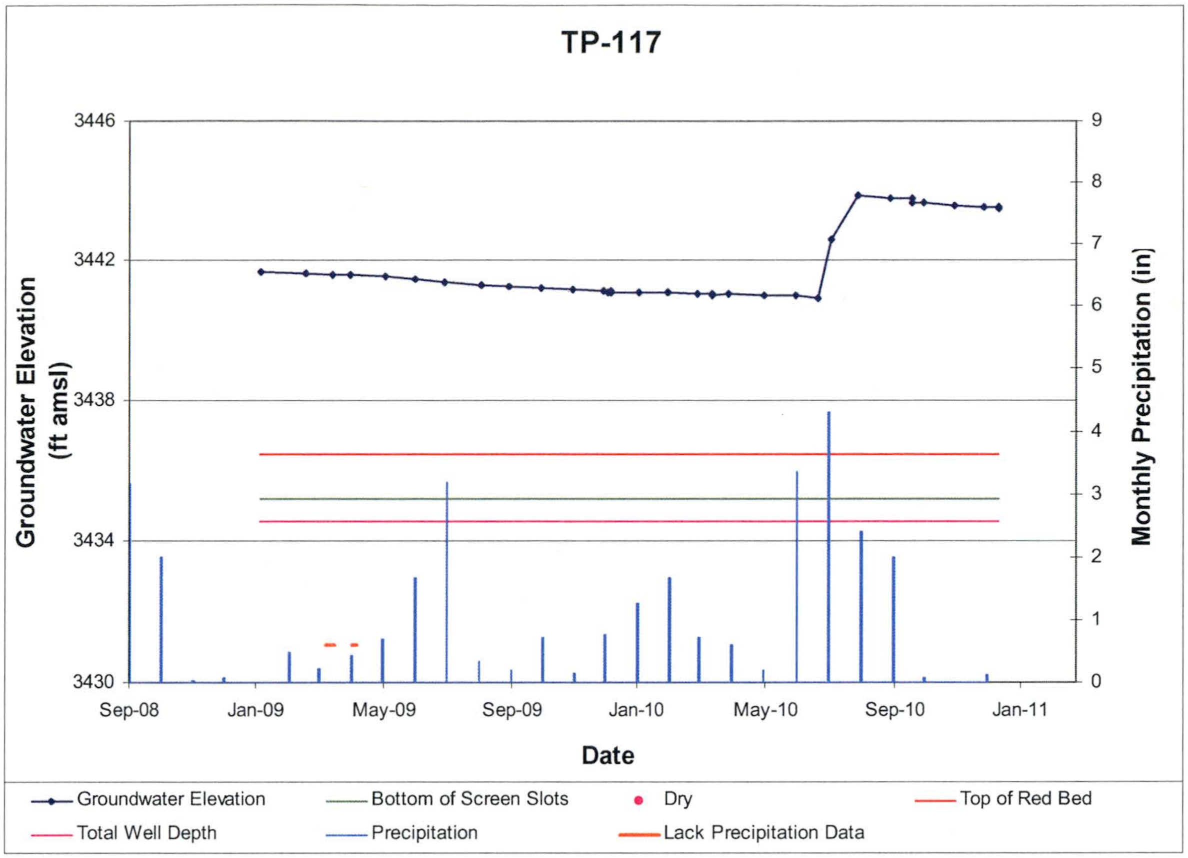

PM-01
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3437
3433
3429
3425
3421
9
8
7
6
5
4
3
2
1
0
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data

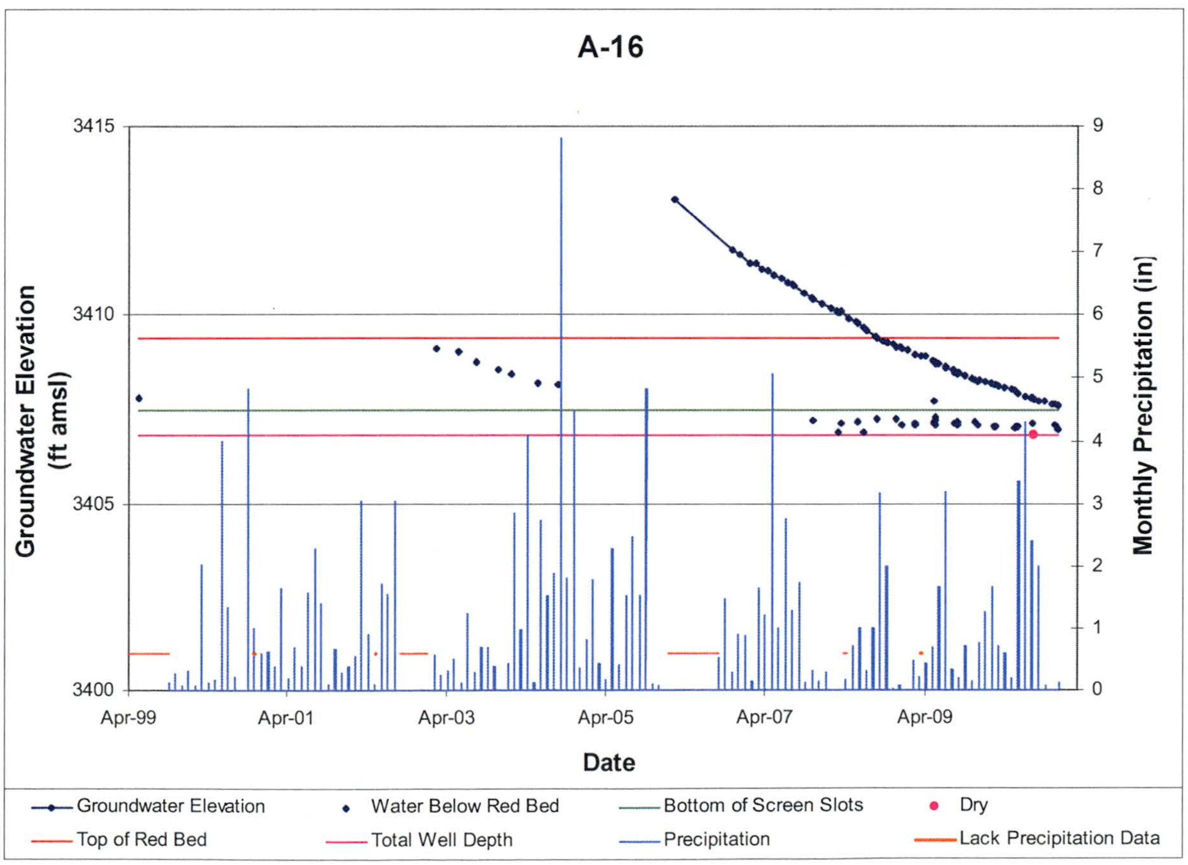

TP-68
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3426.5
3422.5
3418.5
3414.5
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

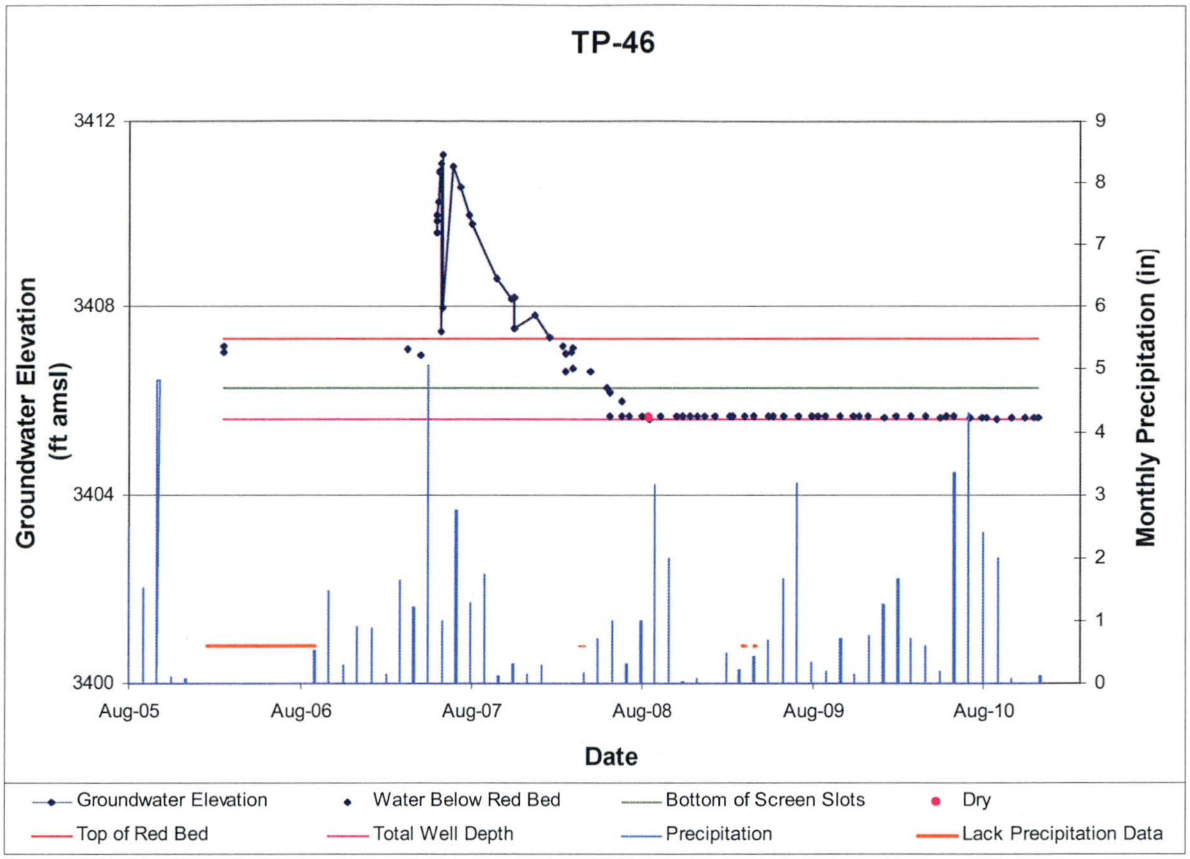

TP-19
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3435
3431
3427
3423
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-39
Groundwater Elevation (ft amsl)
3442
3438
3434
3430
Monthly Precipitation (in)
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

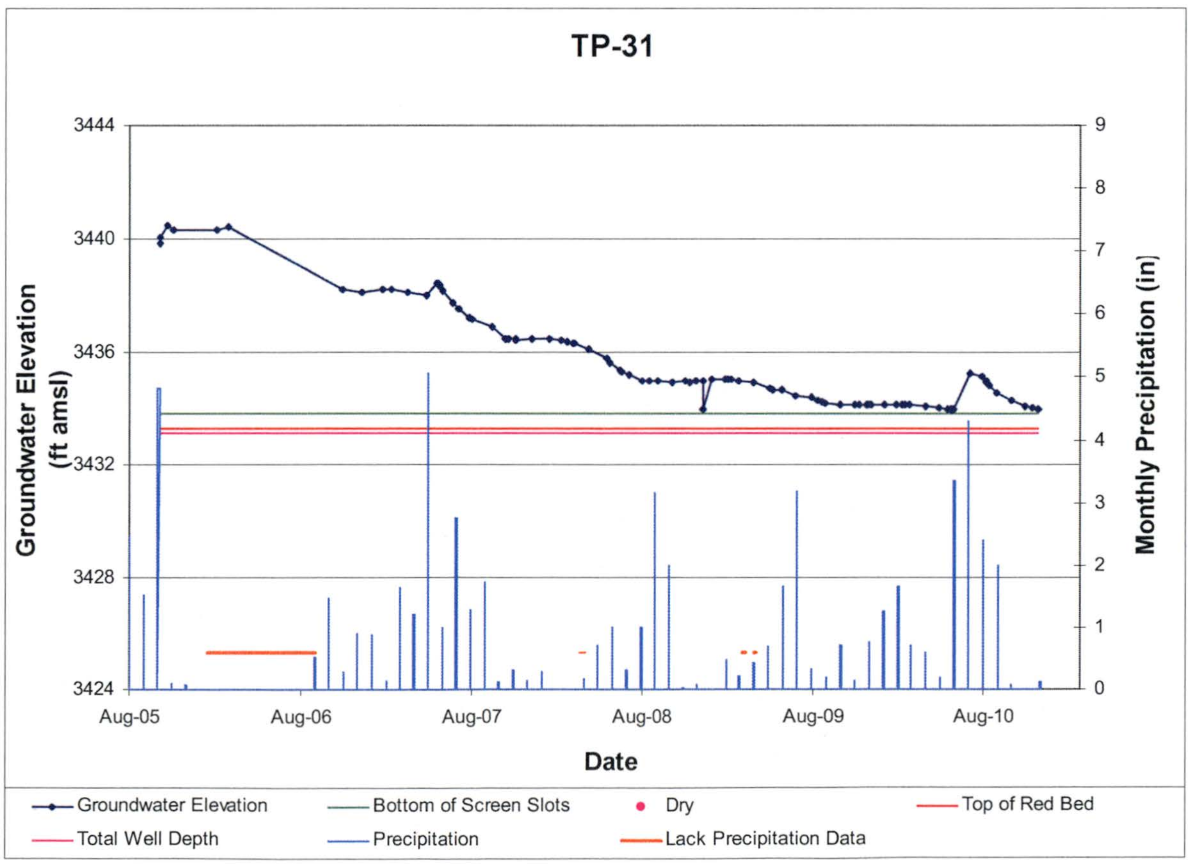

TP-63
Groundwater Elevation (ft amsl)
3455
3450
3445
3440
3435
3430
Monthly Precipitation (in)
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-117
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3446
3442
3438
3434
3430
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

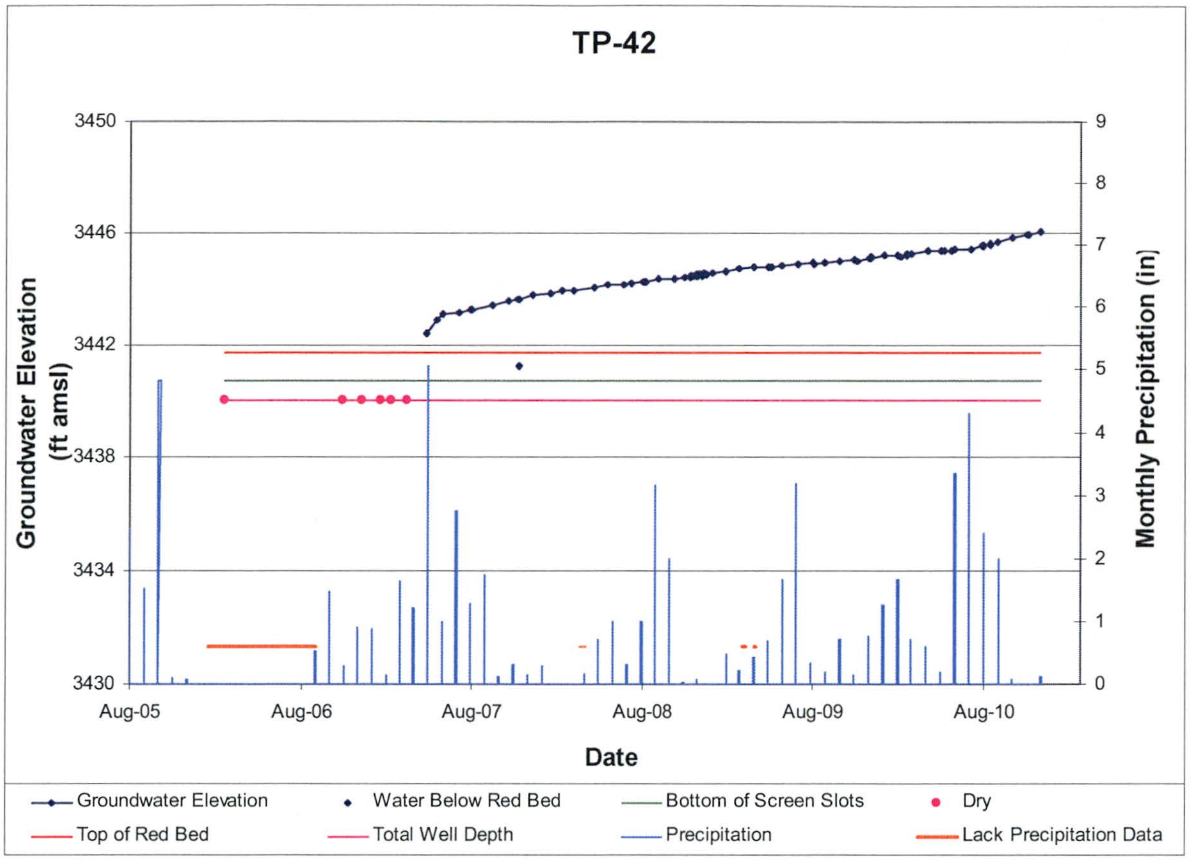

A-16
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3415
3410
3405
3400
9
8
7
6
5
4
3
2
1
0
Apr-99
Apr-01
Apr-03
Apr-05
Apr-07
Apr-09
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

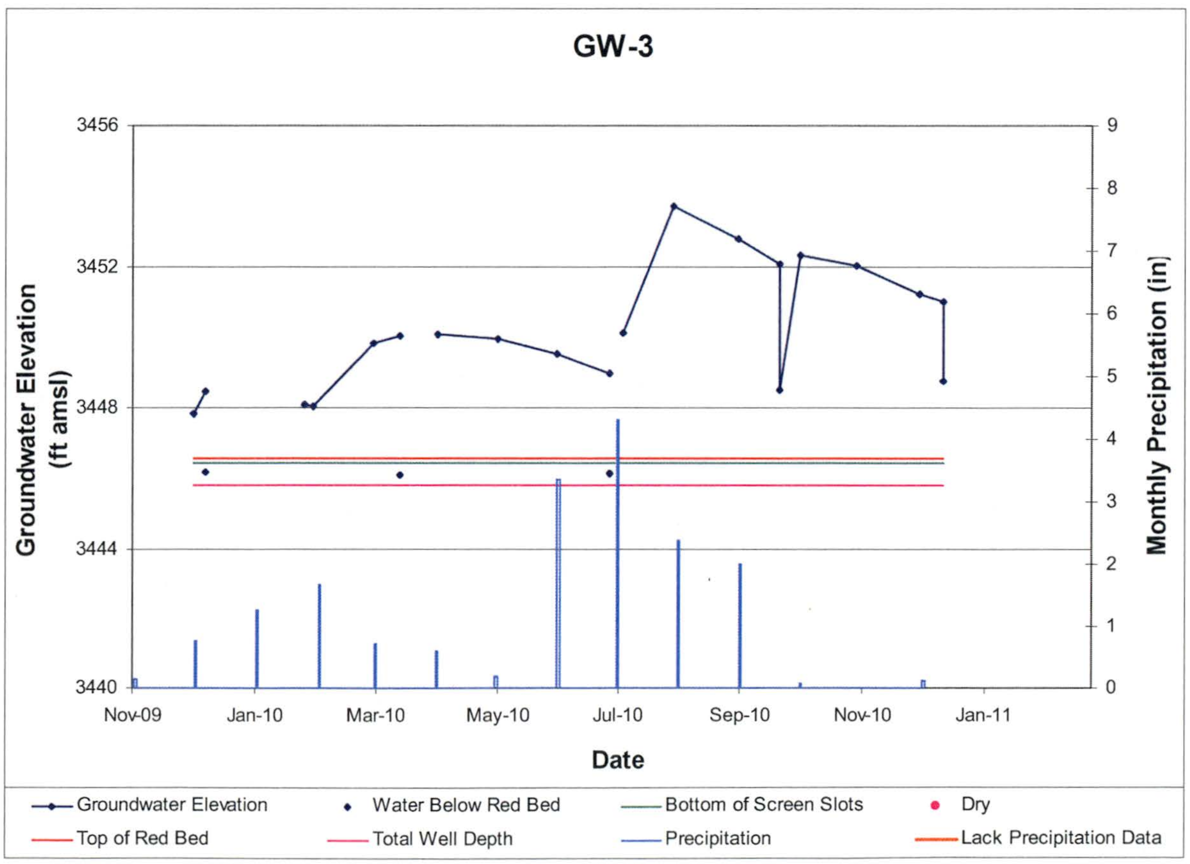


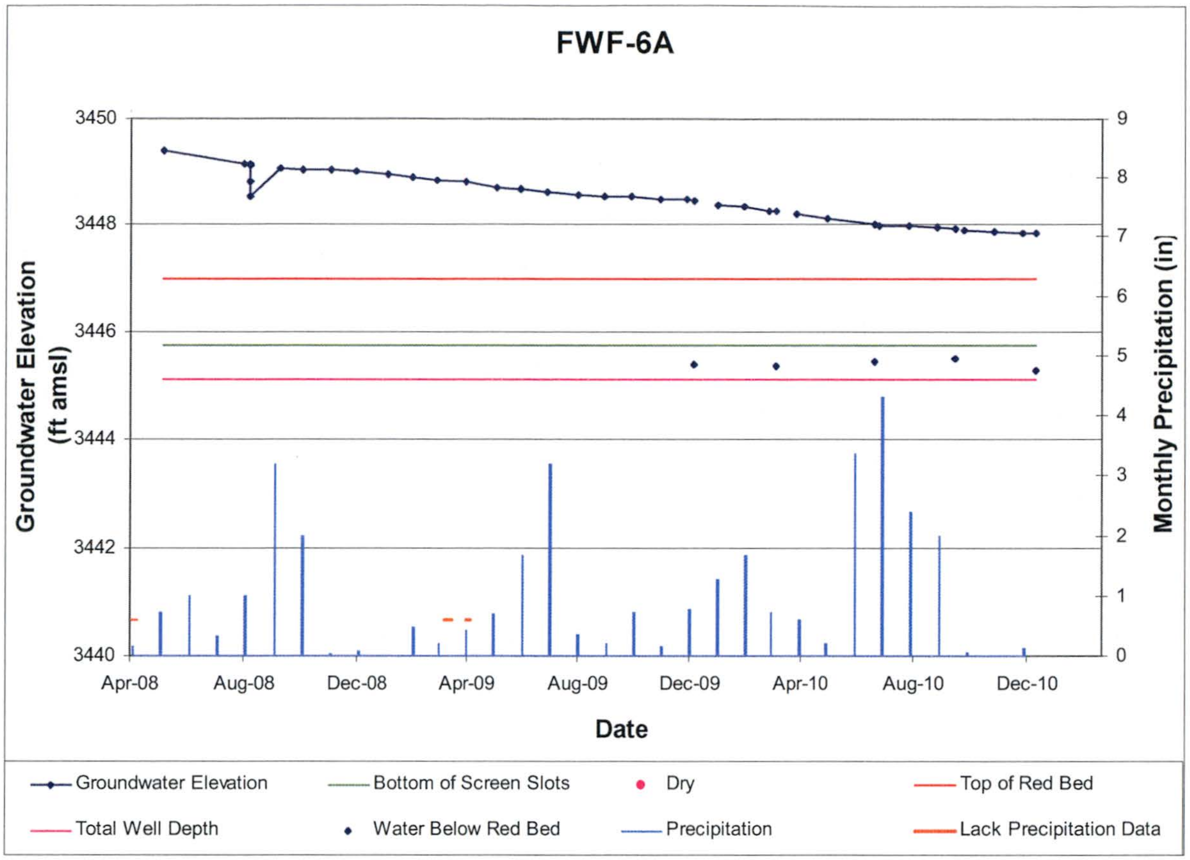
TP-46
3412
3408
3404
3400
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

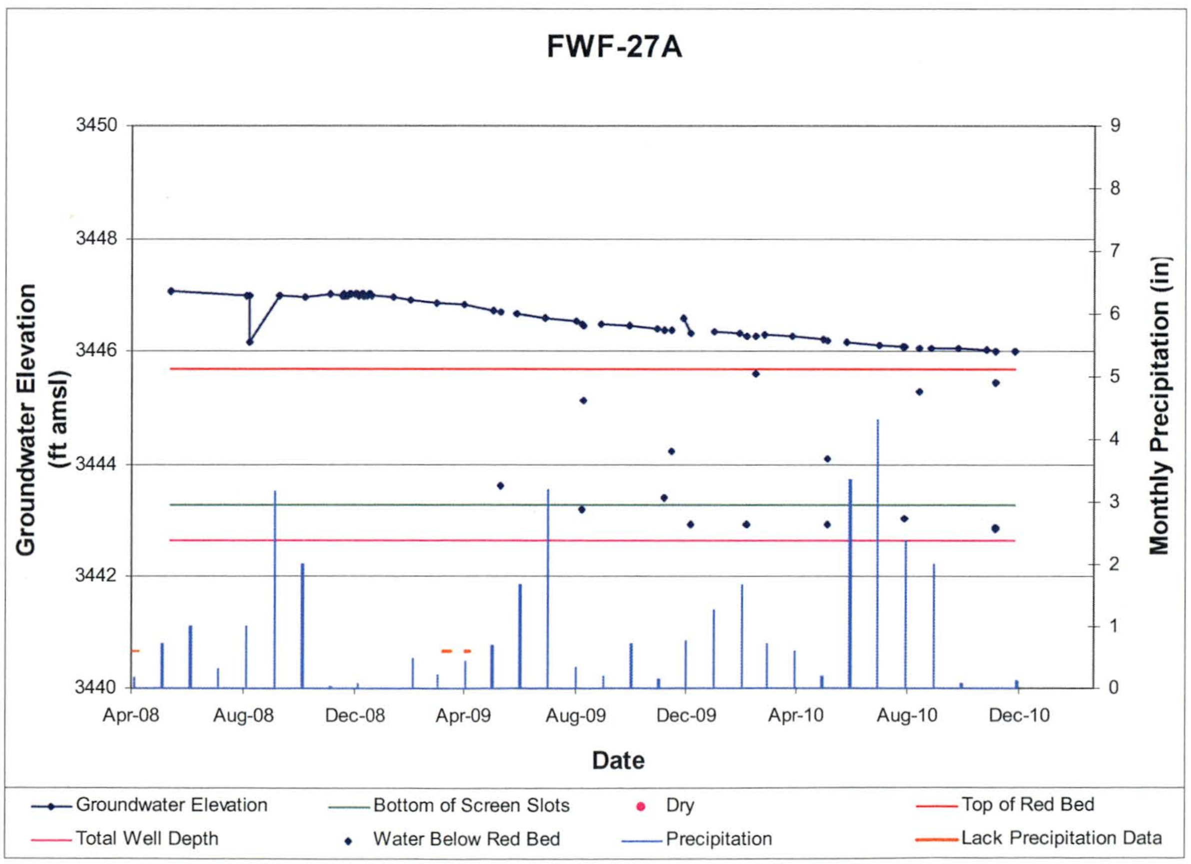


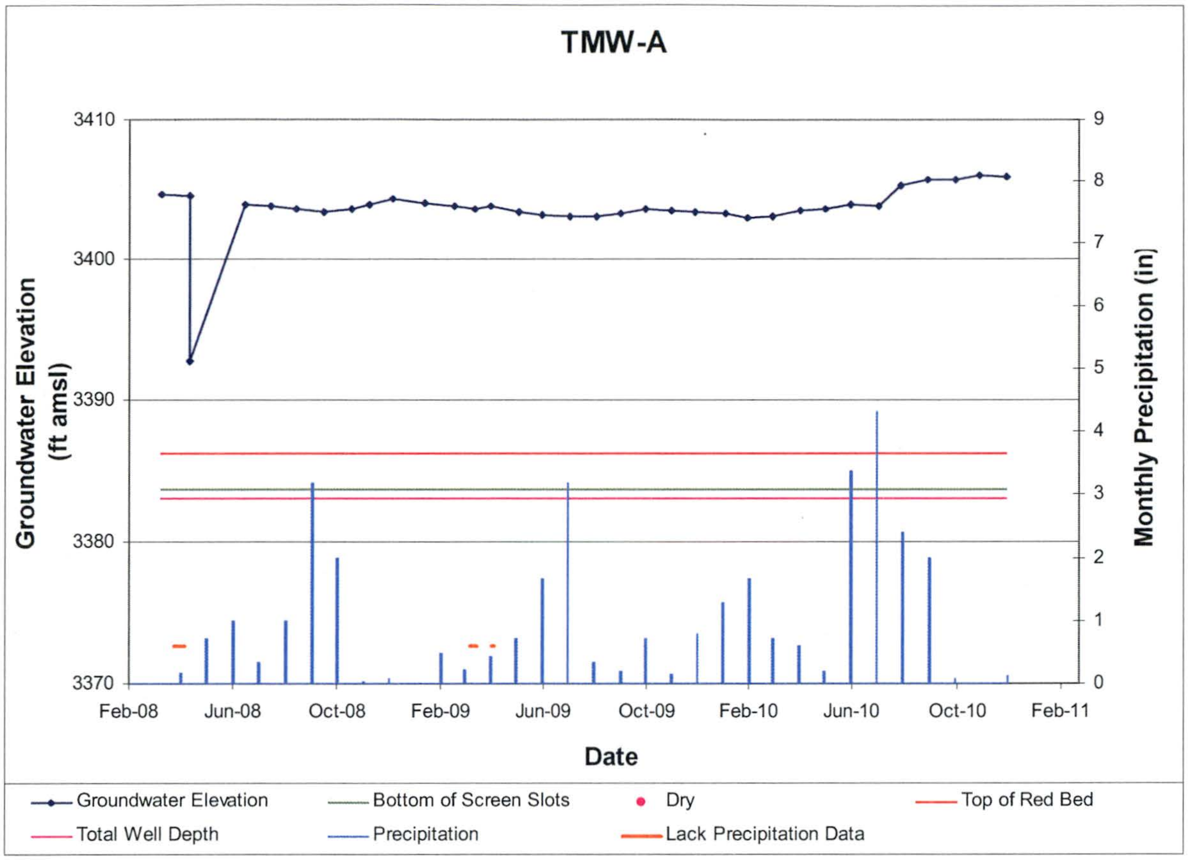
TP-31
3444
3440
3436
3432
3428
3424
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

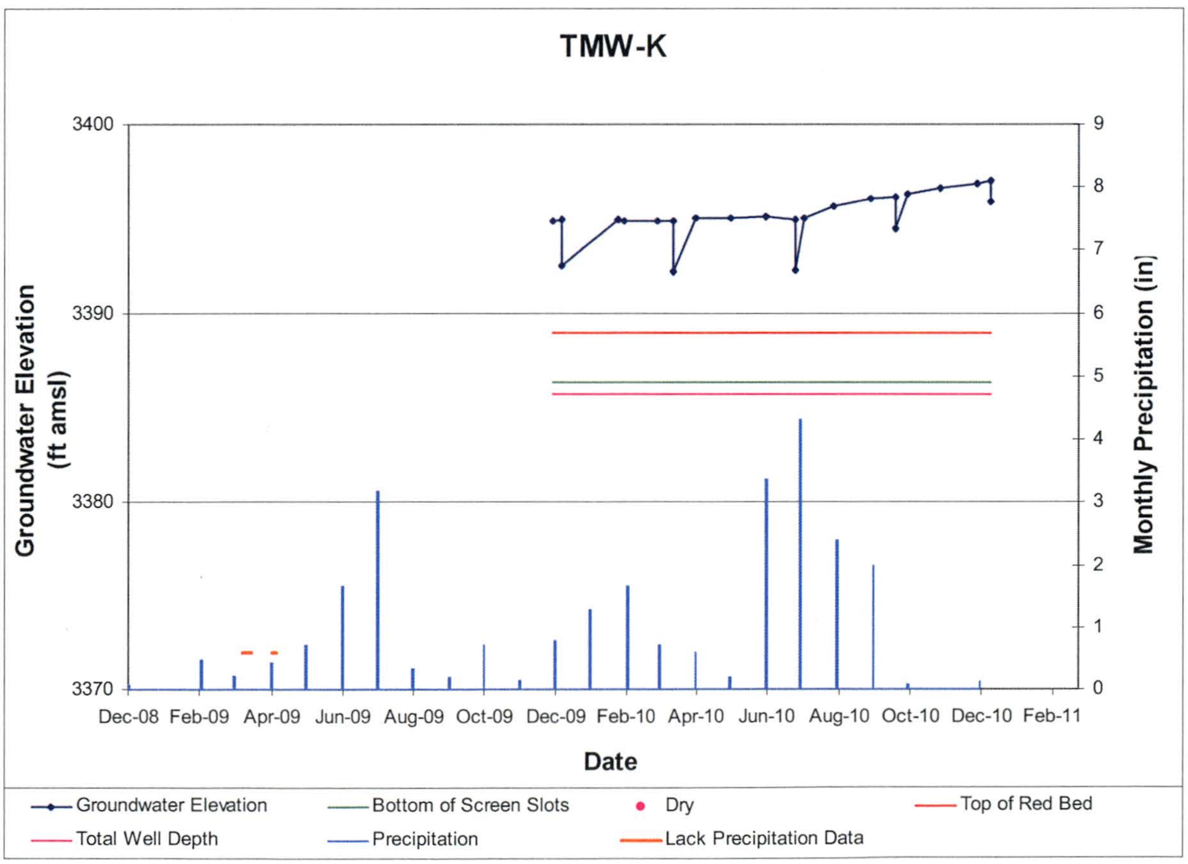

TP-42
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
3450
3446
3442
3438
3434
3430
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

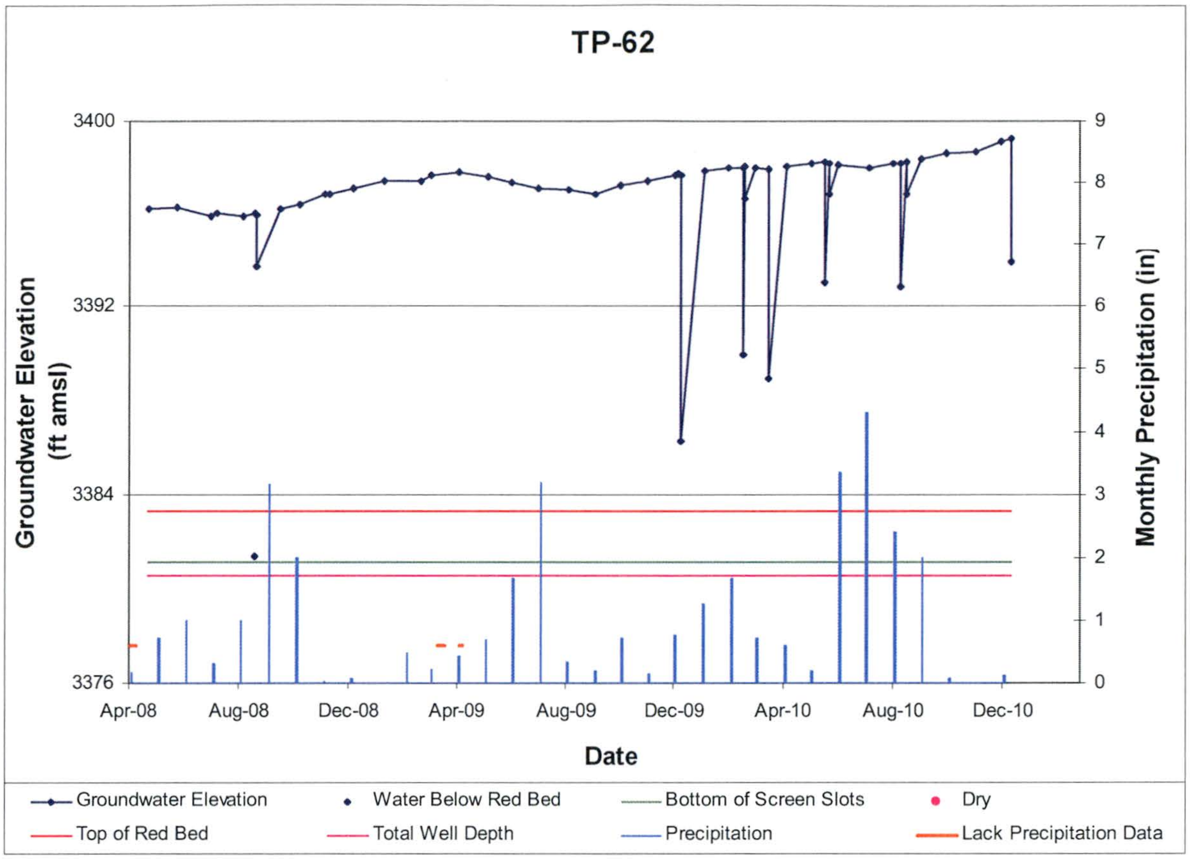

GW-3
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
3456
3452
3448
3444
3440
9
8
7
6
5
4
3
2
1
0
Nov-09
Jan-10
Mar-10
May-10
Jul-10
Sep-10
Nov-10
Jan-11
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

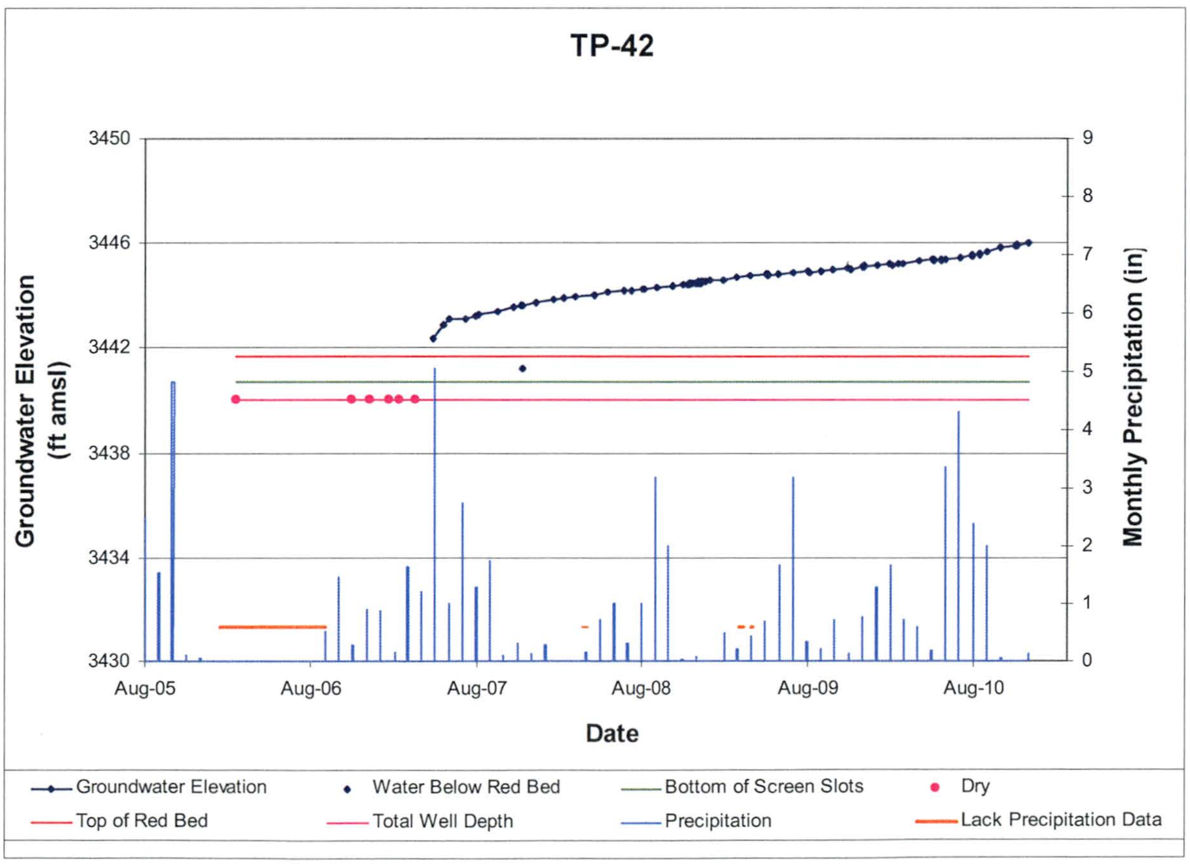

FWF-6A
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3450
3448
3446
3444
3442
3440
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data

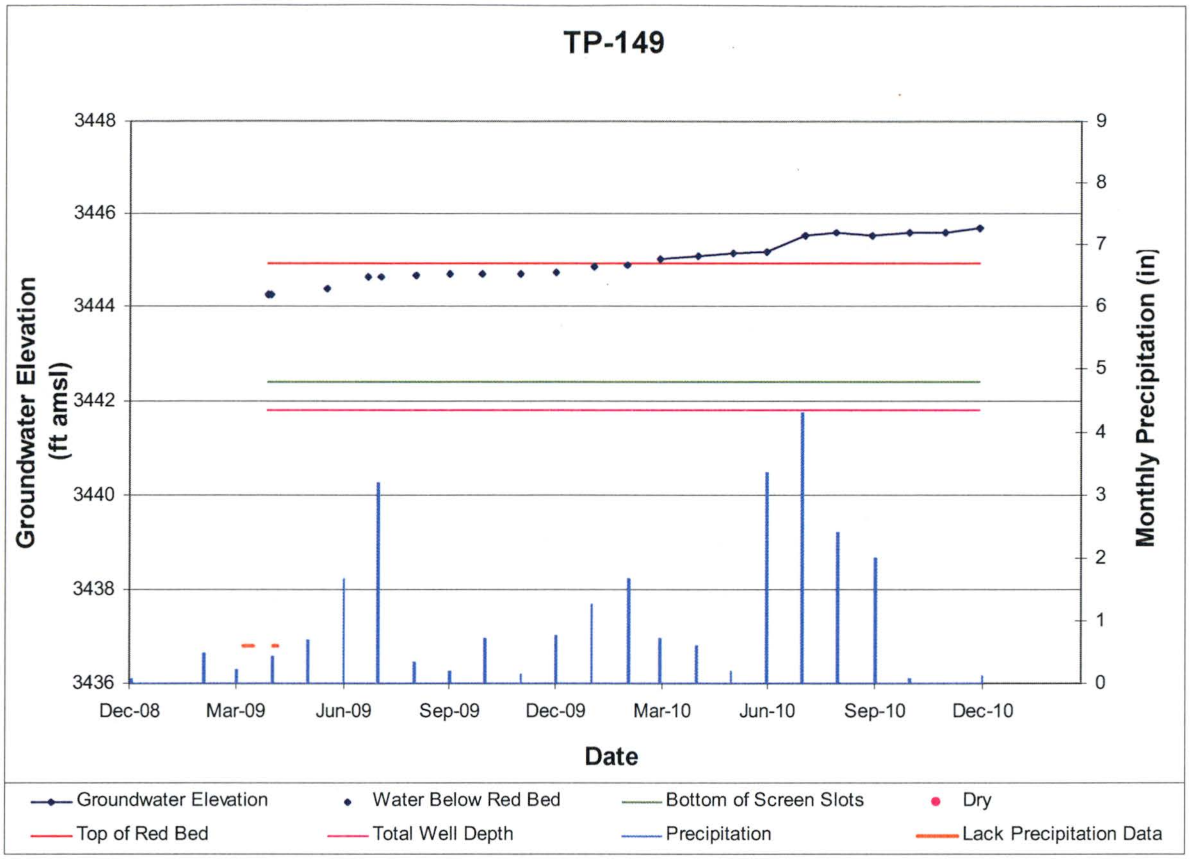

FWF-27A
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3450
3448
3446
3444
3442
3440
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data

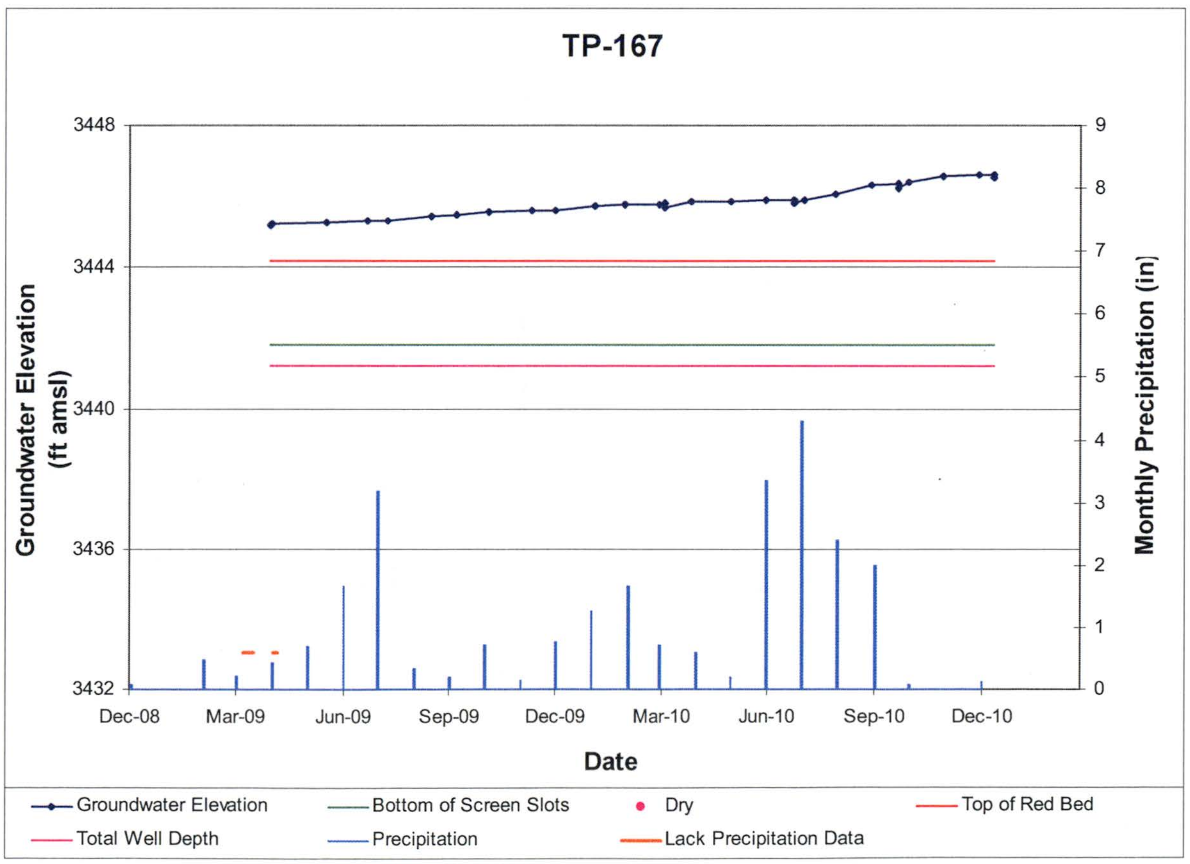

TMW-A
3410
3400
3390
3380
3370
Groundwater Elevation (ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Feb-08
Jun-08
Oct-08
Feb-09
Jun-09
Oct-09
Feb-10
Jun-10
Oct-10
Feb-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

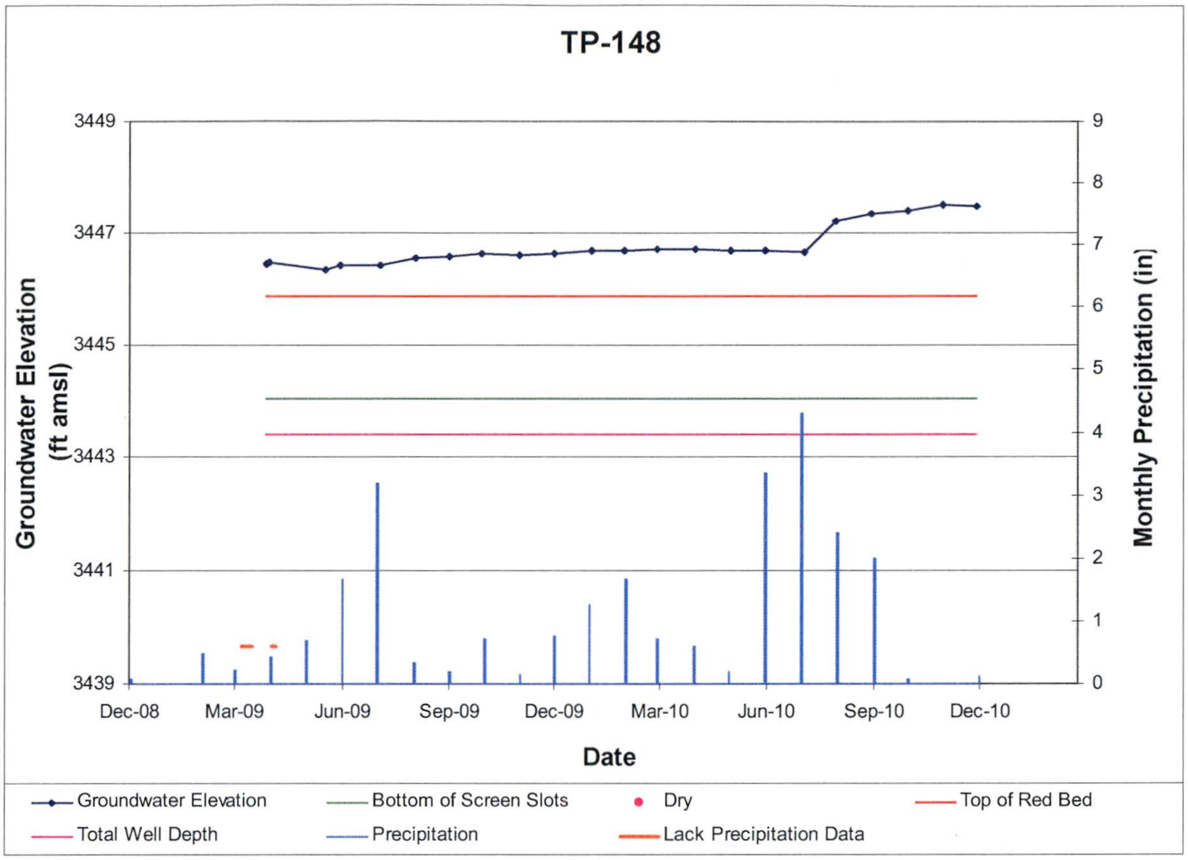

TMW-K
3400
3390
3380
3370
Groundwater Elevation (ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Dec-08
Feb-09
Apr-09
Jun-09
Aug-09
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
Feb-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

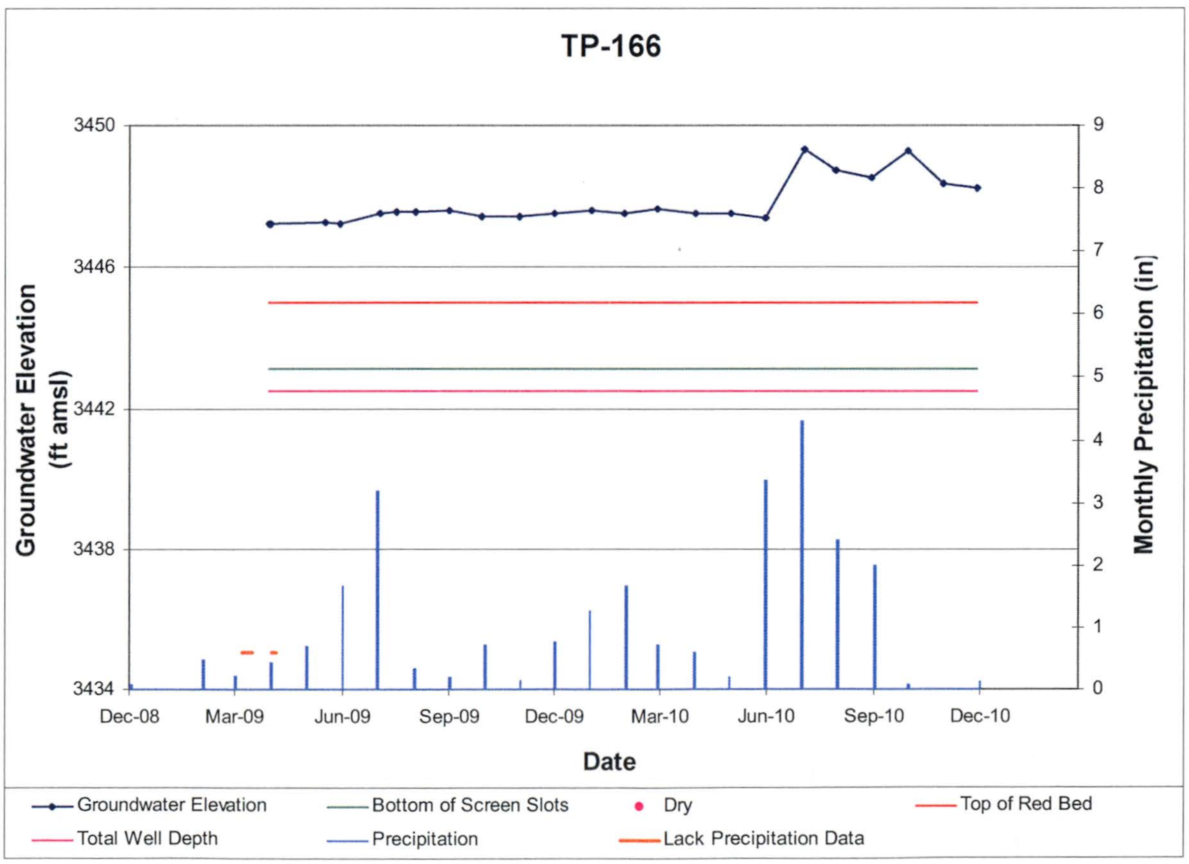

TP-62
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3400
3392
3384
3376
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

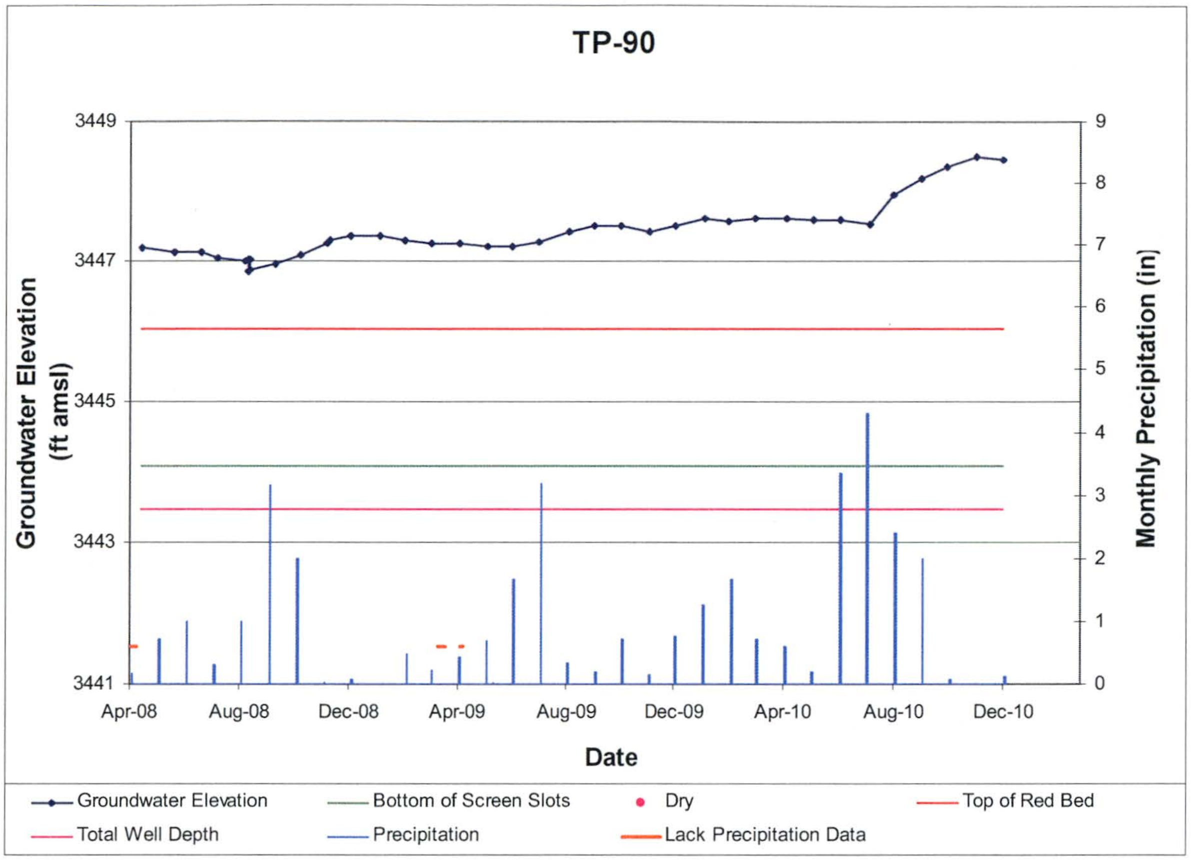

TP-42
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3450
3446
3442
3438
3434
3430
9
8
7
6
5
4
3
2
1
0
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-149
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3448
3446
3444
3442
3440
3438
3436
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

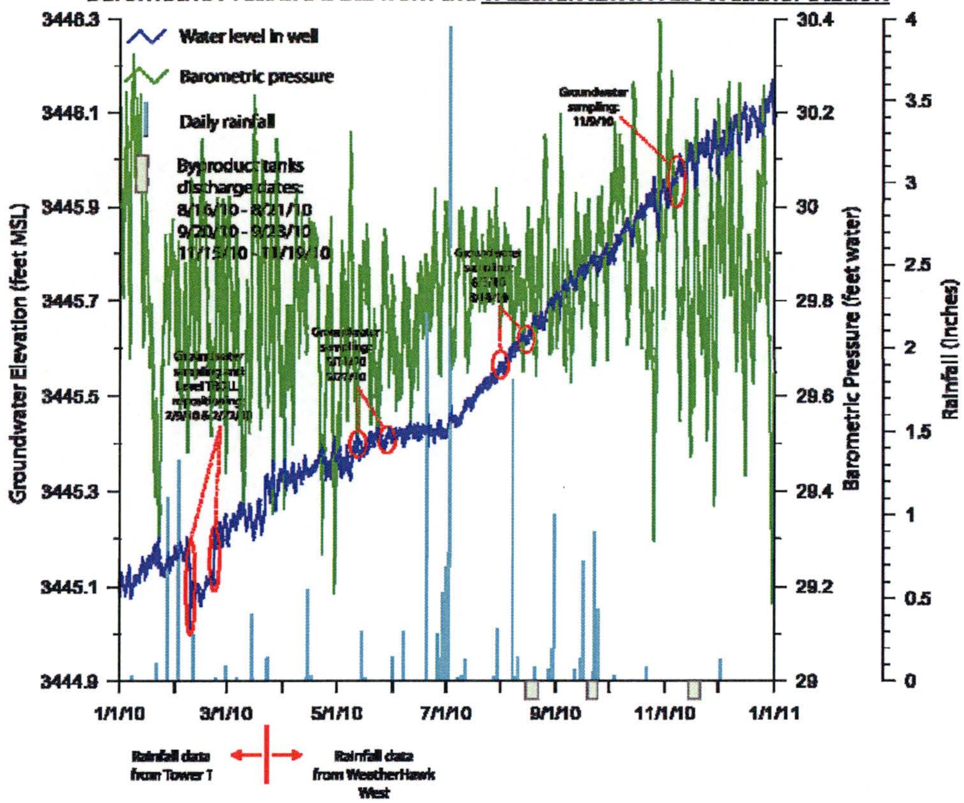

TP-167
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3448
3444
3440
3436
3432
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-148
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3449
3447
3445
3443
3441
3439
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

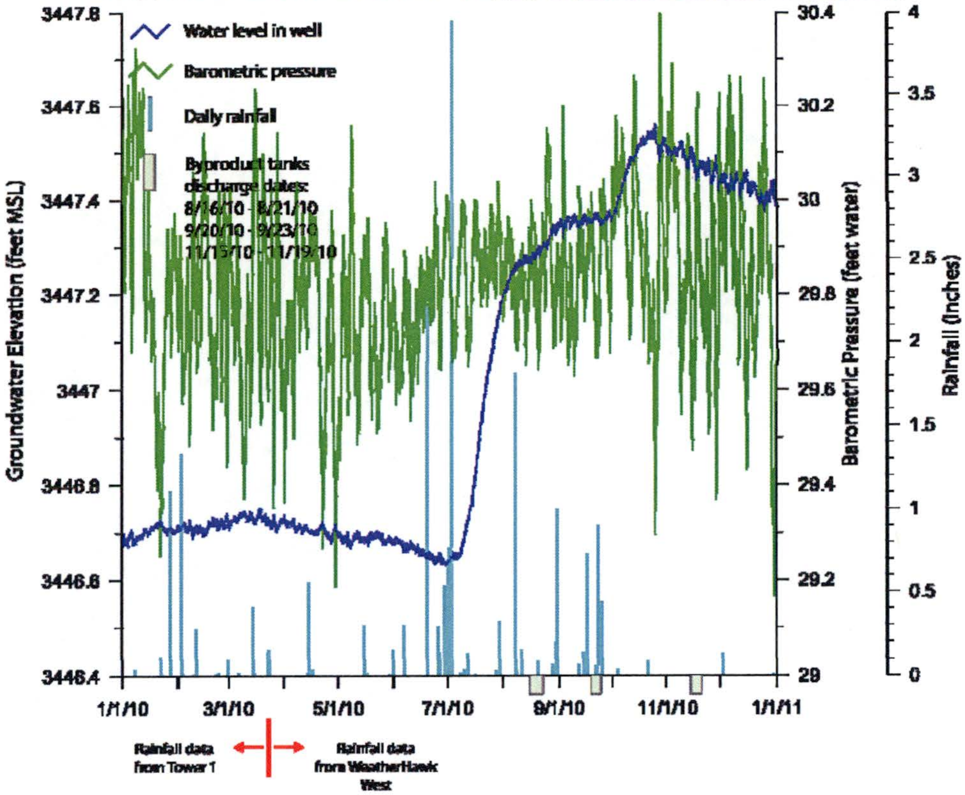

TP-166
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3450
3446
3442
3438
3434
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-90
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3449
3447
3445
3443
3441
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

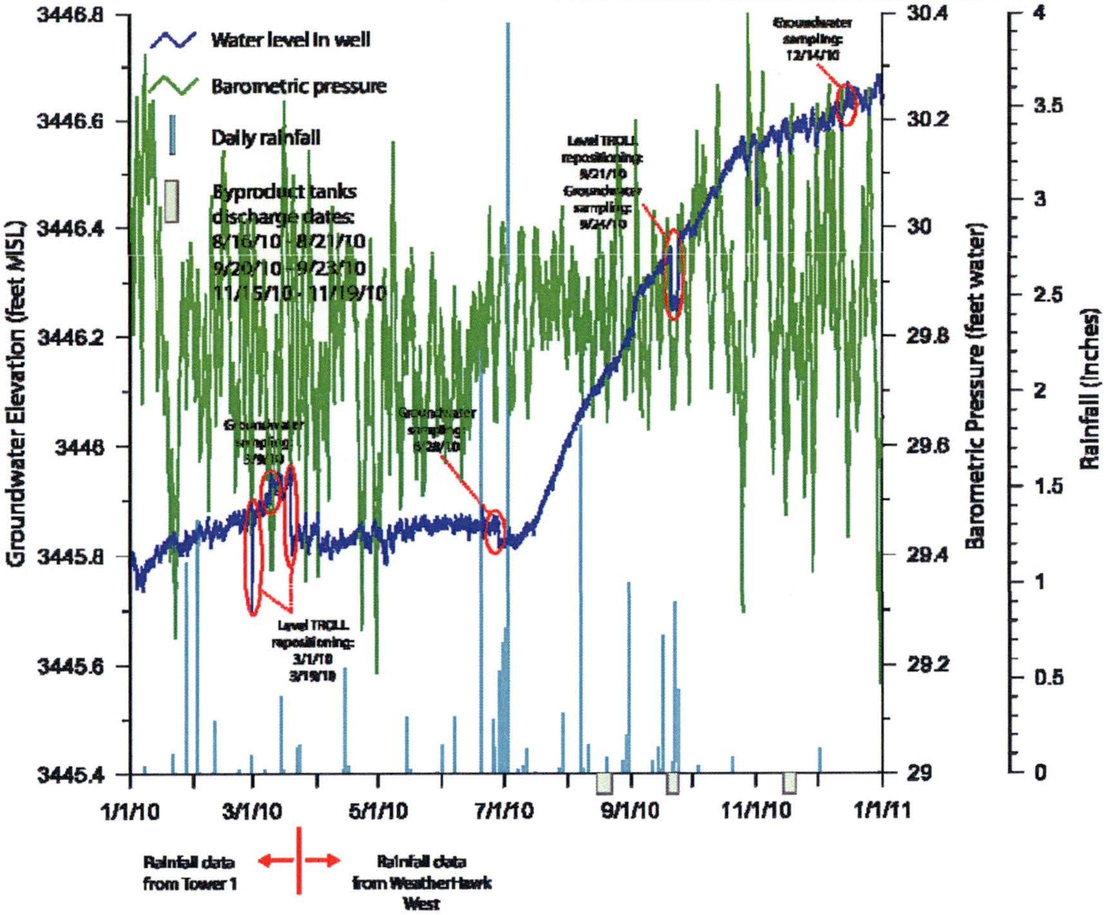
TP-42 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station



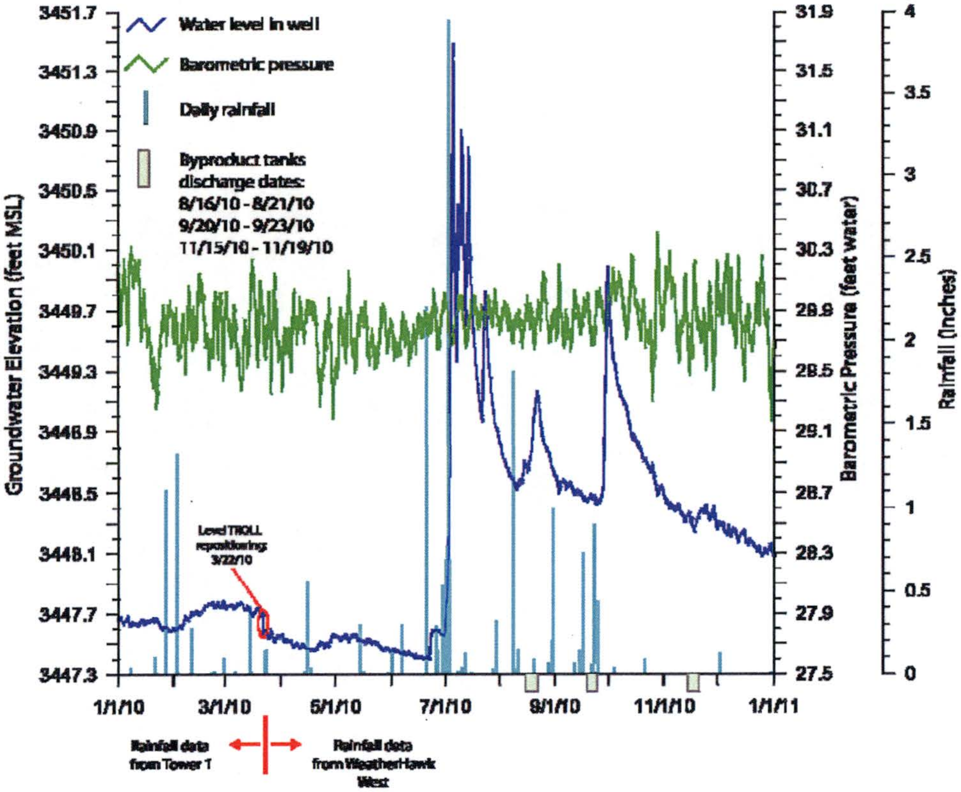
TP-148 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station



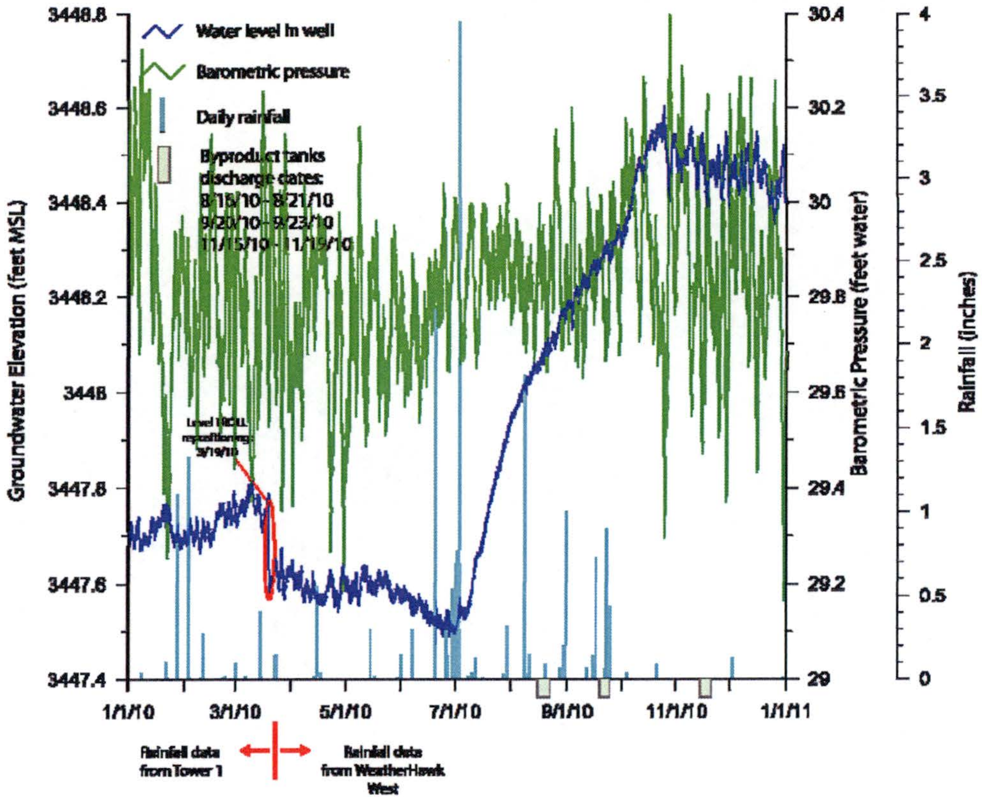
TP-167 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

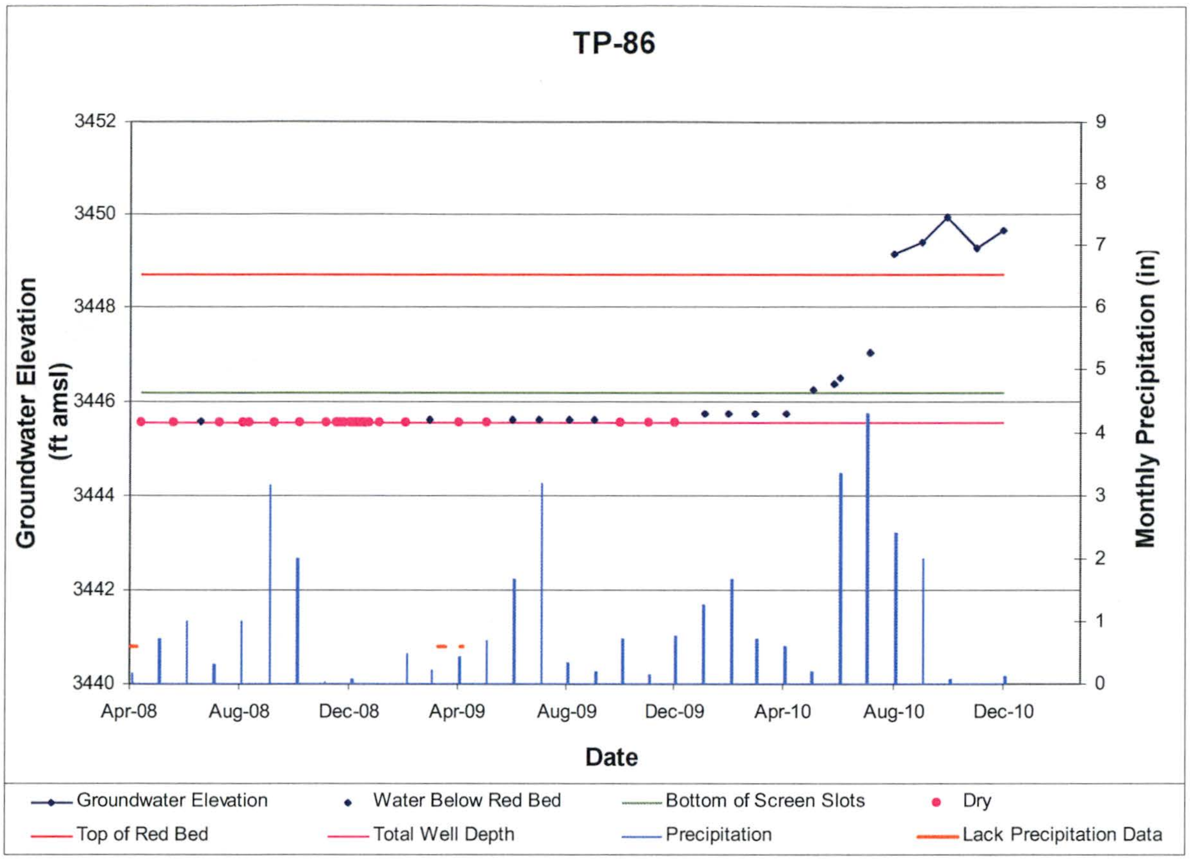


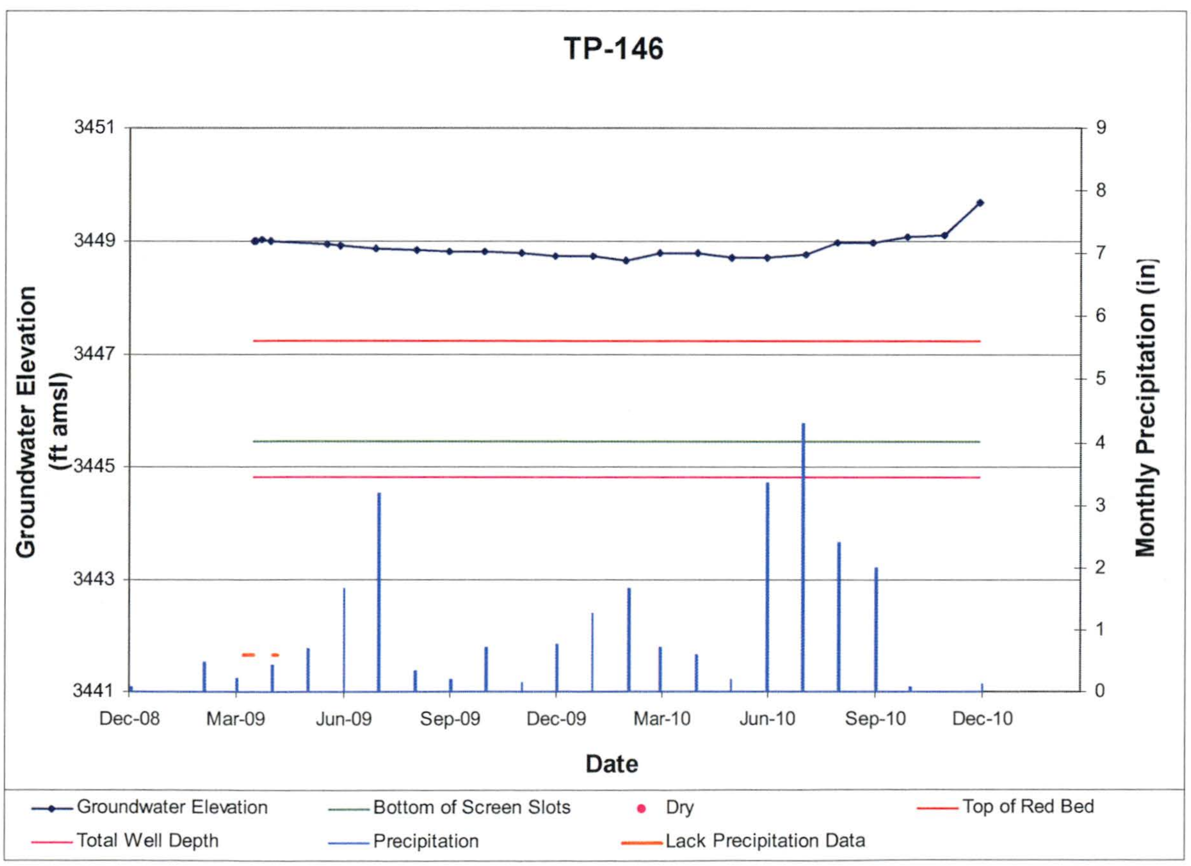
TP-166 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

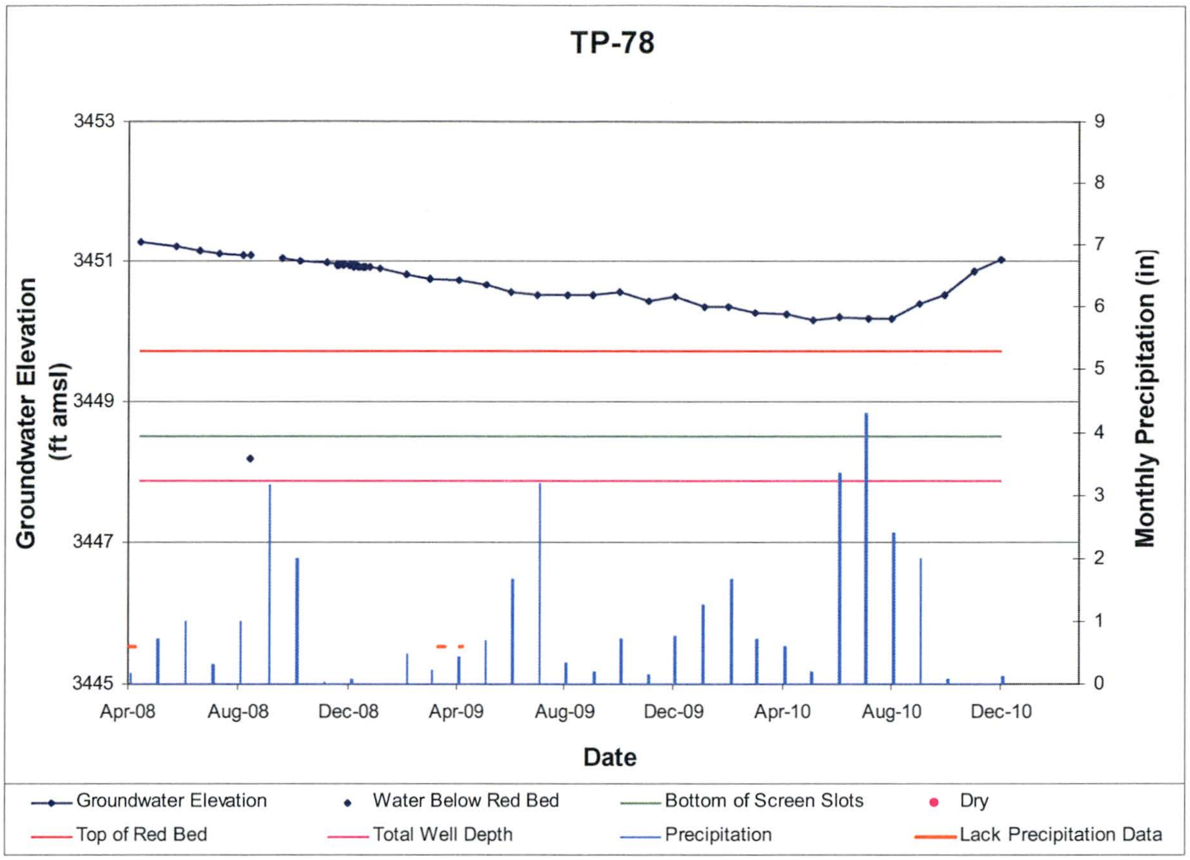


TP-90 Level TROLL Water Level Data with Rainfall and
Barometric Pressure Data from the WeatherHawk West Weather Station

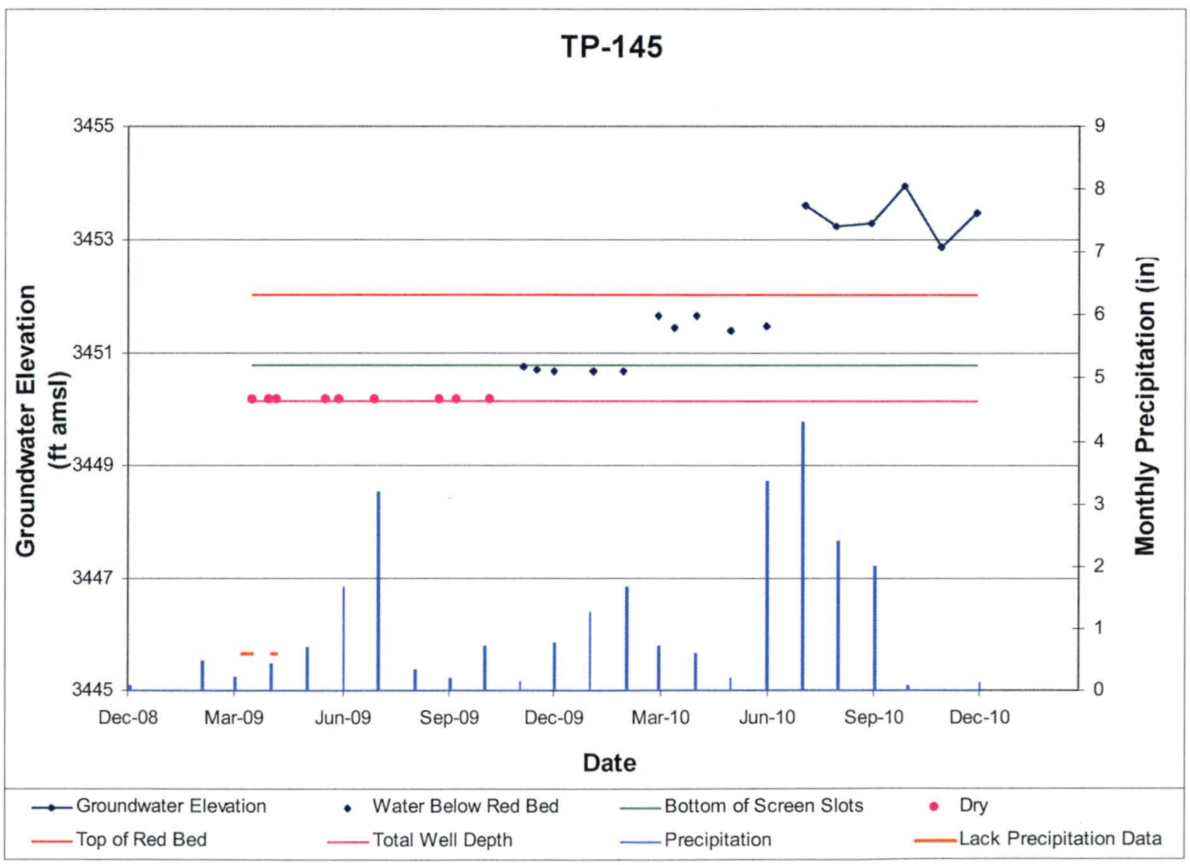



TP-86
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3452
3450
3448
3446
3444
3442
3440
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-146
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3451
3449
3447
3445
3443
3441
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

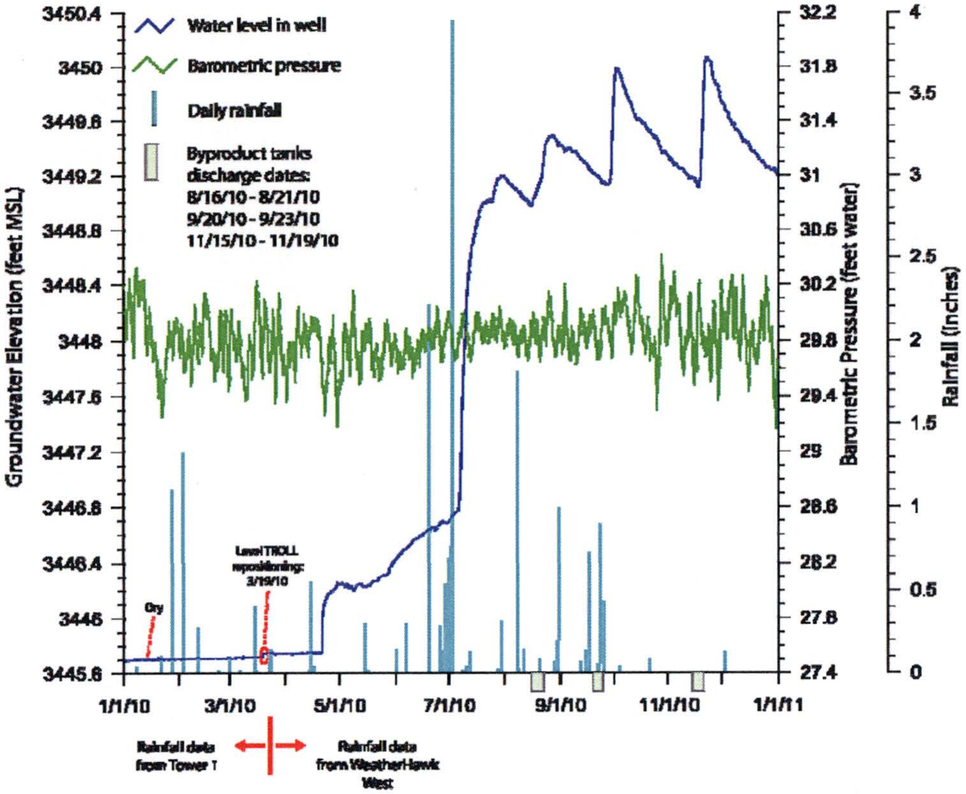


TP-78
3453
3451
3449
3447
3445
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

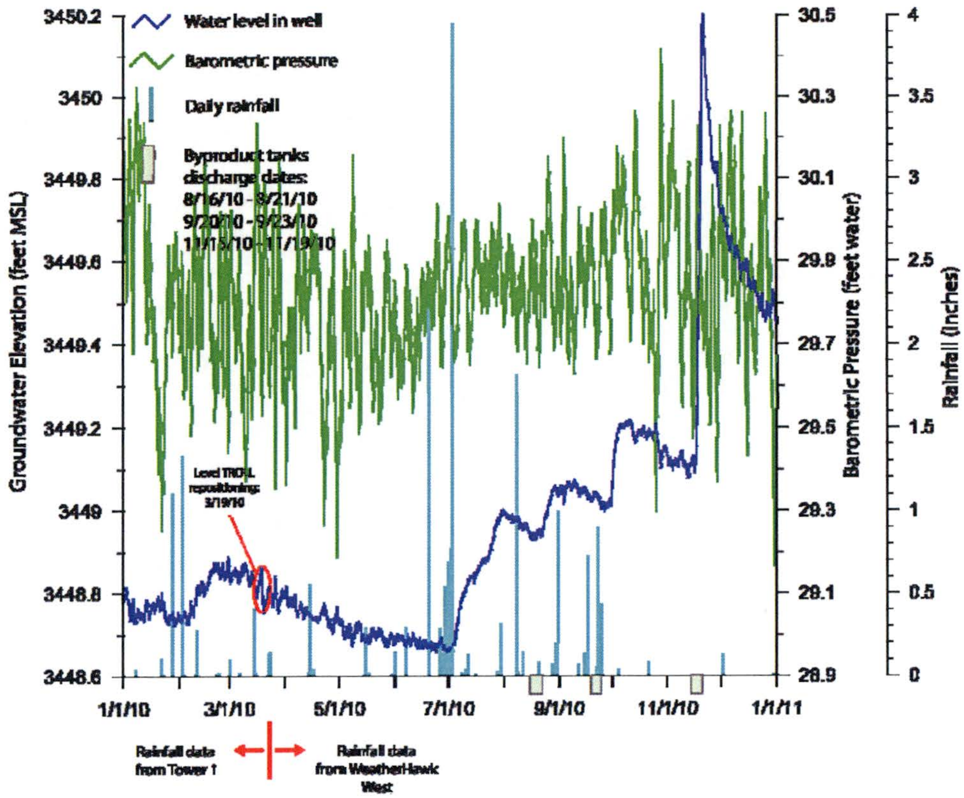


TP-145
3455
3453
3451
3449
3447
3445
9
8
7
6
5
4
3
2
1
0
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

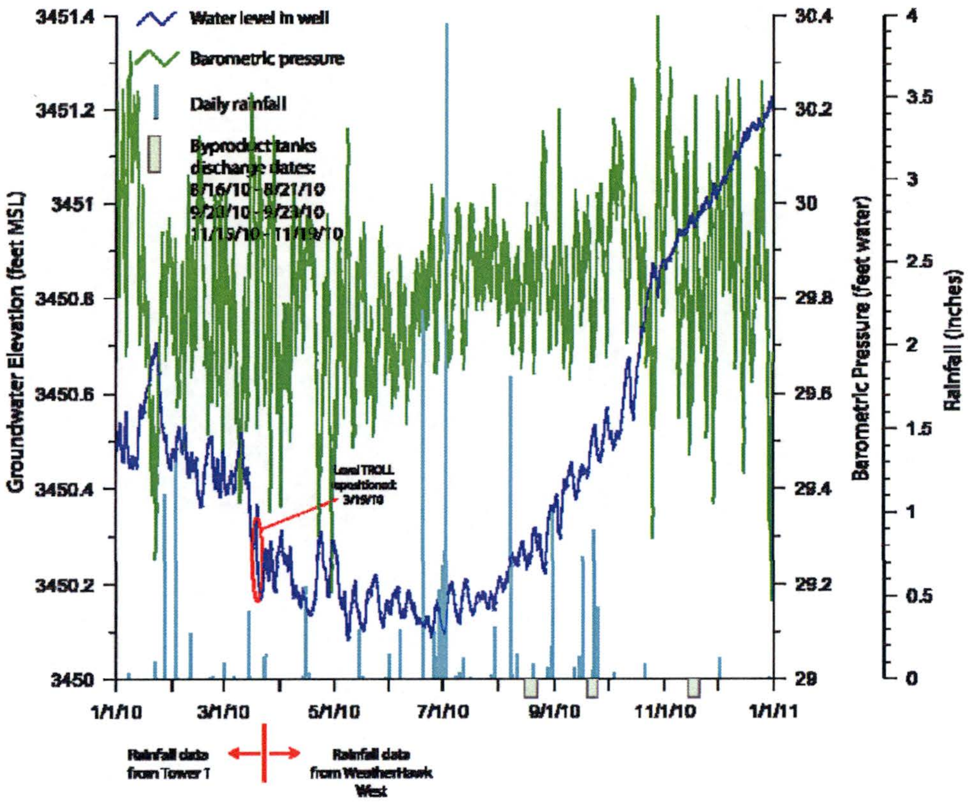
TP-86 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

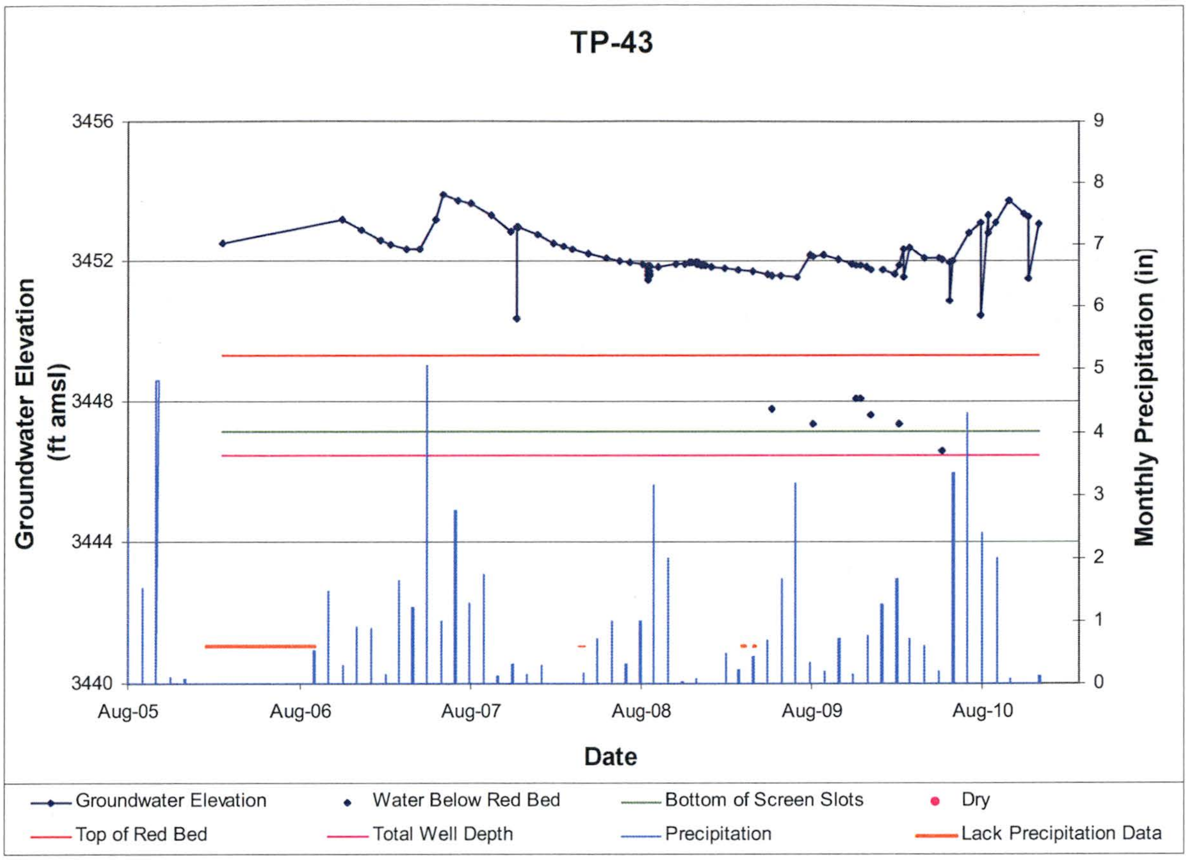


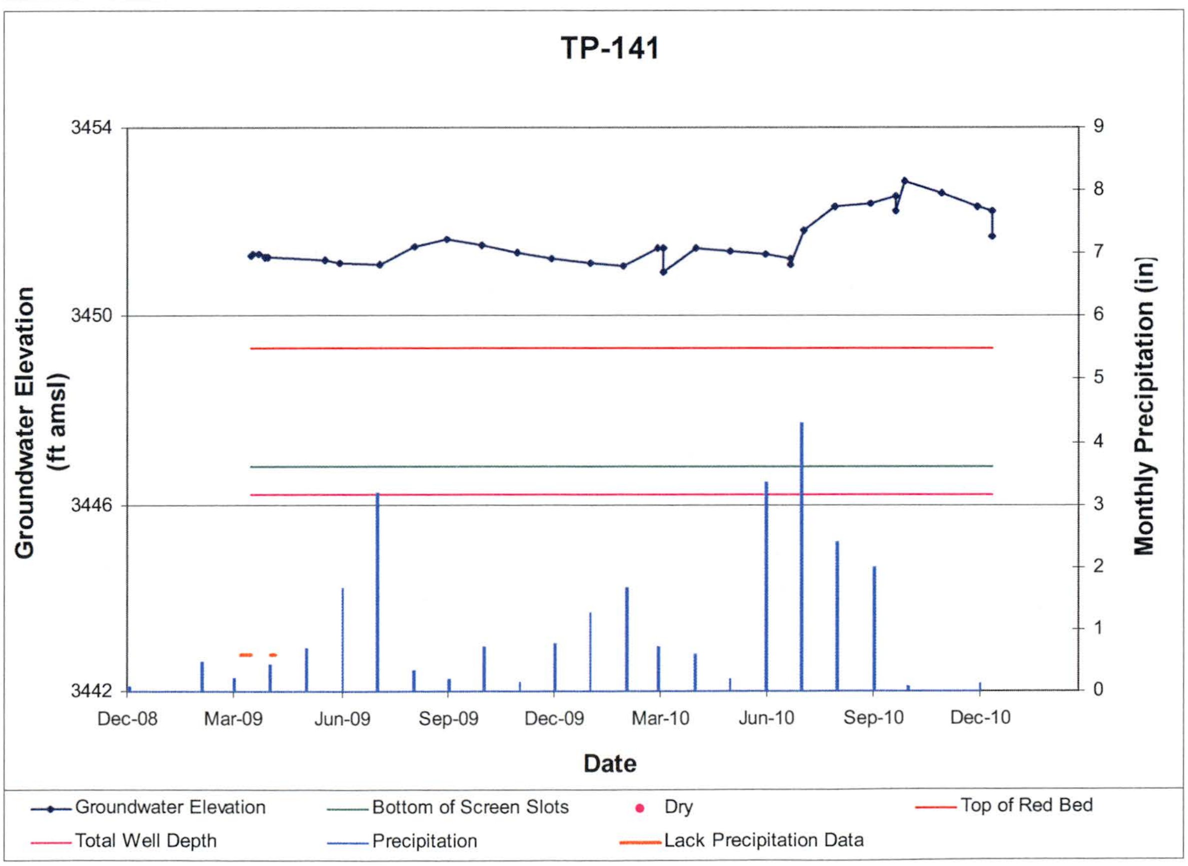
TP-146 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

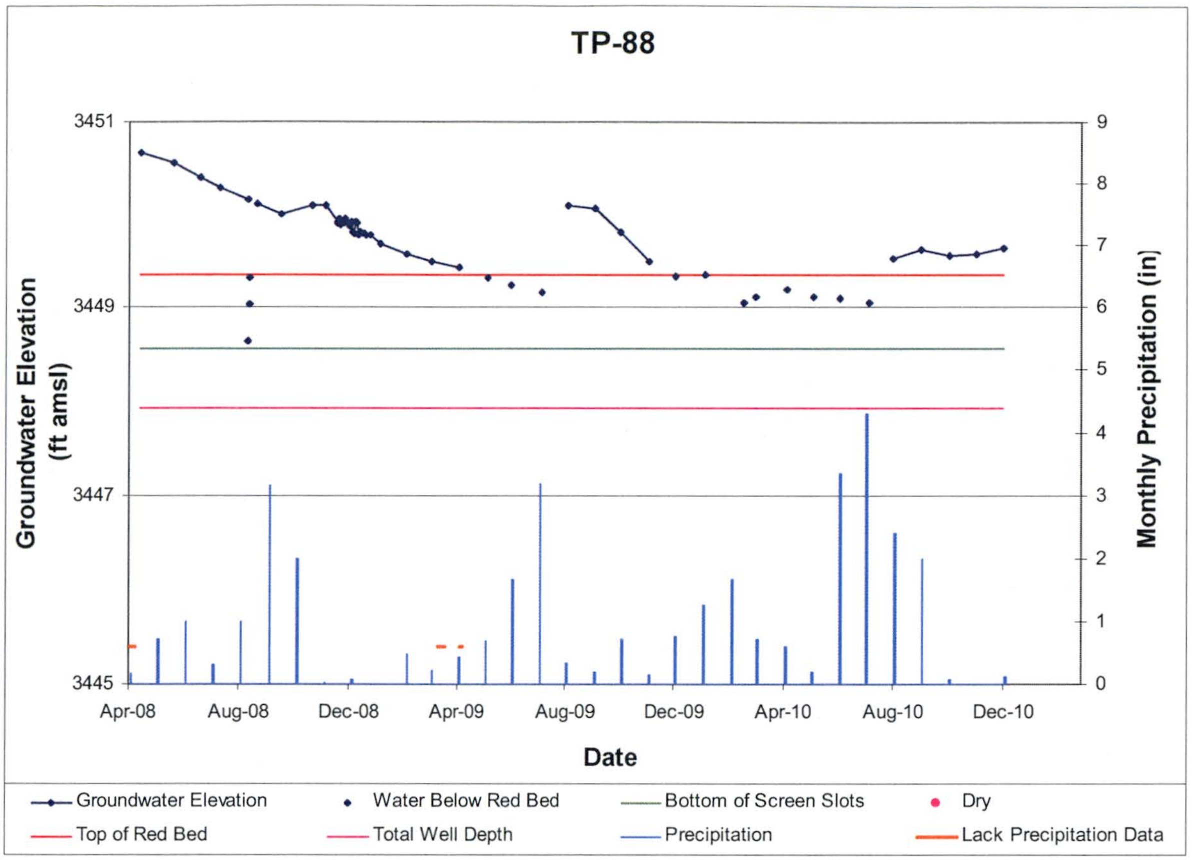


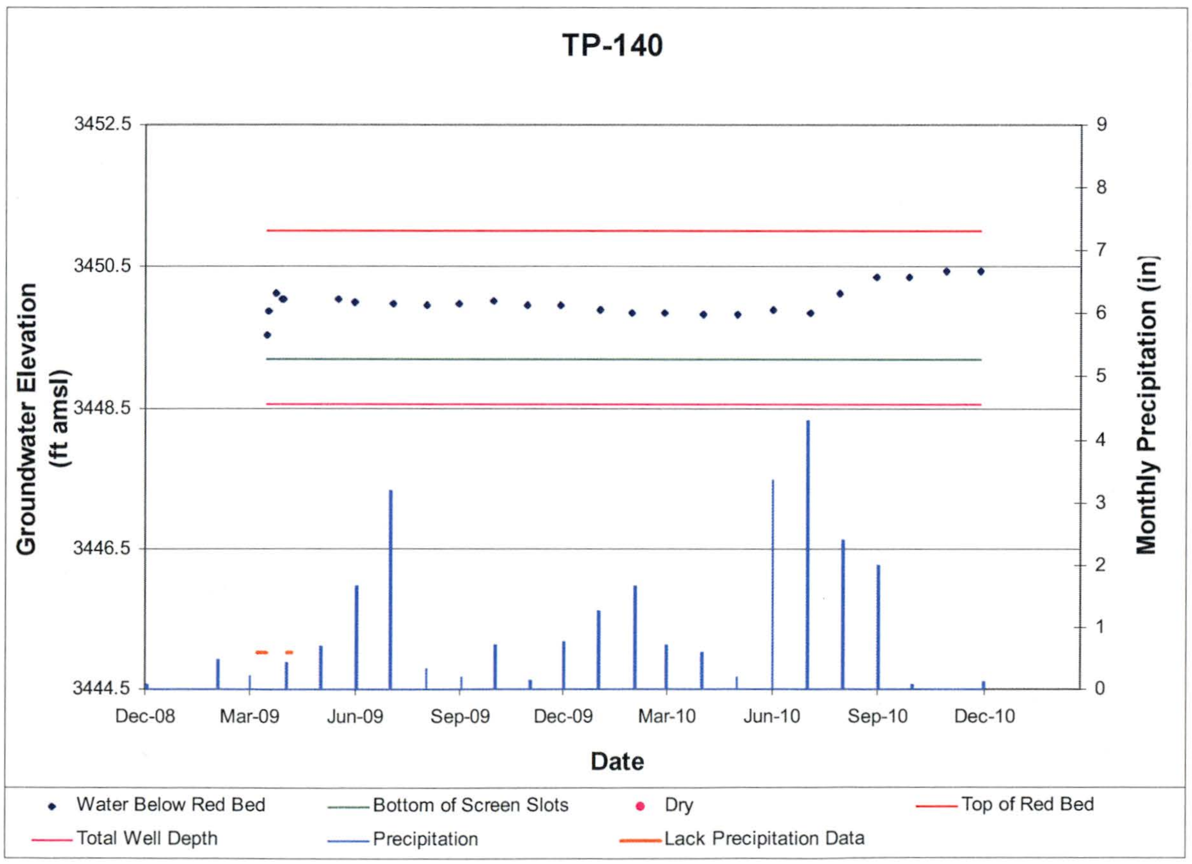
TP-78 Level TROLL Water Level Data with Rainfall and
Barometric Pressure Data from the <u>WeatherHawk West Weather Station</u>

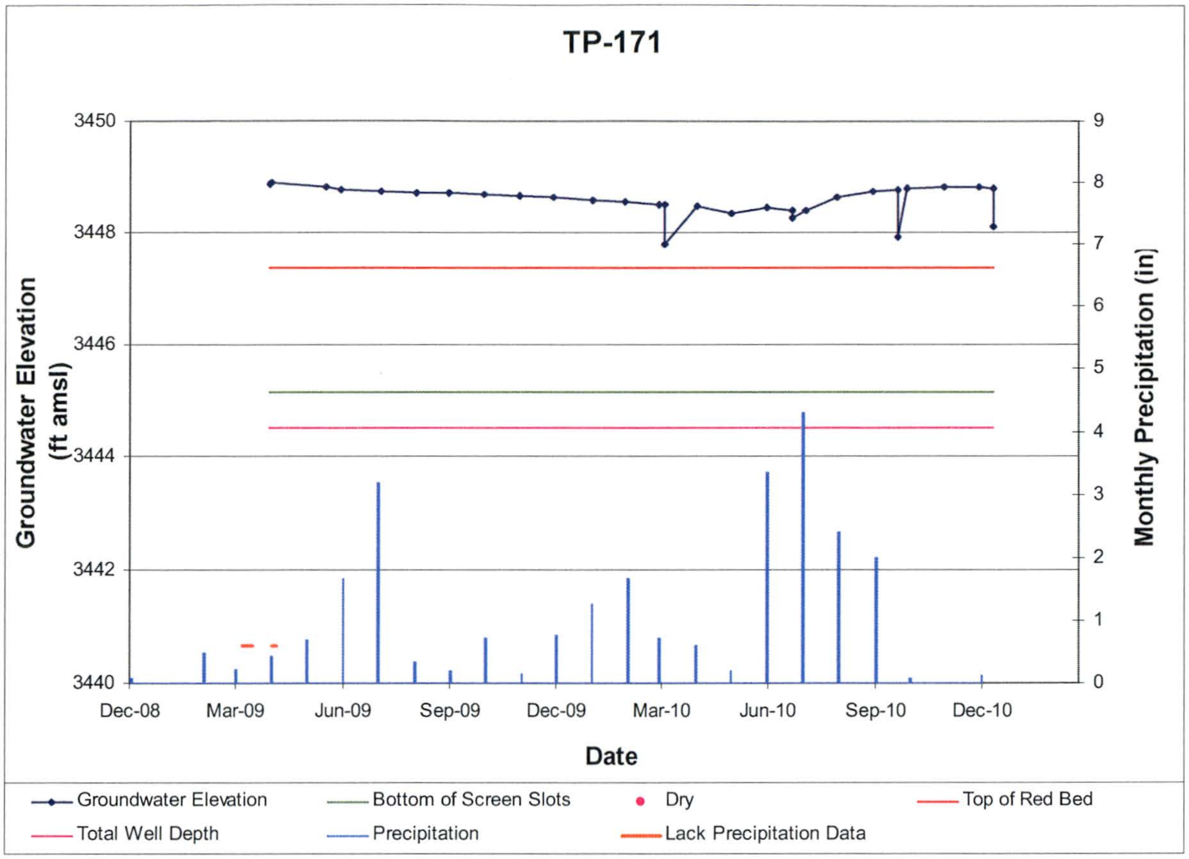


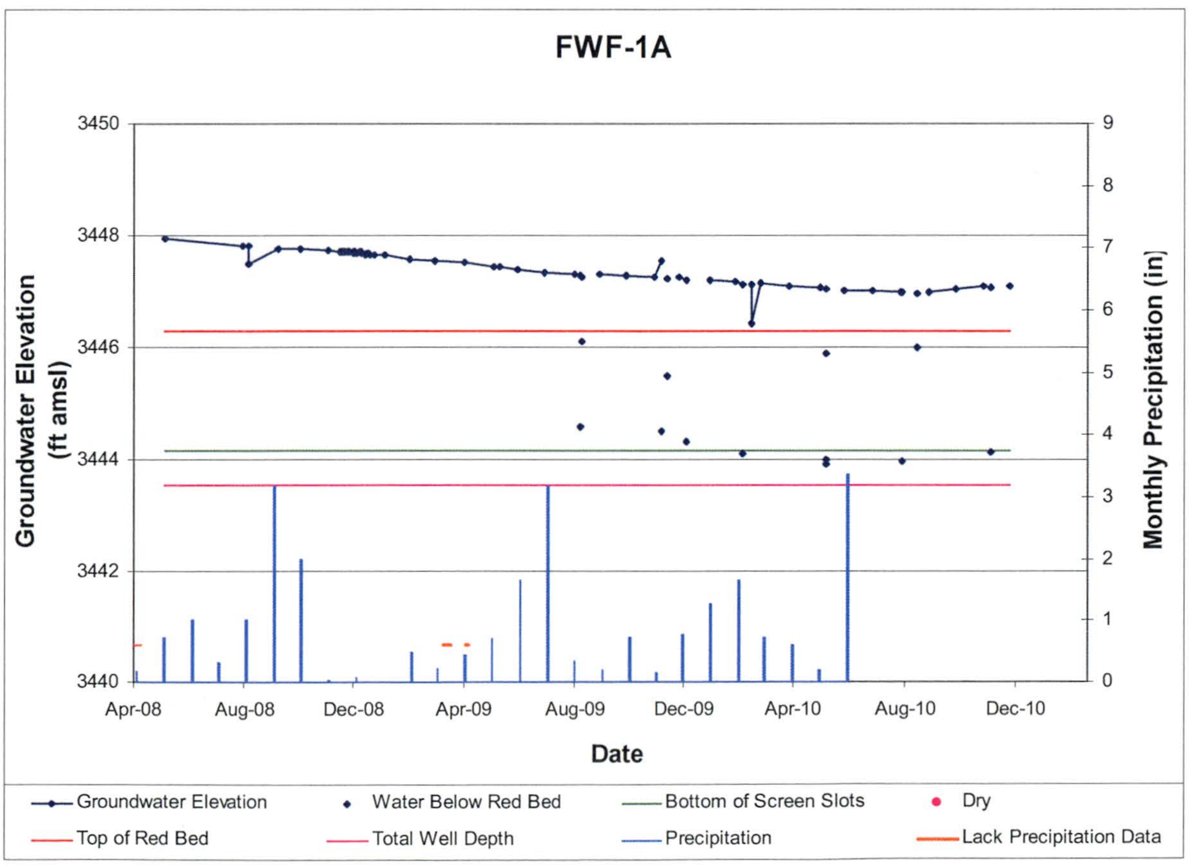

TP-43
3456
3452
3448
3444
3440
Groundwater Elevation (ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-141
3454
3450
3446
3442
Groundwater Elevation (ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

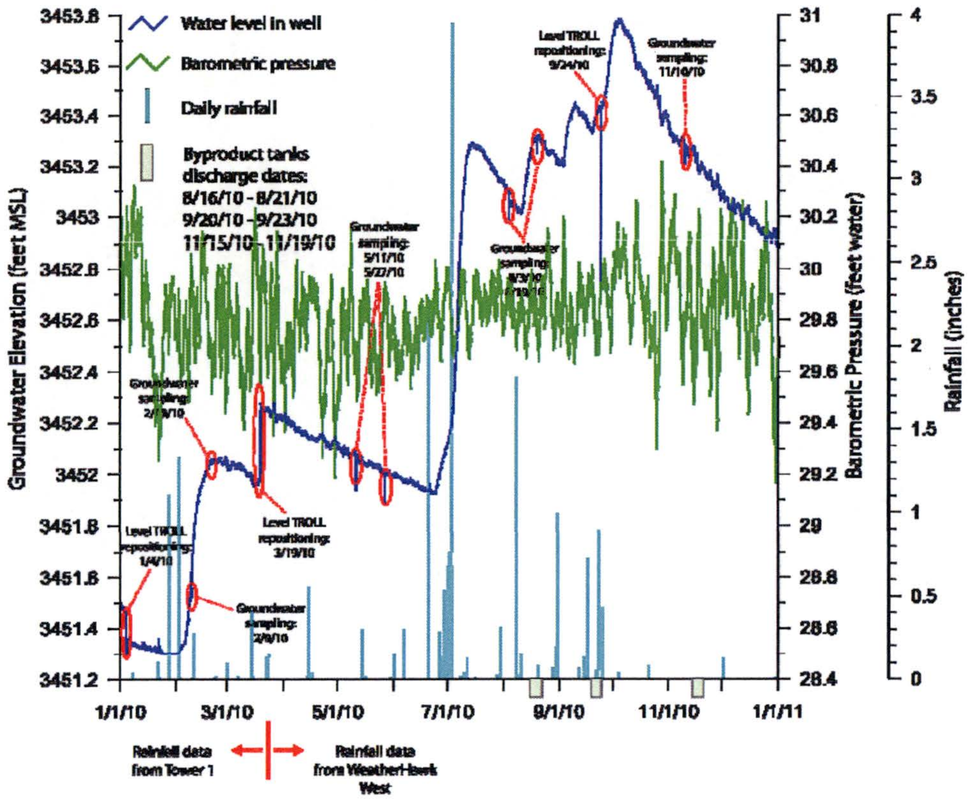

TP-88
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3451
3449
3447
3445
9
8
7
6
5
4
3
2
1
0
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TP-140
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3452.5
3450.5
3448.5
3446.5
3444.5
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

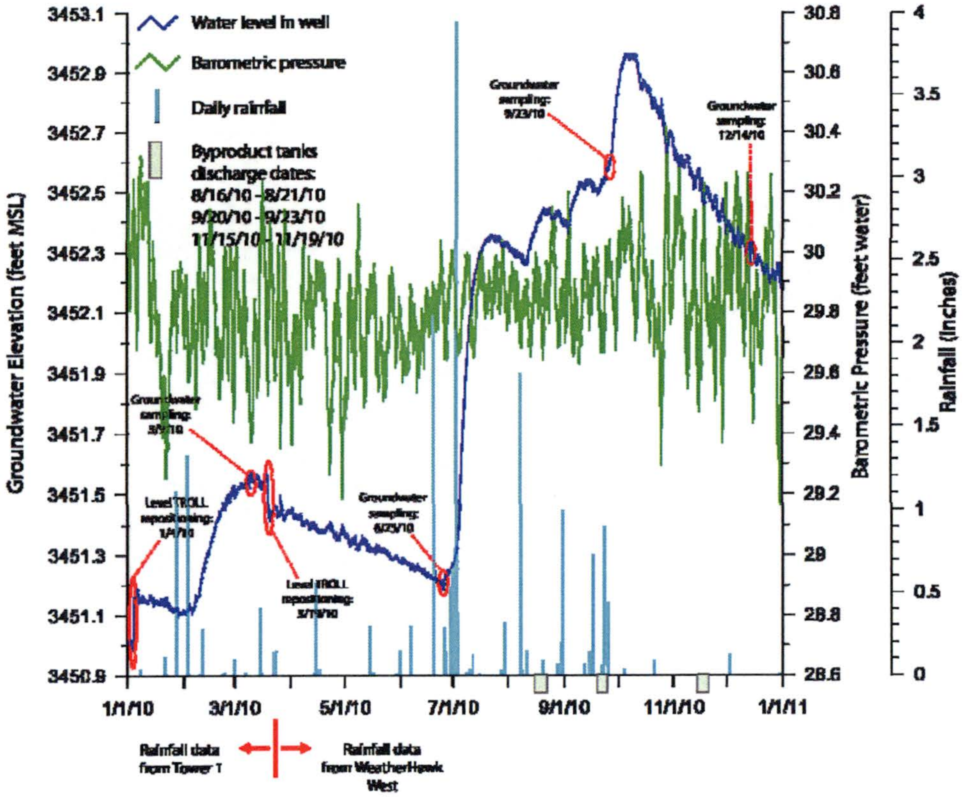

TP-171
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

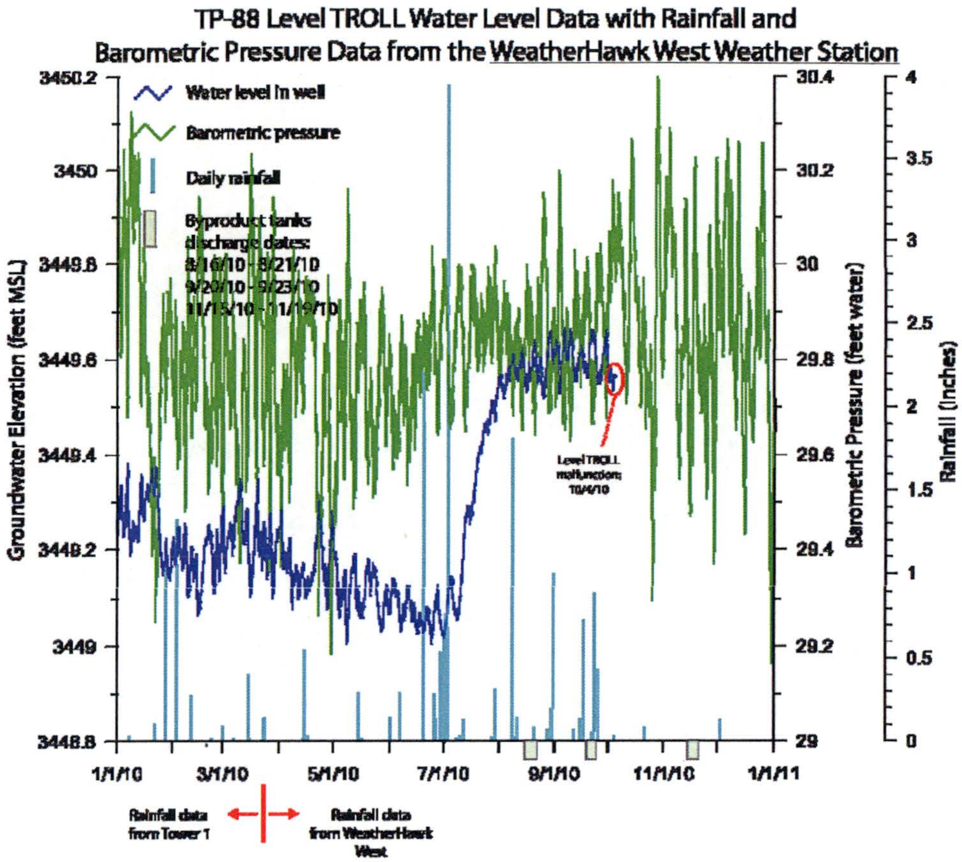

FWF-1A
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

TP-43 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

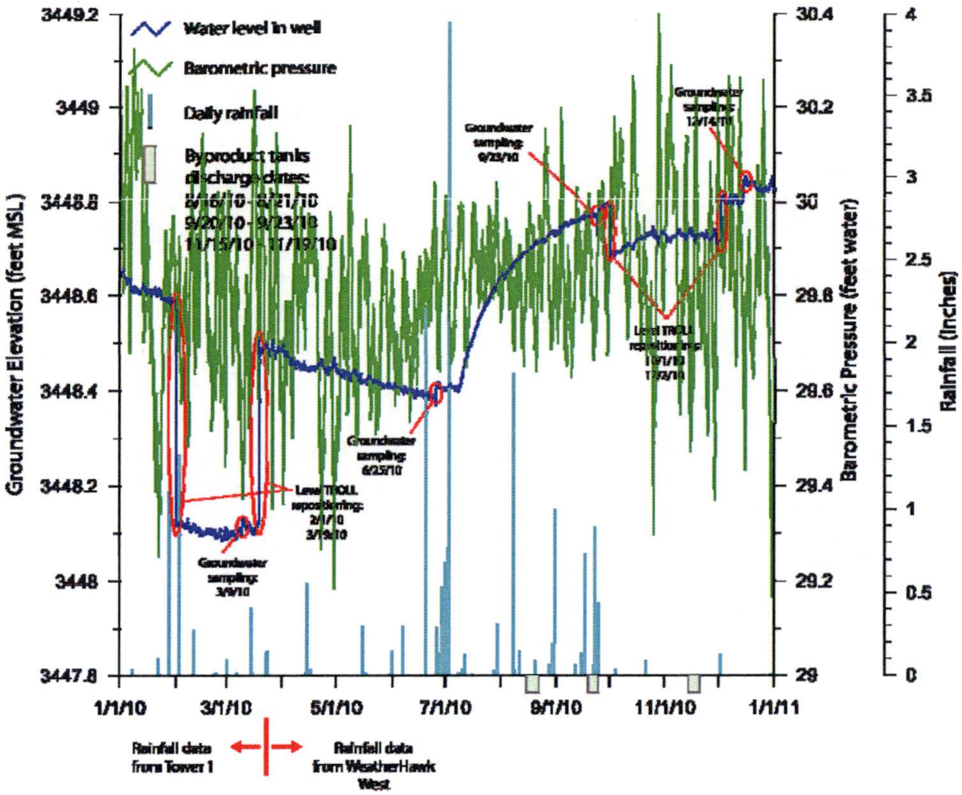


TP-141 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

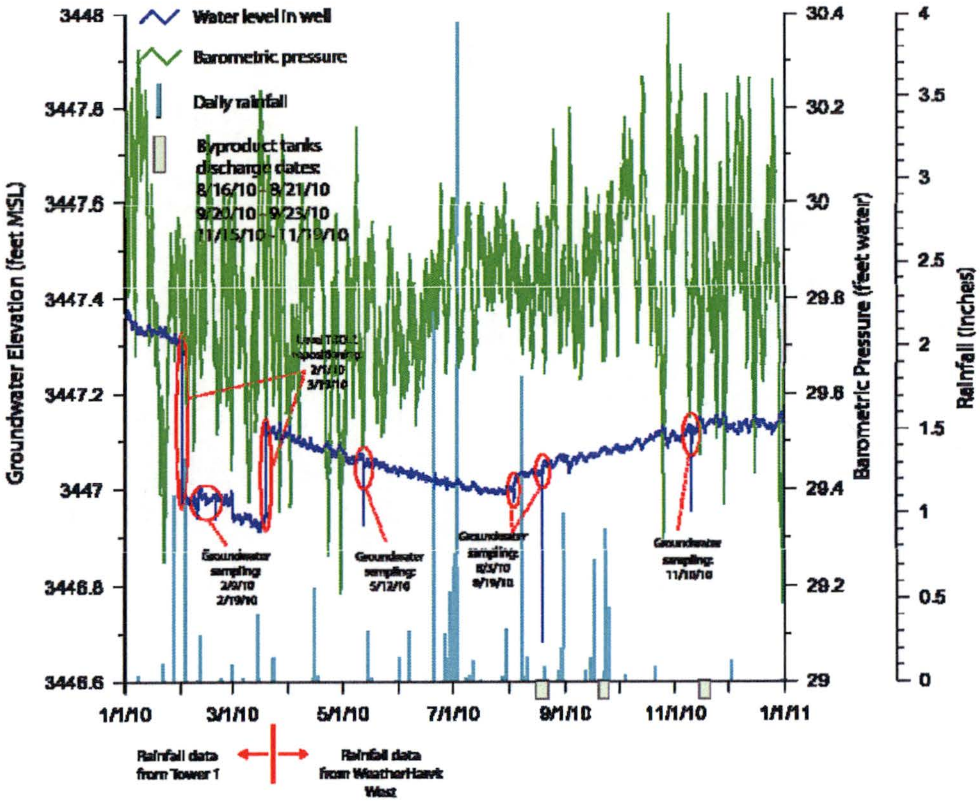


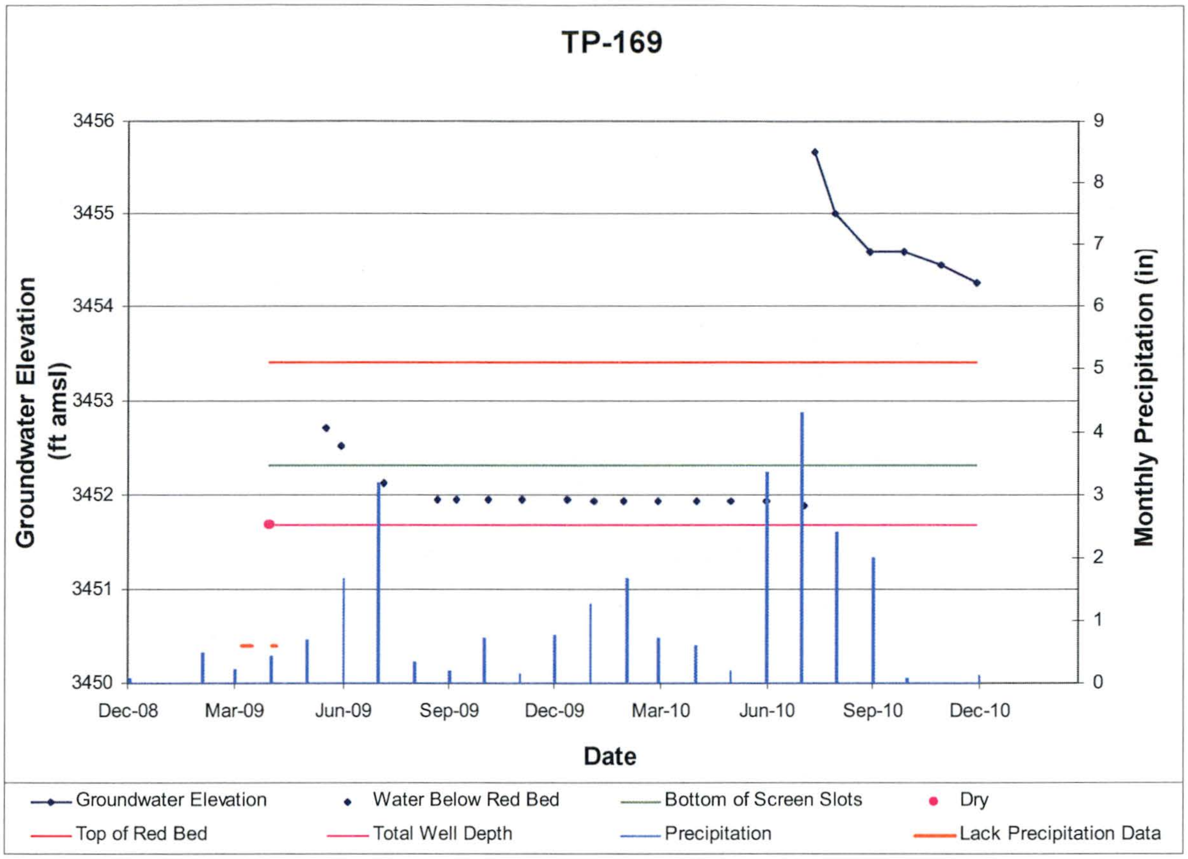

TP-88 Level TROLL Water Level Data with Rainfall and
Barometric Pressure Data from the WeatherHawk West Weather Station
Water level in well
Barometric pressure
Daily rainfall
Byproduct tanks discharge dates:
8/16/10 - 8/21/10
9/20/10 - 9/23/10
11/15/10 - 11/19/10
Groundwater Elevation (feet MSL)
Barometric Pressure (feet water)
Rainfall (inches)
Level TROLL malfunction: 10/4/10
1/1/10
3/1/10
5/1/10
7/1/10
9/1/10
11/1/10
1/1/11
Rainfall data from Tower 1
Rainfall data from WeatherHawk West

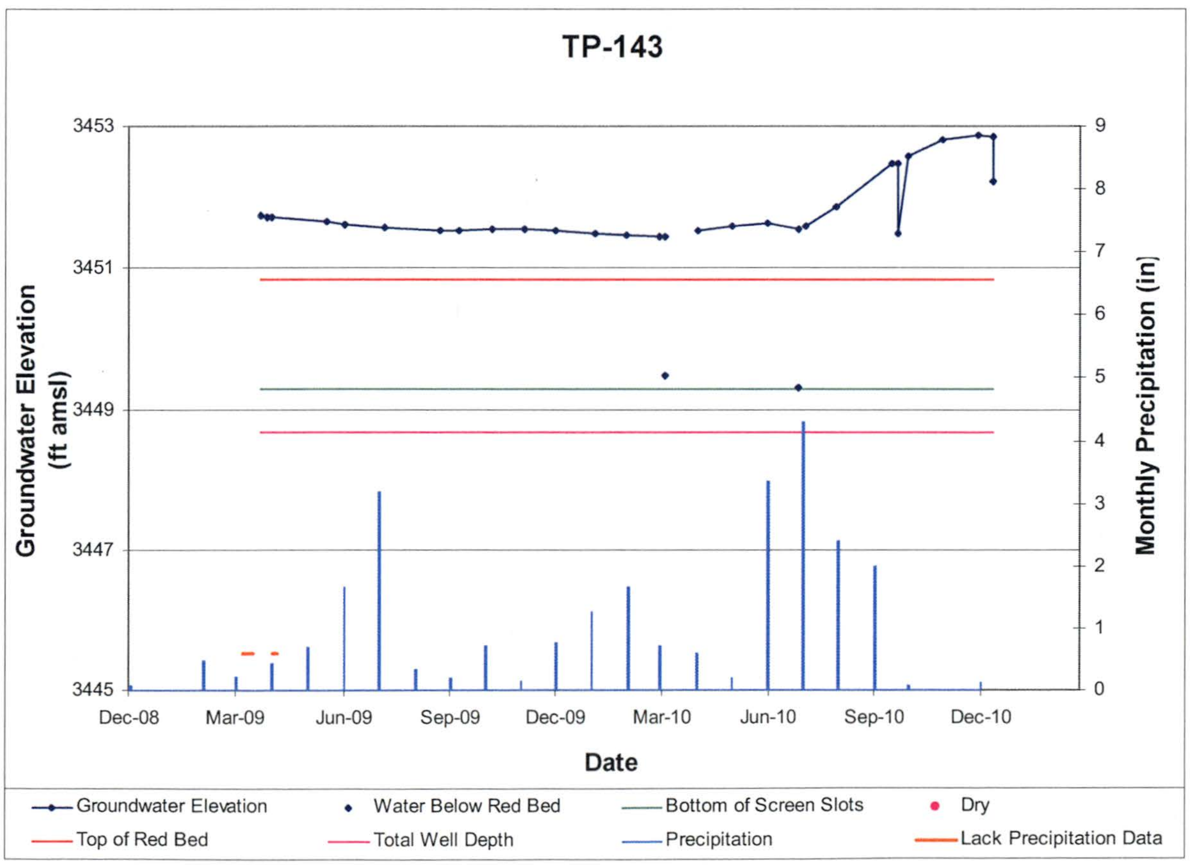
TP-171 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

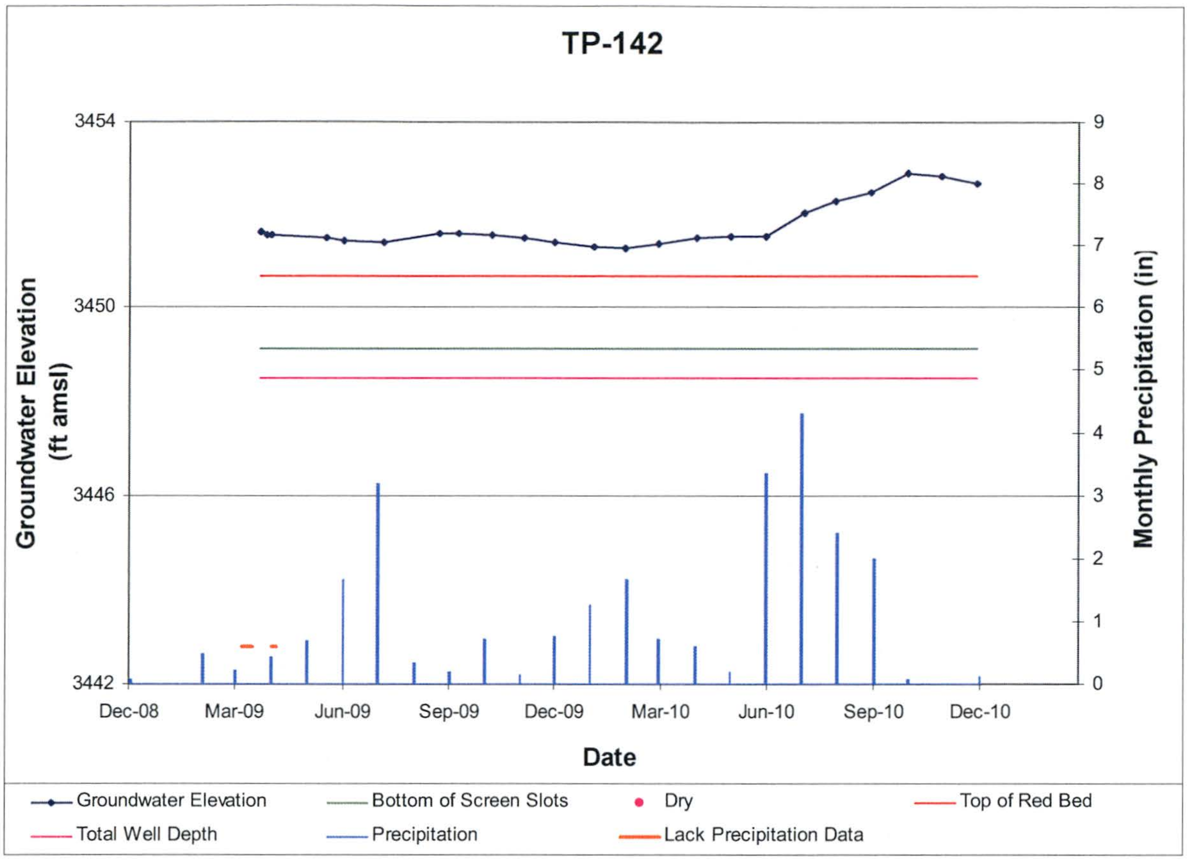


FWF-1A Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

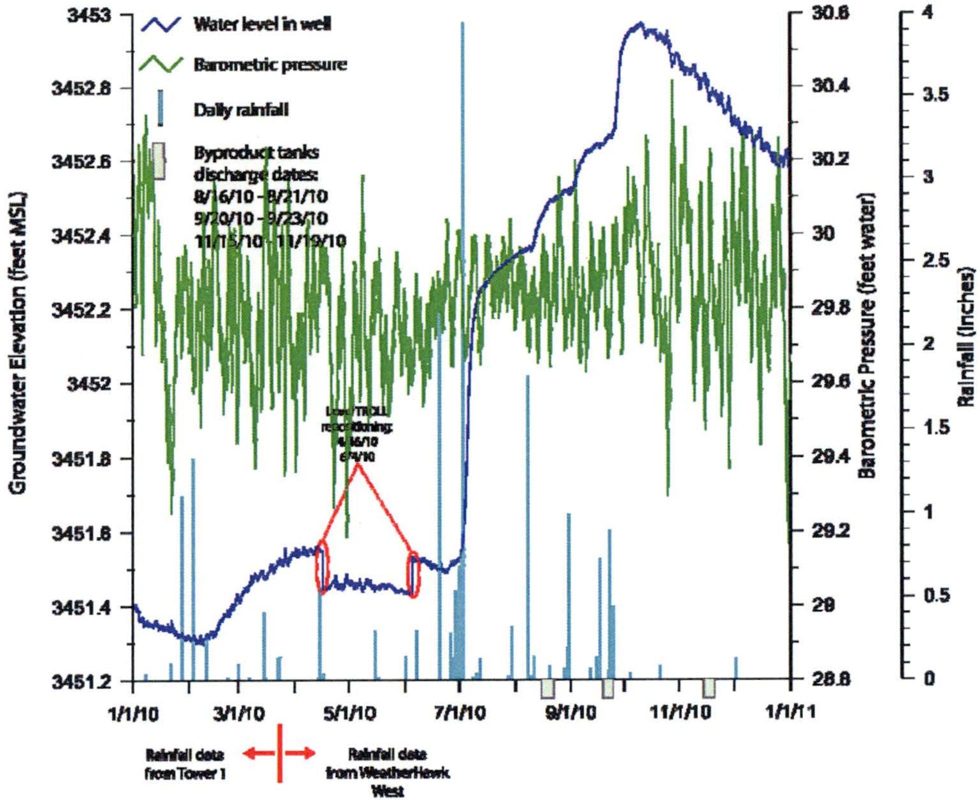



TP-169
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
3456
3455
3454
3453
3452
3451
3450
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

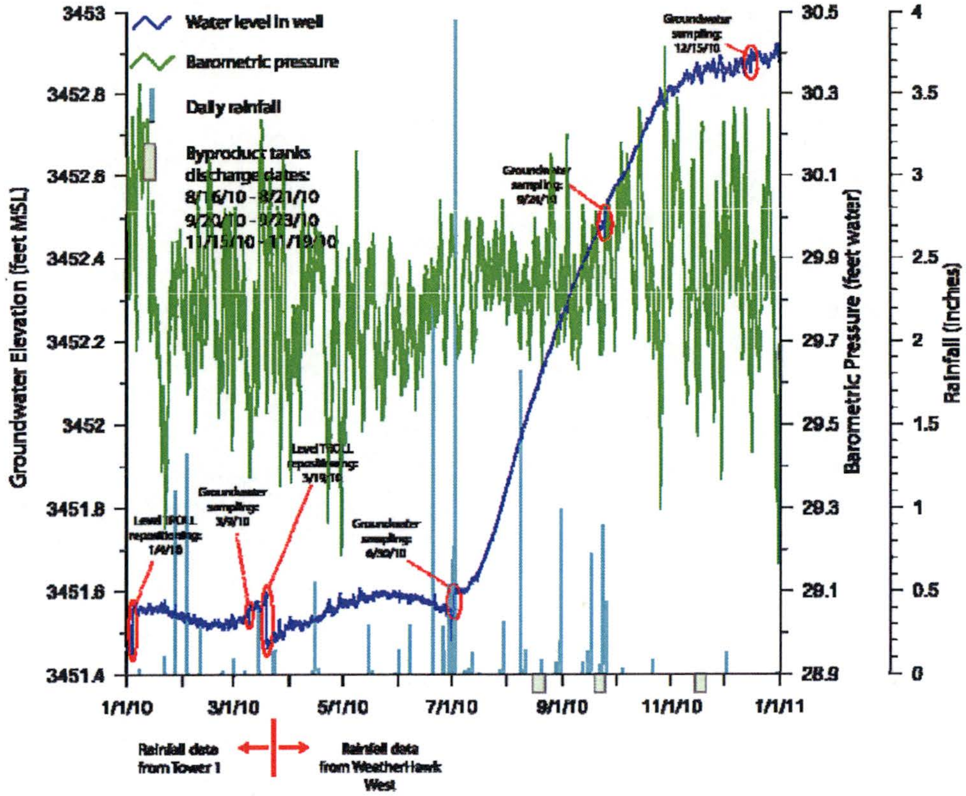

TP-143
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
Date
3453
3451
3449
3447
3445
9
8
7
6
5
4
3
2
1
0
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

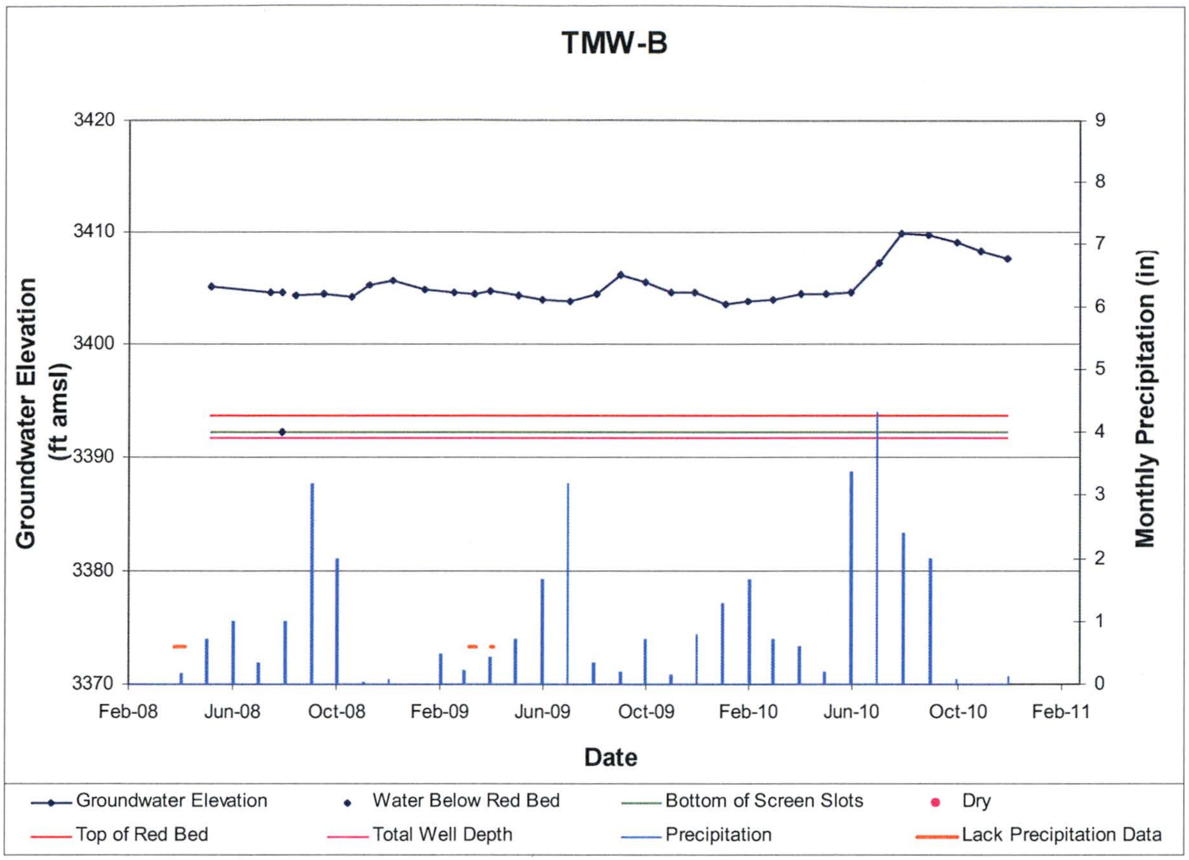

TP-142
3454
3450
3446
3442
Groundwater Elevation (ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Dec-08
Mar-09
Jun-09
Sep-09
Dec-09
Mar-10
Jun-10
Sep-10
Dec-10
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data

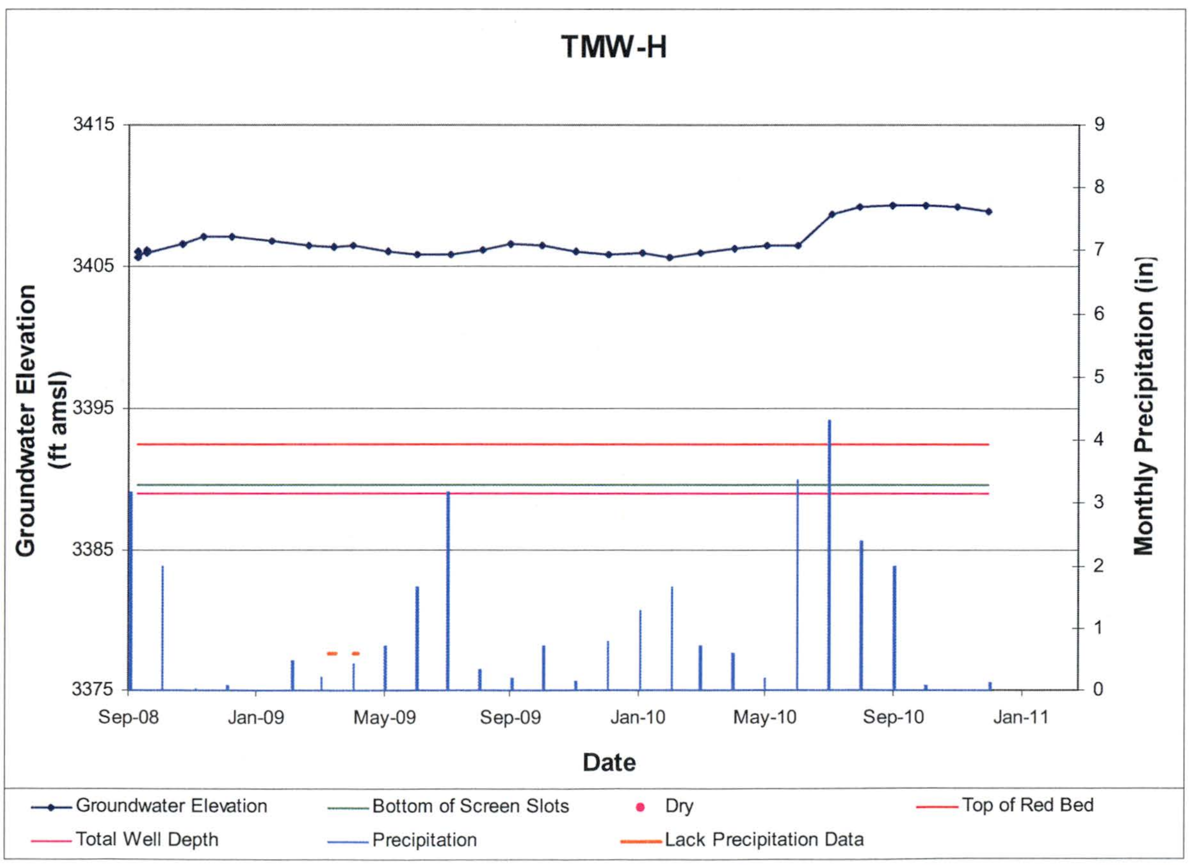
TP-142 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

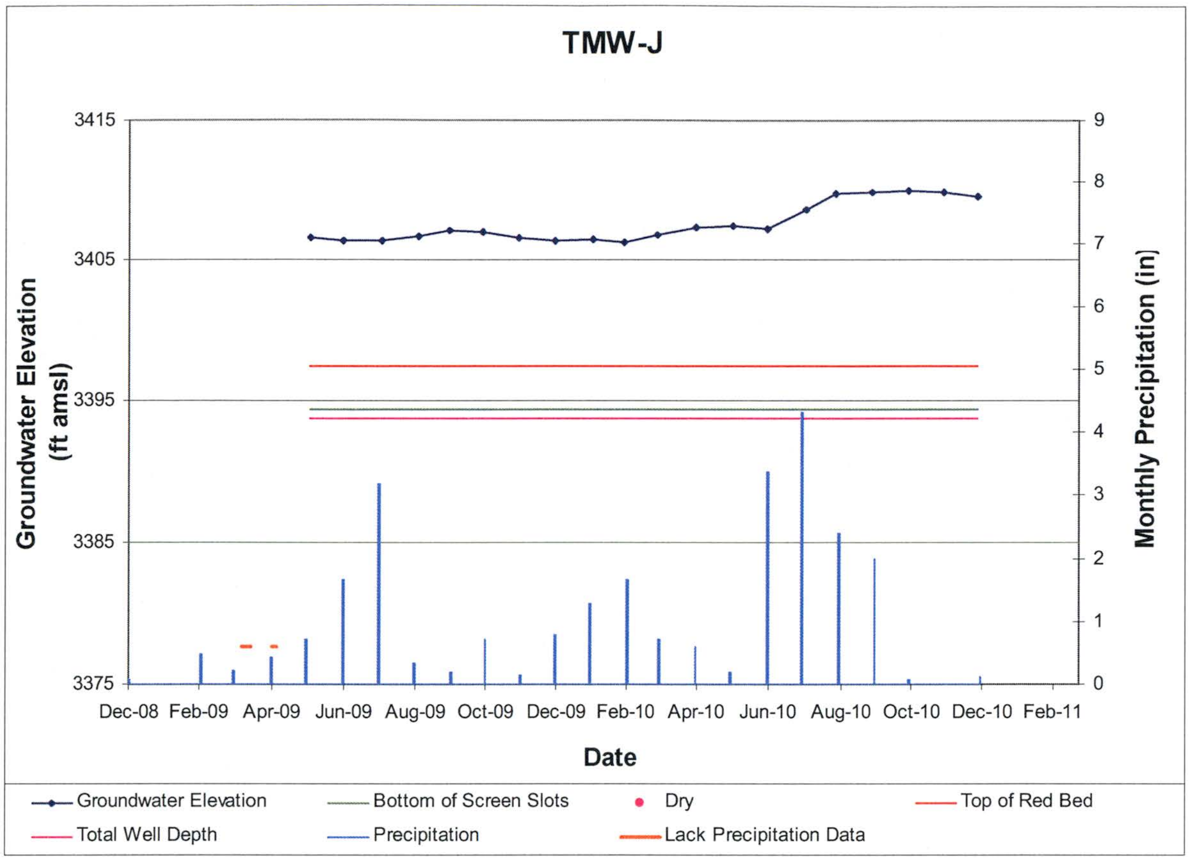


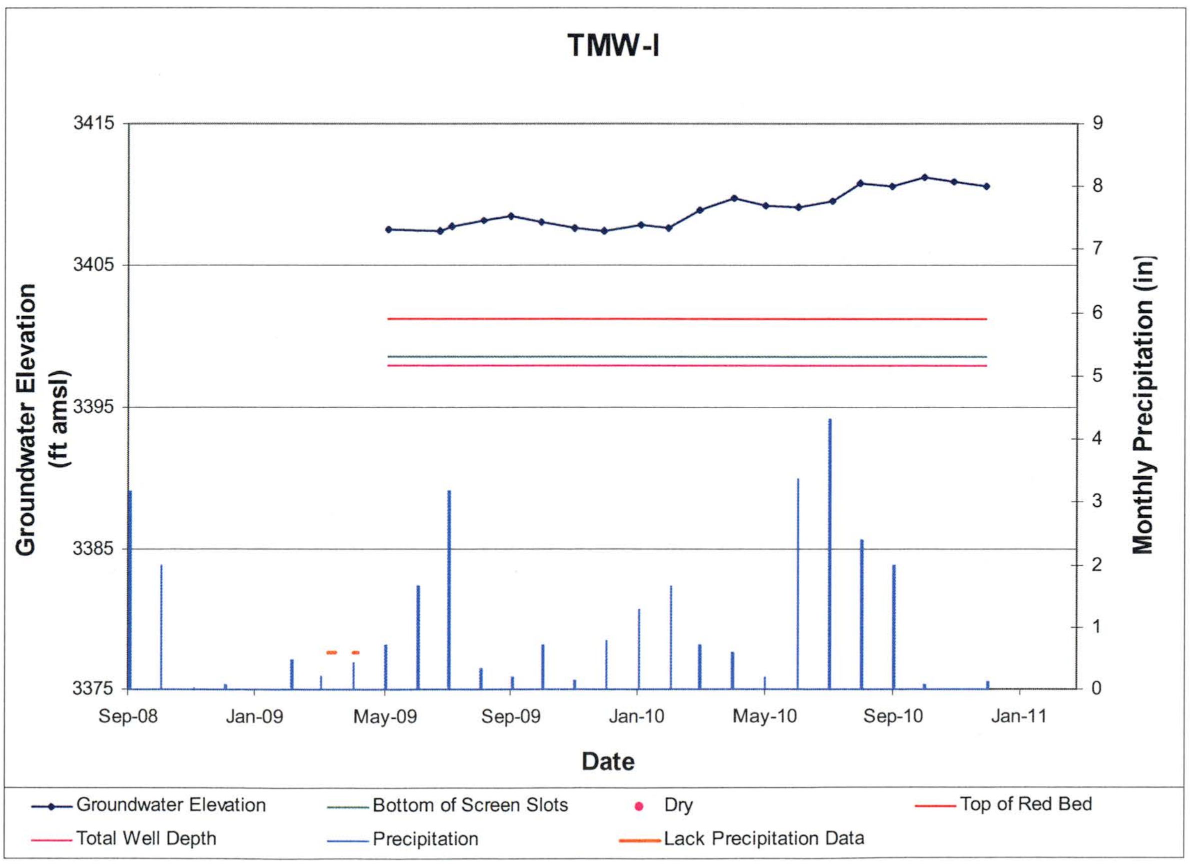
TP-143 Level TROLL Water Level Data with Rainfall and Barometric Pressure Data from the WeatherHawk West Weather Station

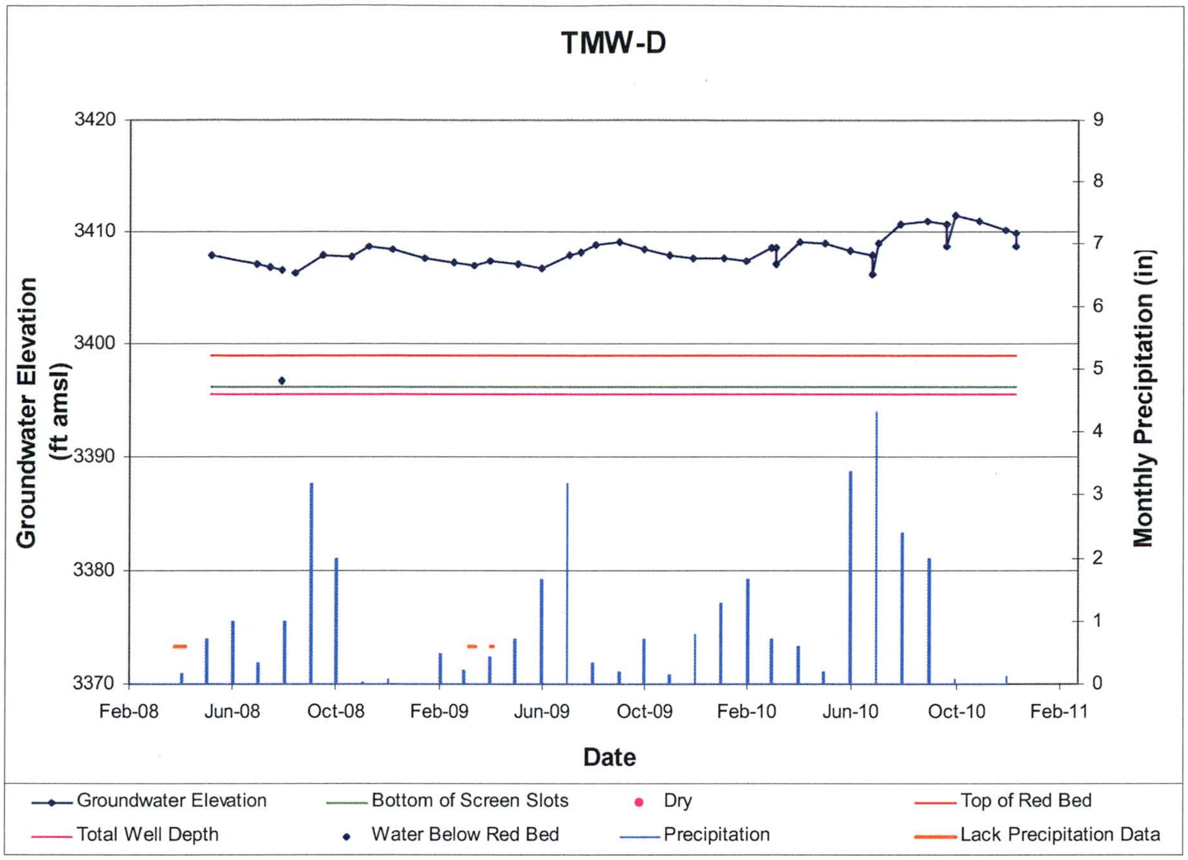



TMW-B
Groundwater Elevation (ft amsl)
3420
3410
3400
3390
3380
3370
Monthly Precipitation (in)
9
8
7
6
5
4
3
2
1
0
Feb-08
Jun-08
Oct-08
Feb-09
Jun-09
Oct-09
Feb-10
Jun-10
Oct-10
Feb-11
Date
Groundwater Elevation
Water Below Red Bed
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TMW-H
Groundwater Elevation (ft amsl)
3415
3405
3395
3385
3375
Monthly Precipitation (in)
9
8
7
6
5
4
3
2
1
0
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TMW-J
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3415
3405
3395
3385
3375
9
8
7
6
5
4
3
2
1
0
Dec-08 Feb-09 Apr-09 Jun-09 Aug-09 Oct-09 Dec-09 Feb-10 Apr-10 Jun-10 Aug-10 Oct-10 Dec-10 Feb-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TMW-I
Groundwater Elevation (ft amsl)
Monthly Precipitation (in)
3415
3405
3395
3385
3375
9
8
7
6
5
4
3
2
1
0
Sep-08 Jan-09 May-09 Sep-09 Jan-10 May-10 Sep-10 Jan-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Precipitation
Lack Precipitation Data


TMW-D
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3410
3400
3390
3380
3370
Groundwater Elevation
(ft amsl)
9
8
7
6
5
4
3
2
1
0
Monthly Precipitation (in)
Feb-08
Jun-08
Oct-08
Feb-09
Jun-09
Oct-09
Feb-10
Jun-10
Oct-10
Feb-11
Date
Groundwater Elevation
Bottom of Screen Slots
Dry
Top of Red Bed
Total Well Depth
Water Below Red Bed
Precipitation
Lack Precipitation Data

APPENDIX II

Infiltration Modeling

INTRODUCTION

Two-dimensional vadose zone flow models were developed to illustrate the impact of un-managed land disturbance on infiltration and water accumulation in the OAG at the WCS site. Evapotranspiration and flow processes were simulated in a vertical plane through a generic representation of the hydrogeologic units above the Dockum red beds at the WCS site. These units include the OAG, caprock caliche, soft caliche, and surficial soils. For this modeling, we assumed that subsurface water flow is described by Richard's equation and used the block-centered finite difference code VS2DI (Hsieh et al., 2000) to simulate flow and evapotranspiration processes. No effort has been made to calibrate these models to specific well observations or locations at the WCS site.

Three infiltration scenarios were developed and simulated. In Scenario 1, the land surface is undisturbed, and surface water is not allowed to pond during precipitation events. This scenario represents the case of undisturbed surface conditions at the WCS site. In Scenario 2, surface water is allowed to pond in two locations, reflecting ditches or other anthropogenic disturbances, during precipitation events. It is assumed that the surface water freely drains away from the ponding locations after precipitation events. In Scenario 3, surface water is allowed to pond in the same two locations as Scenario 2 during precipitation events; however, surface water ponds are allowed to remain up to seven days after a rainfall event. This scenario represents the case where surface water is allowed to pond in ditches and depressions following rainfall events. All three scenarios are identical except for changes in boundary conditions that reflect ponding conditions.

Model results illustrate potential impacts of surface water management on groundwater conditions in the OAG and illuminate the mechanisms of recharge in the OAG. These simulations show that water from unlined ditches and ponds can quickly infiltrate to the OAG-

Dockum contact, resulting in saturated conditions in the OAG. Under natural conditions, evapotranspiration prevents recharge to the OAG, except in localized depressions and playas where ponding occurs. Surface water management efforts in the WCS facilities area, which focus on lining ditches to prevent infiltration and regrading areas where surface water ponds due to construction related activities, will successfully mitigate anthropogenically-induced recharge to the OAG.

METHODS

We used the U.S. Geological Survey code VS2DI version 1.2 (Hsieh et al., 2000) to simulate unsaturated flow processes in a generic representation of the shallow units present at the WCS site. VS2DI uses a regular block-centered, finite-difference scheme to solve a pressure-formulation of Richard's equation (Lappala et al., 1983). The code includes options for infiltration and ponding, evaporation, evapotranspiration, and seepage faces. The reader is referred to Lappala et al. (1983) for the mathematical models used to simulate these processes and their numerical implementation. All model input files and output files are contained in Attachment 1.

Model Domain and Hydrogeologic Units

The model domain is 250 m long and up to 11 m high. It is subdivided into 250 1.0-m grid blocks in the horizontal direction and up to 22 0.5-m grid blocks in the vertical direction. The model domain and associated hydrogeologic units are shown in Figure 1.

The base of the model is the top of the Dockum red beds. The Dockum is a very low-permeability unit with an effective vertical hydraulic conductivity of ~ 10^{-6} m/day (e.g., Holt et al., 2009), four to five orders of magnitude lower than the hydraulic conductivity of the overlying units. Because of this hydraulic conductivity disparity, groundwater fluxes in the Dockum are likely to be very slow when compared to those of the overlying units; therefore, we consider the top of the Dockum to be the base of our model and represent it as a no-flow boundary. The upper surface of the Dockum is erosional. To represent this erosional variability, the top of the Dockum has a depression on the left side of the model domain, and a gentle slope from the center of the domain to the right edge. Across the 250 m wide model domain, the elevation of the top of the Dockum varies by 2.5 m.

The OAG is a thin hydrogeologic unit consisting mainly of silts, sands, and gravels of the Ogallala, Antlers, and Gatuña Formations. It is likely the most permeable unit above the Dockum red beds. Variations in recharge and in the elevation of the eroded Dockum surface control the spatial distribution of saturated conditions in the OAG. Natural recharge to the OAG is topographically focused and occurs in playas and other depressions. The OAG drapes the Dockum surface. Here, it is represented with a variable thickness that ranges from 0.5 m on the left side of the domain to a maximum of 2 m on the right side.

Two caliche (calcrete) units are present at the WCS site. The lower most caliche is a Stage V – VI calcrete that is laterally equivalent to the Ogallala caprock caliche of the Texas High Plains. It is a hard, dense, well-developed calcrete. The uppermost caliche is a Stage III – IV calcrete that is laterally equivalent to the Mescalero Caliche of southeastern New Mexico. At the WCS site, this caliche is softer and easier to excavate than the caprock caliche. In the vicinity of the Red Bed Ridge at the WCS site, the upper Mescalero caliche is developed directly on top of the caprock caliche. To the north of the WCS site, these two caliches are vertically separated by poorly cemented sands. Both caliche units are represented in this model. In the model, the lower caprock caliche varies in thickness from 1.5 m to 5.5 m, and the upper caliche ranges from 0 m, on the left side of the domain, to 4 m near the center of the domain.

1 m of surface soil drapes the underlying caliche units, and the surface topography drops 2 m from the right side to the left side of the domain.

Hydraulic Properties

In VS2DI, hydraulic characteristic functions (pressure-saturation curves, moisture-characteristic curves, and relative permeability curves) can be described using three different models or tabular data from samples. We chose to use the van Genuchten (1980) - Mualem ([1976) model which, for convenience, is summarized here. We assume that the tension-saturation curve, $S(\psi)$, is a monotonic function completely described by the van Genuchten parametric model (van Genuchten, 1980)

$$S(\psi) = \left[1 + (-\alpha\psi)^n\right]^{1/n - 1} \quad (1)$$

where ψ is the matric potential, n is a parameter related to standard deviation of the effective pore radii, and α is a parameter that is related to an air-entry pressure. The moisture-characteristic curve, $\theta(\psi)$, is described by

$$\theta(\psi) = (\phi - \theta_r)S(\psi) + \theta_r \quad (2)$$

where ϕ is the porosity, and θ_r is the residual moisture content, here assumed to be zero. We assume that the unsaturated hydraulic conductivity, $K(\psi)$, is completely described using Mualem's ([1976) relationship, which for the van Genuchten model is

$$K(\psi) = K_s S(\psi)^{\frac{1}{2}} \left\{1 - \left[1 - S(\psi)^{\frac{n}{n-1}}\right]^{1 - 1/n}\right\}^2 \quad (3)$$

where K_s is the saturated hydraulic conductivity.

Because hydraulic property data are limited for most of the near surface geological units present at the WCS site, model hydraulic properties (Table 1) were selected based on literature values and hydrogeologic interpretation.

The hydraulic properties of the OAG were assumed to be the same as that used in previous VS2DI modeling (WCS, 2009).

The hydraulic property selection for the caprock and soft caliche units (Table 1) were informed by Duniway et al. (2007). They report measured saturated hydraulic conductivity values that range from 1.2 to 3.7 m/day for solid pieces of well-indurated caliche. We chose slightly higher values to reflect the presence of high permeability fissures within the caliche. Duniway et al. (2007) also reported α values ranging from 0.012 to 0.162 (m^{-1}) and van Genuchten n values for ranging from 1.22 to 1.5 (Duniway et al., 2007). We chose intermediate values for α (0.077 and

0.085 m^{-1}), with the smallest value applied to the caprock caliche, reflecting a slightly higher air entry pressure. We chose an intermediate value of *n* for the caprock caliche (1.36) and a higher value (1.6) for the soft caliche, reflecting a narrower pore-size distribution in the soft caliche. Porosity values varied greatly in the samples described by Duniway et al., ranging from 0.16 to 0.40. We selected an intermediate value for the caprock caliche (0.26) and a slightly higher value for the soft caliche (0.30).

For the surficial soil, we assumed a saturated hydraulic conductivity of 1.08 m/day, a porosity of 0.30, an α value of 2 m^{-1} (to reflect a fairly low air entry pressure), and an *n* value of 1.41 (to reflect a fairly wide pore-size distribution.

VS2DI allows the input of a specific storage value to account for the effects of fluid and soil/rock compressibility. Since these effects are small compared to the soil-water capacity, we assumed that the specific storage for each unit was zero.

Evaporation and Transpiration

Both evaporation and transpiration are simulated. The potential evaporation rate is set to ~0.0056 m/day, with a surface resistance of 4.0, and a pressure potential for the atmosphere of -1,000 m. The potential transpiration rate is set to ~0.0024 m/day, with a rooting depth of 5 m, a top root activity of 10 m/m^3, a basal root activity of 0.01 m/m^3, and a pressure head in the root of -1,500 m.

Boundary and Initial Conditions

Three infiltration scenarios were developed and simulated to illustrate the impacts of un-managed anthropogenic activities (e.g., unlined ditches and areas where water is allowed to pond) on recharge to the OAG. Each model scenario includes seven recharge periods in which boundary conditions are varied to accommodate the specifics of the model scenario. The scenarios are described below:

- Scenario 1 – This scenario represents the base case, where there have been no anthropogenic impacts to the land surface. The land surface is undisturbed, and surface water is not allowed to pond during precipitation events.

- Scenario 2 – In this scenario, surface water is allowed to pond in two locations, reflecting ditches or other anthropogenic disturbances, during precipitation events. It is assumed that the surface water freely drains away from the ponding locations after precipitation events.
- Scenario 3 – Here, surface water is allowed to pond in the same two locations as Scenario 2 during precipitation events; however, surface water ponds are allowed to remain up to seven days after a rainfall event. This scenario represents the case where surface water is allowed to pond in ditches and depressions following rainfall events.

All three scenarios are identical except for changes in boundary conditions that reflect standing water in ditches/ponds.

Boundary conditions for all three scenarios are shown in Figure 2. No flow boundaries are defined for the left and right sides of the model domain and the bottom boundary (top of the Dockum red beds). A seepage face boundary is applied to the left and right sides of the OAG to allow ponded water to exit the model. The upper boundary of the domain contains two regions representing the undisturbed land surface (Variable Boundary 1) and the location of unlined ditches/ponds (Variable Boundary 2). The upper boundary conditions are changed between scenarios and are described in Tables 2, 3, and 4.

For all scenarios, boundary conditions and simulation results are identical for the first 160 day recharge period (Tables 2, 3, and 4). For the first recharge period, the initial condition is an equilibrium profile defined by a water table at a depth of 10.5 m. To minimize the impact of the initial condition on the results for each scenario, the initial condition is allowed to decay in response to 160 days of evapotranspiration.

The second recharge period represents a single day (simulation days160.0 – 161.0; Tables 2, 3, and 4) of intense precipitation. Here, the boundary conditions are changed to a constant flux of 0.051 m/day (~ 2 in./day of rainfall) in areas with undisturbed land surface, and constant head boundaries equivalent to 0.3 m of water are applied in the ditch/pond areas (Scenarios 2 and 3). During this recharge period, no evaporation or transpiration is simulated.

The third recharge period represents three days (simulation days 161.0 – 164.0) of no precipitation. In Scenarios 1 and 2, all upper boundaries are returned to evapotranspiration boundaries. In Scenario 3, water is allowed to remain ponded in the ditch/pond areas to a depth of 0.3 m.

The fourth recharge period simulates four days (simulation days 164.0– 168.0) of rainfall (Tables 2, 3, and 4). A constant flux of 0.01 m/day (~ 0.4 in./day of rainfall) is applied in areas with undisturbed land surface, and constant head boundaries equivalent to 0.3 m of water are applied in the ditch/pond areas (Scenarios 2 and 3). During this recharge period, no evaporation or transpiration is simulated.

The fifth recharge period simulates two days (simulation days 168.0– 170.0) of intense precipitation (Tables 2, 3, and 4). A constant flux of 0.051 m/day (~ 2 in./day of rainfall) is applied in areas with undisturbed land surface, and constant head boundaries equivalent to 0.3 m of water are applied in the ditch/pond areas (Scenarios 2 and 3). During this recharge period, no evaporation or transpiration is simulated.

The sixth recharge period simulates a seven day period (simulation days 170.0 – 177.0) of evapotranspiration in Scenarios 1 and 2 (Tables 2 and 3). In Scenario 3, undisturbed areas are returned to an evapotranspiration boundary, and constant head boundaries equivalent to 0.3 m of water are applied in the ditch/pond areas (Table 4).

All upper boundaries are set to evapotranspiration boundaries in the seventh, and final, recharge period (Tables 2, 3, and 4). This recharge period lasts 65 days (simulation days 177.0 – 242.0).

Observation Points

Four observation points were included in each modeling scenario (Figure 3) to illustrate observations in OAG piezometers or wells. At each observation point, the total head, pressure head, moisture content, and saturation were output at each model time step.

RESULTS

In the following, the results for each of the three modeling scenarios are presented. We begin by discussing the first recharge period, which is the same for all three scenarios. We then discuss each of the three scenarios individually.

First Recharge Period (0-160 days) Decay of Initial Condition

The initial condition for all scenarios includes a water table located at a depth of 10.5 m and an equilibrium pressure head profile above the water table (pressure head decreases linearly with elevation). As a result, saturated conditions exist in the OAG in the lowermost row of gridblocks on the right side of the domain. This initial condition is allowed to decay due to evapotranspiration for 160 days. At the end of 160 days, the OAG is unsaturated, and the surface soils have become very dry with pressure heads less than – 50 m and saturations of ~ 0.12 (Figure 4). In general, the pressure head increases with depth and decreases toward the left side of the domain, which is thinner and affected more by evapotranspiration. Darcy flux vectors (Figure 4) indicate flow directions mainly upward and toward the left side of the domain, where plant roots reach deeper. Saturations are lowest in the surficial soils and the OAG, because they have poor water retention characteristics (e.g., $\alpha = 2\ m^{-1}$). Saturations are greatest in the caliche units which have high water retention (α of 0.085 and $0.077 m^{-1}$).

Scenario 1 – Undisturbed Soil

In Scenario 1, there have been no anthropogenic impacts to the land surface. The land surface is undisturbed, and surface water is not allowed to pond during precipitation events.

On simulation day 160, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall). At the beginning of day 161 (Figure 5), the surface soils have become much wetter, pressure heads throughout the domain have increased, and Darcy flux vectors are mainly downward, indicating infiltration.

On simulation days 161 – 164, no precipitation occurs, and evapotranspiration resumes. At the beginning of day 164 (Figure 6), saturation in the surficial soils have decreased, pressure heads remain higher, but flow directions are mainly upward and toward the left, due to evapotranspiration.

On simulation days 164 – 168, a constant flux of 0.01 m/day is applied to the land surface (equivalent to ~ 0.4 in./day of rainfall). At the beginning of day 168 (Figure 7), the surface soils have again become much wetter, pressure heads throughout the domain have increased, and Darcy flux vectors are mainly downward, indicating infiltration.

On simulation days 168 – 170, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall). At the beginning of day 170 (Figure 8), the saturation of the caliche units has increased appreciably, pressure heads throughout the domain have increased substantially, and Darcy flux vectors indicate strong downward infiltration.

On simulation days 170 – 177, no precipitation occurs, and evapotranspiration resumes. At the beginning of day 177 (Figure 9), pressure heads and saturation levels have decreased, and flow directions are upward and toward the left.

On simulation days 177 – 242, no precipitation occurs, and evapotranspiration removes water from the domain. At the beginning of day 242 (Figure 10), pressure heads and saturation levels have decreased significantly, and flow directions are mainly upward and to the left.

At no time after the decay of the initial condition did saturated conditions develop in the OAG. This is also reflected in the pressure head history of the observation points (Figure 11). Pressure head responses to the precipitation events appear delayed.

Scenario 2 – Well-Draining Unlined Ditches/Ponds

In scenario 2, surface water is allowed to pond in two locations, reflecting ditches or other anthropogenic disturbances, during precipitation events. It is assumed that the surface water freely drains away from the ponding locations after precipitation events.

On simulation day 160, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall) and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 161 (Figure 12), the surface soils have become much wetter, and wetted bulbs have developed beneath the ditch/pond locations. Darcy flux vectors are focused downward beneath the ditch/pond locations and outward from the wetter bulbs. Saturated conditions have developed beneath the ditch/pond locations.

On simulation days 161 – 164, no precipitation occurs, and evapotranspiration resumes. At the beginning of day 164 (Figure 13), the surficial soils have noticeably dried. Water within the wetted bulbs has begun to redistribute laterally, decreasing the pressure head and saturation within the bulbs and increasing the pressure head and saturation in adjacent areas. Downward flow beneath the ditch/pond areas has ceased, and flow vectors reflect lateral redistribution. No saturated regions have developed in the OAG.

On simulation days 164 – 168, a constant flux of 0.01 m/day is applied to the land surface (equivalent to ~ 0.4 in./day of rainfall) and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 168 (Figure 14), the saturation and pressure head values throughout the domain have increased. Flow rates within and around the wetted bulbs have increased, and Darcy flux vectors are mainly downward beneath the ditch/pond locations and sideways along the edges of the bulbs. Saturated conditions have developed beneath the ditch/pond locations, and groundwater mounds have begun to develop.

On simulation days 168 – 170, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall)and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 170 (Figure 15), pressure head and saturation values have continued to increase, and the magnitude of subsurface flow has also increased. Saturated conditions remain beneath the ditch/pond locations, and the groundwater mounds have increased in size. OAG water leaves the domain at the left seepage face boundary.

On simulation days 170 – 177, no precipitation occurs, and evapotranspiration resumes. By simulation day 174, OAG saturated conditions no longer exist in the right part of the domain. At the beginning of day 177 (Figure 16), pressure heads and saturation levels have decreased in the surface soils, but remain higher in the deeper units. Flow directions are generally upward toward areas of lower pressure head. The groundwater mounds have diminished due to evapotranspiration and flow out of the domain at the left seepage face boundary, leaving only an isolated pocket of water in the OAG (left side of the domain).

On simulation days 177 – 242, no precipitation occurs, and evapotranspiration removes water from the domain. OAG water in the left part of the domain is completely removed by evapotranspiration by simulation day 188. At the beginning of day 242 (Figure 17), pressure heads and saturation levels have decreased significantly in the shallow soils, but relatively high pressure heads and saturation values remain in the caliche units. High pressure heads exist in the OAG, but the OAG shows low saturation due to its low air-entry pressure.

Figure 18 shows the pressure head and precipitation history for the observation points during Scenario 2. Observation points 1 and 3 underlying the ditch/pond locations show a slightly delayed response to the precipitation events. In these observation points, the peak water levels occur on simulation day 170. The water-levels quickly decline as water is redistributed to the unsaturated materials around the groundwater mounds. Observation points 2 and 4 show delayed responses and never show saturated conditions (pressure heads ≥ 0 m).

Scenario 3 – Poorly-Draining Unlined Ditches/Ponds

In scenario 3, surface water is allowed to pond in the same two locations as Scenario 2 during precipitation events; however, surface water is allowed to remain in the ditch/pond locations up to seven days after a rainfall event. This scenario represents the case where surface water is allowed to pond in ditches and depressions following rainfall events.

On simulation day 160, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall) and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 161 (Figure 19), the surface soils have become much wetter, and wetted bulbs have developed beneath the ditch/pond locations. Darcy flux vectors are focused downward beneath the ditch/pond locations and outward from the wetter bulbs. Saturated conditions have developed beneath the ditch/pond locations.

On simulation days 161 – 164, no precipitation occurs, and evapotranspiration resumes outside of the ditch/pond locations. Aconstant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 164 (Figure 20), the surficial soils have noticeably dried, except in the vicinity of the ditch/pond locations. Water within the wetted bulbs has begun to redistribute laterally, decreasing the pressure head and saturation within the bulbs and increasing the pressure head and saturation in adjacent areas. Downward flow beneath the ditch/pond areas has continued, and saturated regions have begun to develop in the OAG.

On simulation days 164 – 168, a constant flux of 0.01 m/day is applied to the land surface (equivalent to ~ 0.4 in./day of rainfall) and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 168 (Figure 21), the saturation and pressure head values throughout the domain have increased. Flow rates within and around the wetted bulbs have increased, and Darcy flux vectors are mainly downward beneath the ditch/pond locations and sideways around the wetted bulb. Saturated conditions remain beneath the ditch/pond locations, and groundwater mounds have begun to develop, and OAG water is leaving the domain at the left seepage face boundary.

On simulation days 168 – 170, a constant flux of 0.051 m/day is applied to the land surface (equivalent to ~ 2 in./day of rainfall)and a constant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 170 (Figure 22), pressure head and saturation values have continued to increase, and the magnitude of subsurface flow has also increased. Saturated conditions remain beneath the ditch/pond locations, and the groundwater mounds have increased in size. OAG water continues to leave the domain at the left seepage face boundary.

On simulation days 170 – 177, no precipitation occurs, and evapotranspiration resumesoutside of the ditch/pond locations. Aconstant head of 0.3 m is applied at the ditch/pond locations. At the beginning of day 177 (Figure 23), pressure heads and saturation levels have decreased in the surface soils. In the deeper units, pressure head and saturation values have homogenized and generally increased across the domain. Flow directions are generally downward beneath the ditch/pond locations, but are upward in many areas. The groundwater mounds have merged (by day 174), and groundwater flows out of the domain at the left seepage face boundary.

On simulation days 177 – 242, no precipitation occurs, and evapotranspiration removes water from the domain. By simulation day 178, OAG groundwater is leaving the domain at both the right and left seepage face. Both seepage faces remain active until simulation day 186, when saturated conditions no longer exist in the OAG at the left boundary. The right seepage face remains active until simulation day 210, when the OAG becomes unsaturated at the right boundary. By simulation day 215, OAG saturated conditions no longer exist in the right part of the domain. OAG water in the left part of the domain is completely removed by evapotranspiration by simulation day 225. At the beginning of day 242 (Figure 24), pressure heads and saturation levels have decreased significantly in the shallow soils, but relatively high pressure heads and saturation values remain in the caliche units. High pressure heads exist in the OAG, but the OAG shows low saturation due to its low air-entry pressure.

Figure 25 shows the pressure head and precipitation history for the observation points during Scenario 2. Observation points 1 and 3 underlying the ditch/pond locations show a rapid response to the first precipitation event. Additional peaks reflect the initiation of later precipitation events, and maximum water levels occur on simulation day 177. The water-levels quickly decline as water is redistributed to the unsaturated materials around the groundwater mounds. Observation points 2 and 4 (Figure 25) show delayed responses to the infiltration events and reach peak values as groundwater mounds and spreads along the OAG-Dockum contact.

SUMMARY AND CONCLUDING REMARKS

A series of three scenarios were developed and numerically simulated to illustrate infiltration processes at the WCS site under natural and disturbed conditions. Evapotranspiration and flow processes were simulated in a vertical plane through a generic representation of the hydrogeologic units above the Dockum red beds at the WCS site. These units include the OAG, caprock caliche, soft caliche, and surficial soils. No effort has been made to calibrate these model to specific well observations or locations at the WCS site.All three scenarios are identical except for changes in boundary conditions that reflect ponding conditions.

In Scenario 1, the land surface is undisturbed, and surface water is not allowed to pond during precipitation events. This scenario represents the case of undisturbed surface conditions at the WCS site.

In Scenario 2, surface water is allowed to pond in two locations, reflecting ditches or other anthropogenic disturbances, during precipitation events. It is assumed that the surface water freely drains away from the ponding locations after precipitation events.

In Scenario 3, surface water is allowed to pond in the same two locations as Scenario 2 during precipitation events; however, surface water ponds are allowed to remain up to seven days after a rainfall event. This scenario represents the case where surface water is allowed to pond in ditches and depressions following rainfall events.

Model results show behavior similar to that observed at the WCS site. In Scenario 1, infiltration occurs during precipitation events, saturated conditions do not develop in the OAG, and infiltrating water is quickly redistributed and removed by evapotranspiration.

In Scenario 2, rapid infiltration occurs beneath ditch/pond locations. A single large infiltration event (following ~ 2 in./day of rainfall), is insufficient to cause saturated conditions in the OAG, because water is quickly redistributed laterally into the relatively dry caliche and OAG units and evapotranspiration quickly begins to return much of the precipitation to the atmosphere. Saturated conditions do develop in the OAG following a sustained rainfall event consisting of four days of precipitation at rate of ~0.4 in./day and two days of precipitation at a rate of ~ 2 in./day. Groundwater mound develop beneath the ditch/pond locations and quickly spread laterally across the Dockum-OAG contact, and lateral flow redistributes the water down dipping Dockum surfaces. Following the precipitation events, lateral flow along the Dockum surface, redistribution of water into the unsaturated zone, and evapotranspiration quickly eliminates saturated conditions in the OAG.

Scenario 3 is similar to Scenario 2, except ponding after precipitation events allows much more water to infiltrate, leading to the development of larger groundwater mounds and allowing saturated conditions to remain in the OAG for longer time periods.

The purpose of this modeling effort is to illustrate the impact of anthropogenic disturbance (e.g., unlined ditches and ponds) on groundwater occurrences in the OAG at the WCS site. While no effort has been made to calibrate this model to specific well observations or locations at the WCS site, the model results illustrate potential impacts of surface water management on groundwater conditions in the OAG and illuminate the mechanism of recharge to the OAG. The following conclusions can be drawn from this modeling effort:

1) Under natural conditions at the WCS site, recharge to the site only occurs in local depressions or playas where water is allowed to pond.

2) Water in unlined ditches and ponds can quickly infiltrate to the OAG causing saturated conditions.

3) OAG monitoring wells are likely to show complicated responses to anthropogenically-induced infiltration, as water levels data will be impacted by the distance of the well from the recharge point(s) (likely influenced by the location of vertical fast paths) and lateral flow along the OAG-Dockum surface.

4) Once saturated conditions have developed in the OAG, OAG groundwater is redistributed in the subsurface by lateral flow along the topography of the Dockum surface and evapotranspiration.

5) Effective lining of ditches and the removal of areas where surface water ponds and the maintenance of plant communities capable of providing high evapotranspiration rates are critical elements of the surface water management plan at the WCS site and will eliminate anthropogenically-induced recharge to the OAG.

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TABLES

Unit	K_s (m/day)	Porosity (–)	α (m^{-1})	*n* (–)
OAG	19.9	0.20	2	1.46
Caprock Caliche	8.64	0.26	0.077	1.36
Soft Caliche	5	0.30	0.085	1.6
Surface Soil	1.08	0.30	2	1.41

Table 1. Hydraulic properties for geologic units.

Simulation Days	Variable Boundary Condition 1	Variable Boundary Condition 2
0 – 160.0	*ET Boundary*	*ET Boundary*
160.0 – 161.0	*Constant Flux = 0.051 m/d*	*Constant Flux = 0.051 m/d*
161.0– 164.0	*ET Boundary*	*ET Boundary*
164.0 – 168.0	*Constant Flux = 0.01 m/d*	*Constant Flux = 0.01 m/d*
168.0– 170.0	*Constant Flux = 0.051 m/d*	*Constant Flux = 0.051 m/d*
170.0– 177.0	*ET Boundary*	*ET Boundary*
177.0 – 242.0	*ET Boundary*	*ET Boundary*

Table 2. Variable boundary conditions for Scenario 1.

Simulation Days	Variable Boundary Condition 1	Variable Boundary Condition 2
0 – 160.0	*ET Boundary*	*ET Boundary*
160.0 – 161.0	*Constant Flux = 0.051 m/d*	*Constant Head = 0.3 m*
161.0 – 164.0	*ET Boundary*	*ET Boundary*
164.0 – 168.0	*Constant Flux = 0.01 m/d*	*Constant Head = 0.3 m*
168.0 – 170.0	*Constant Flux = 0.051 m/d*	*Constant Head = 0.3 m*
170.0 – 177.0	*ET Boundary*	*ET Boundary*
177.0 – 242.0	*ET Boundary*	*ET Boundary*

Table 3. Variable boundary conditions for Scenario 2.

Simulation Days	Variable Boundary Condition 1	Variable Boundary Condition 2
0 – 160.0	*ET Boundary*	*ET Boundary*
160.0 – 161.0	*Constant Flux = 0.051 m/d*	*Constant Head = 0.3 m*
161.0 – 164.0	*ET Boundary*	*Constant Head = 0.3 m*
164.0 – 168.0	*Constant Flux = 0.01 m/d*	*Constant Head = 0.3 m*
168.0 – 170.0	*Constant Flux = 0.051 m/d*	*Constant Head = 0.3 m*
170.0 – 177.0	*ET Boundary*	*Constant Head = 0.3 m*
177.0 – 242.0	*ET Boundary*	*ET Boundary*

Table 4. Variable boundary conditions for Scenario 3.

FIGURES

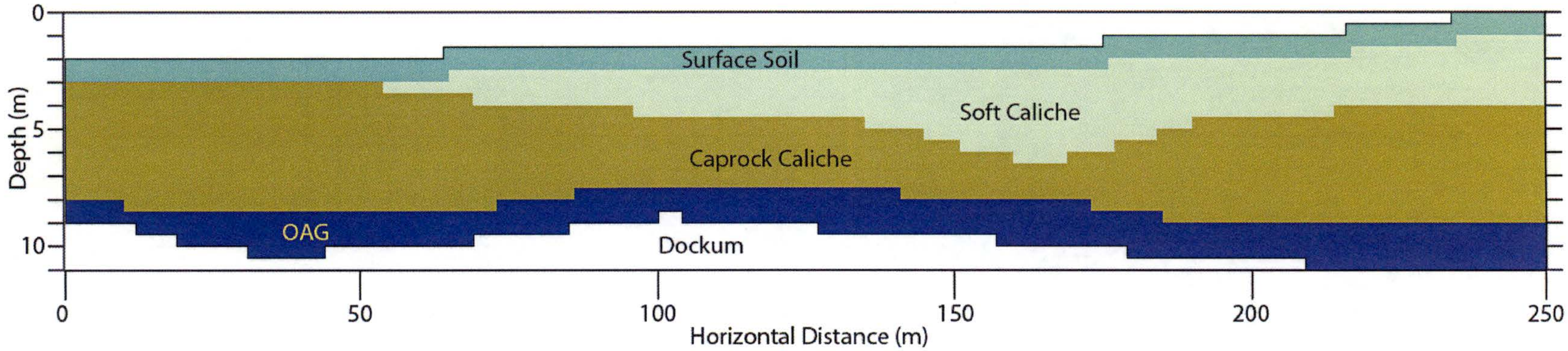


Figure 1. Model domain and hydrogeologic units.

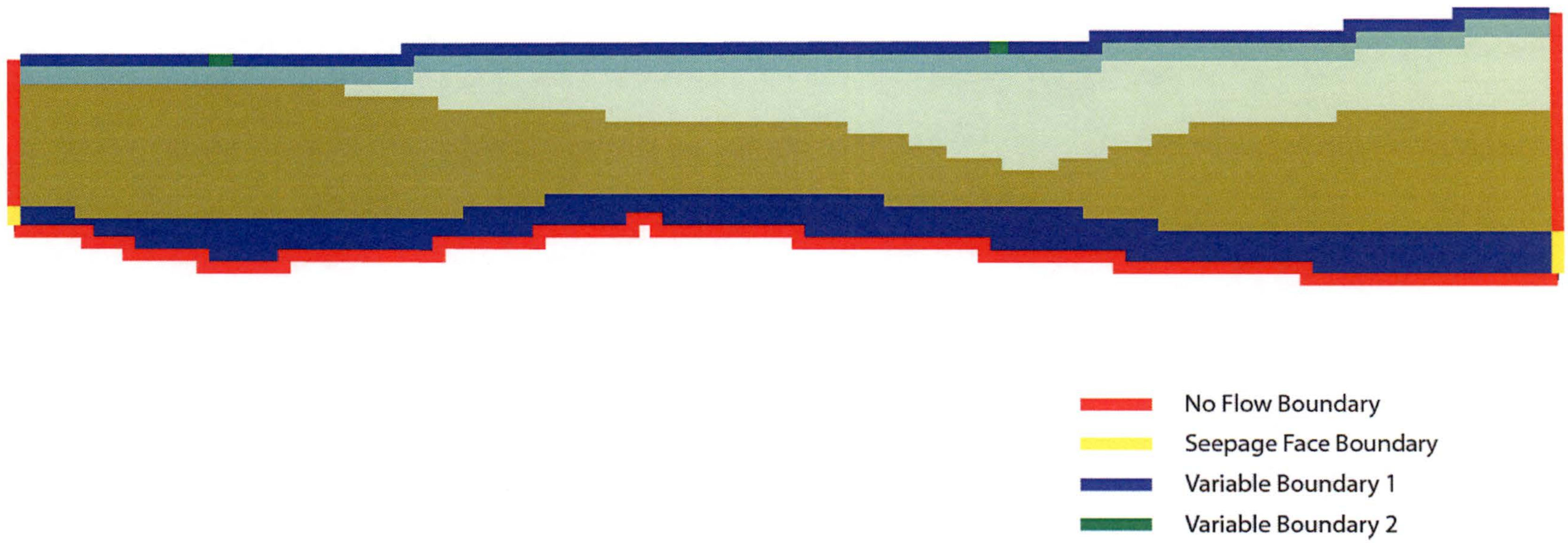


Figure 2. Boundary conditions for Scenarios 1, 2, and 3. Note that the seepage face and no flow boundaries remain constant throughout all three scenarios. Variable boundaries 1 and 2, however, change between the scenarios and their status is reflected in Tables 2 – 4.

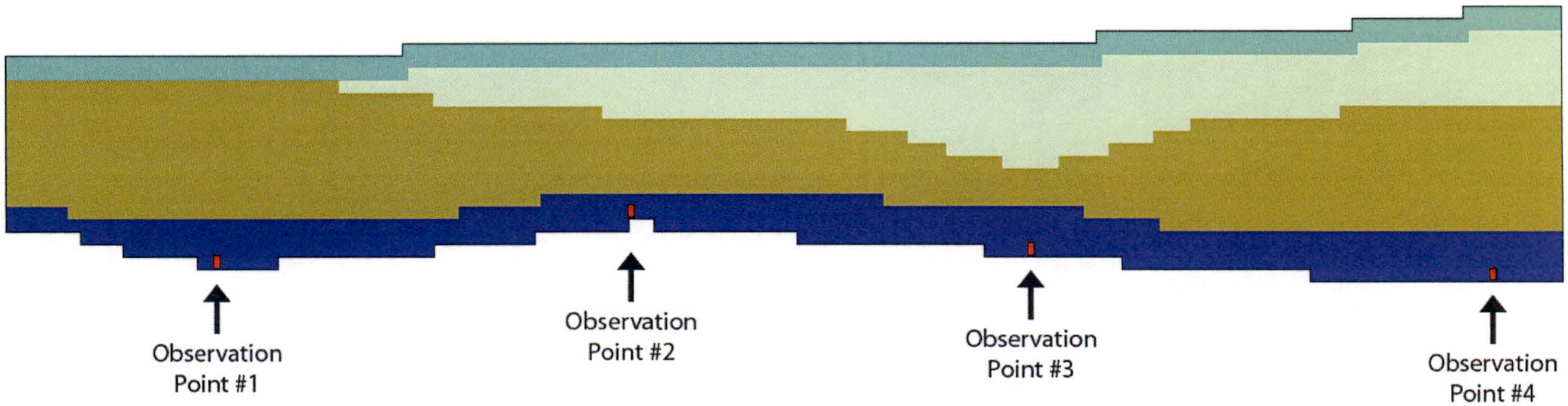


Figure 3. Observation points for all three scenarios.

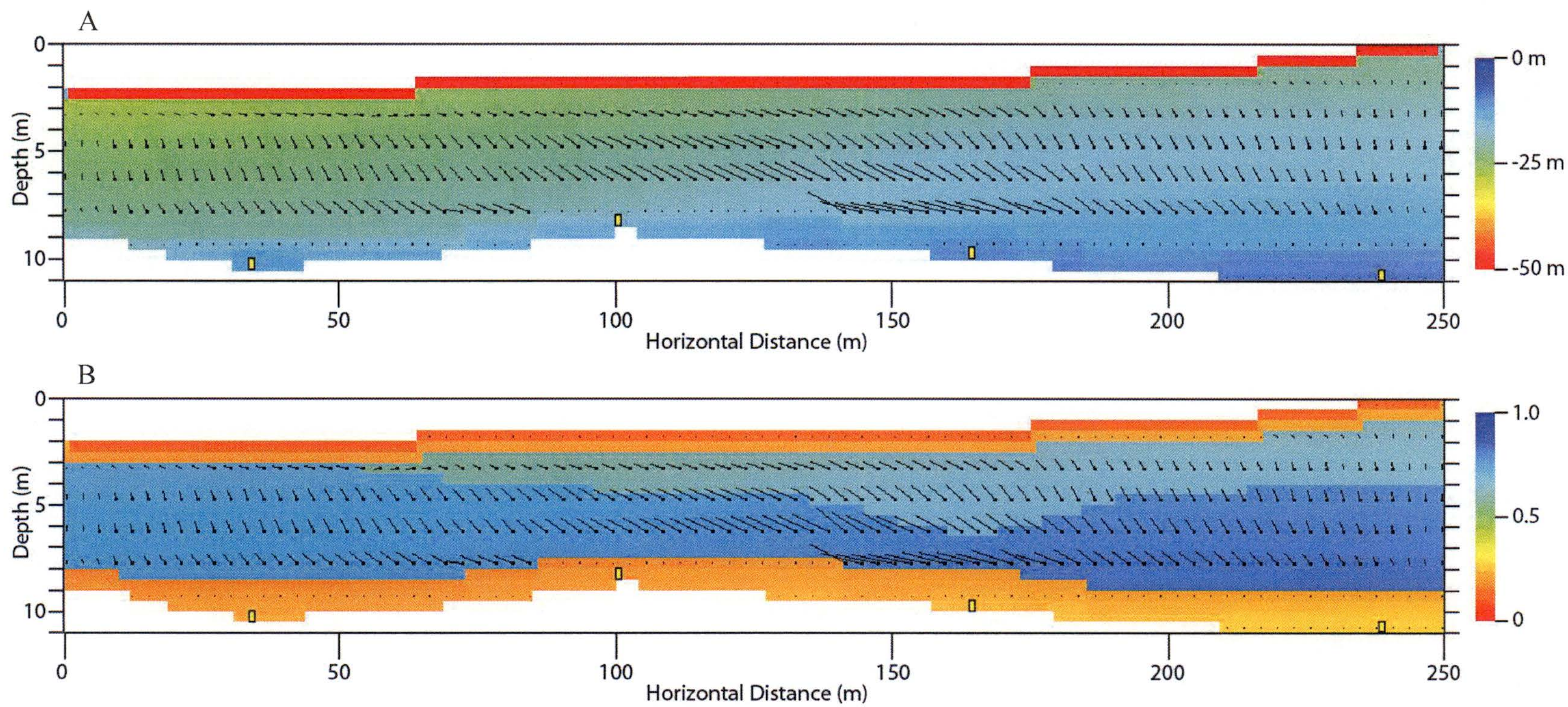


Figure 4. Hydraulic Conditions for following the decay of the initial condition, simulation day 161.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

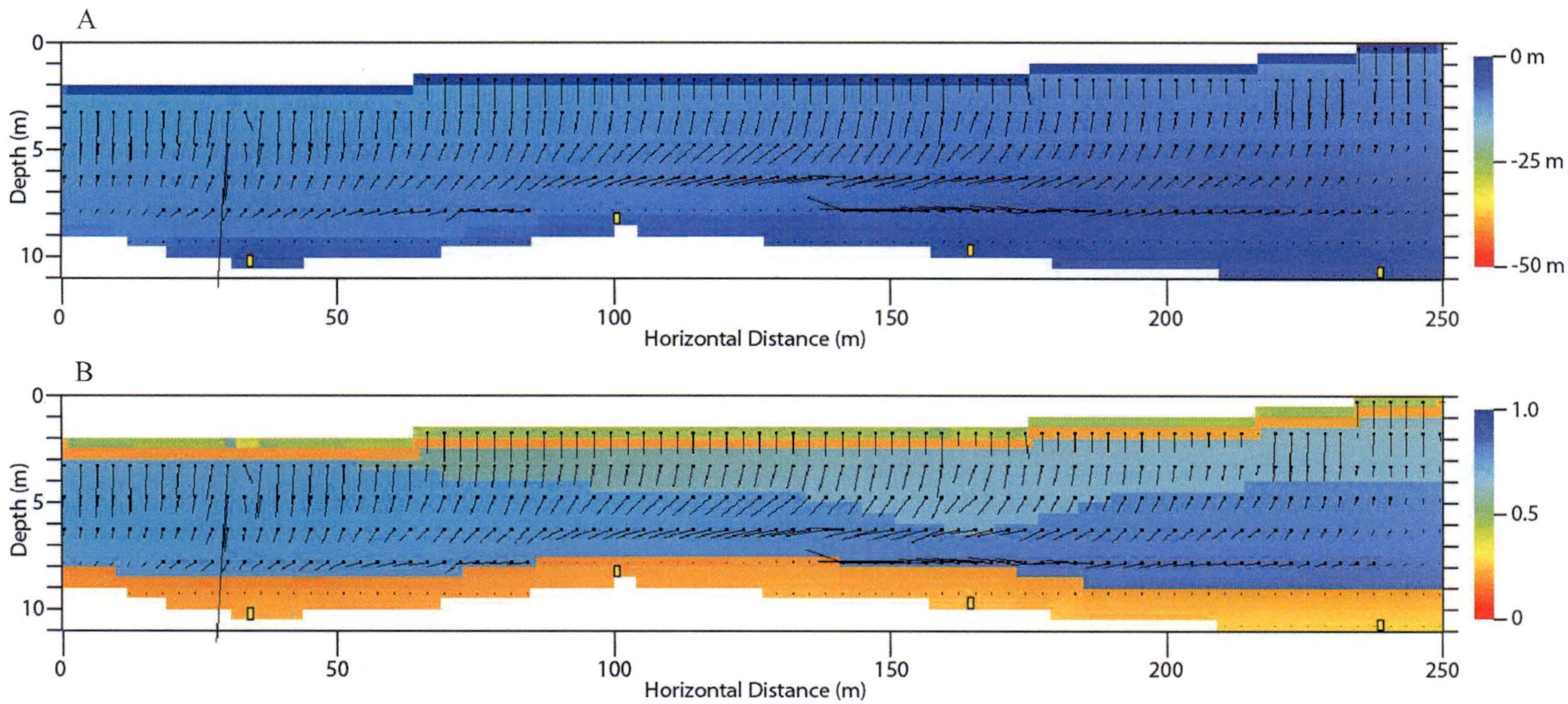
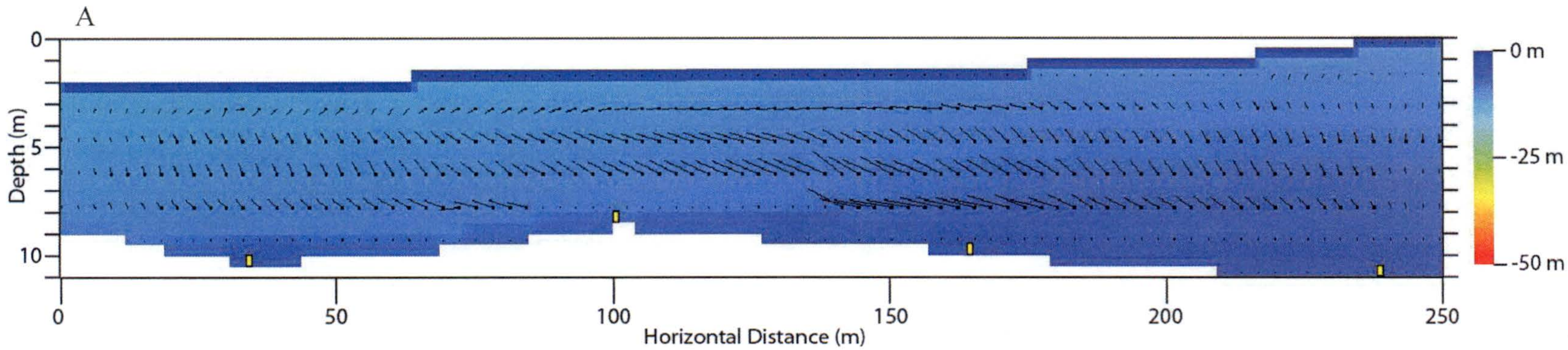


Figure 5. Hydraulic Conditions for Scenario 1, simulation day 161.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.



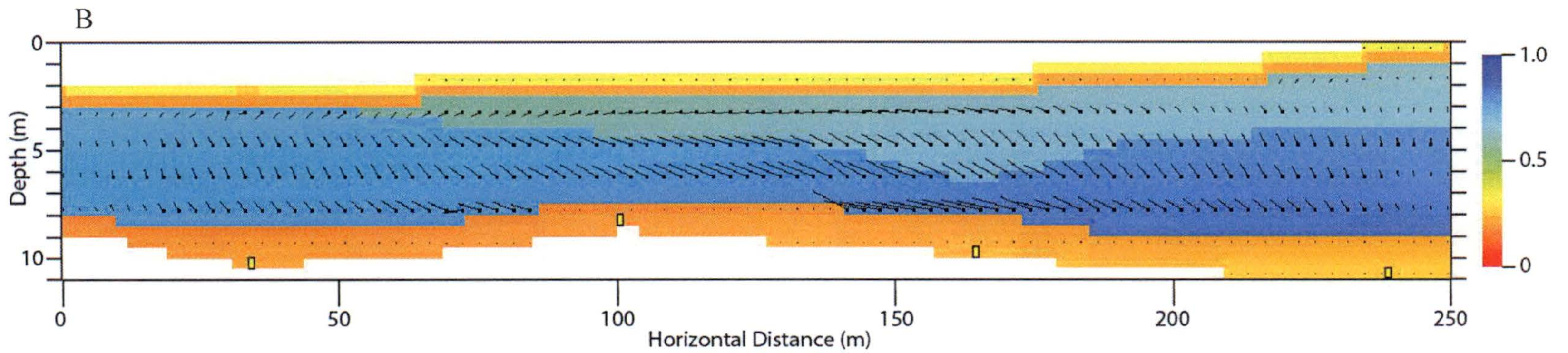


Figure 6. Hydraulic Conditions for Scenario 1, simulation day 164.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

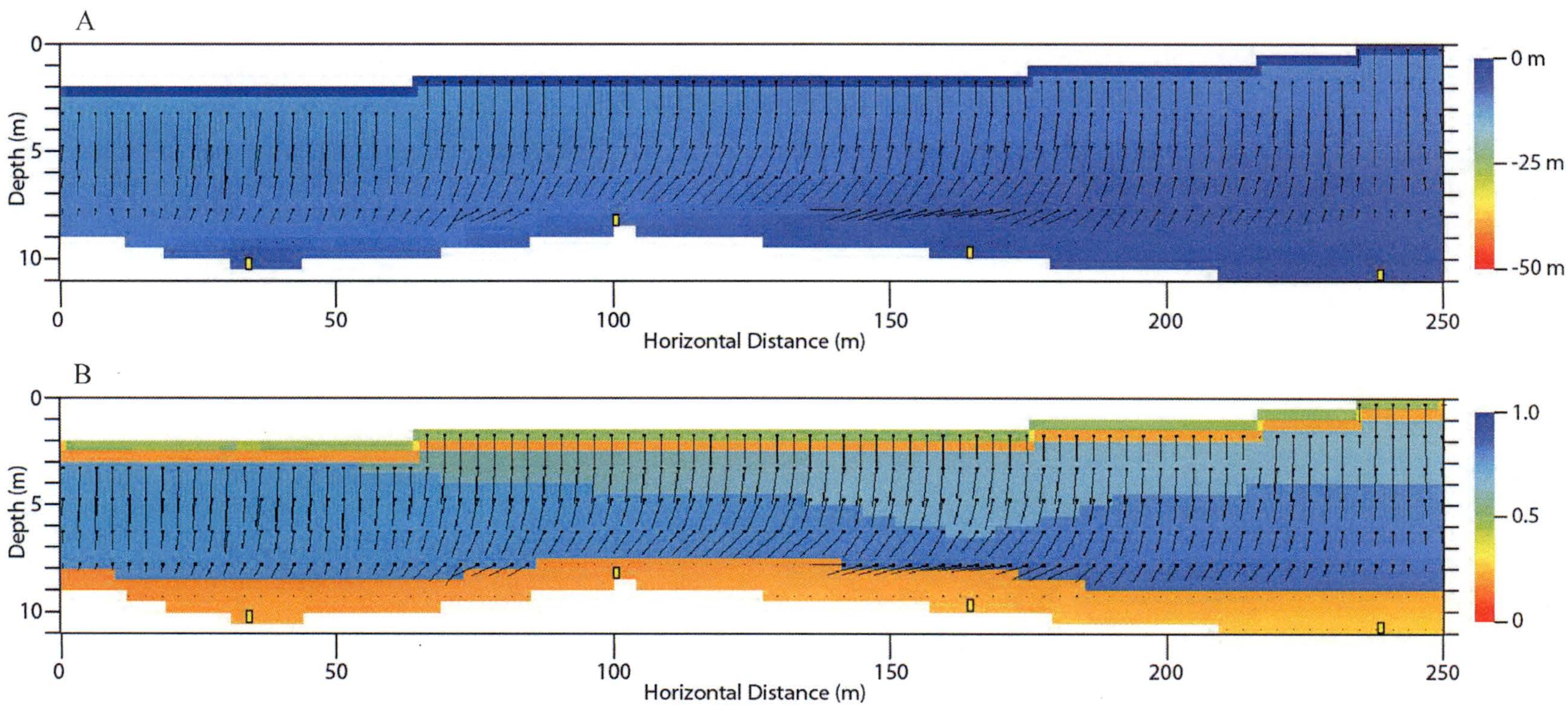


Figure 7. Hydraulic Conditions for Scenario 1, simulation day 168.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

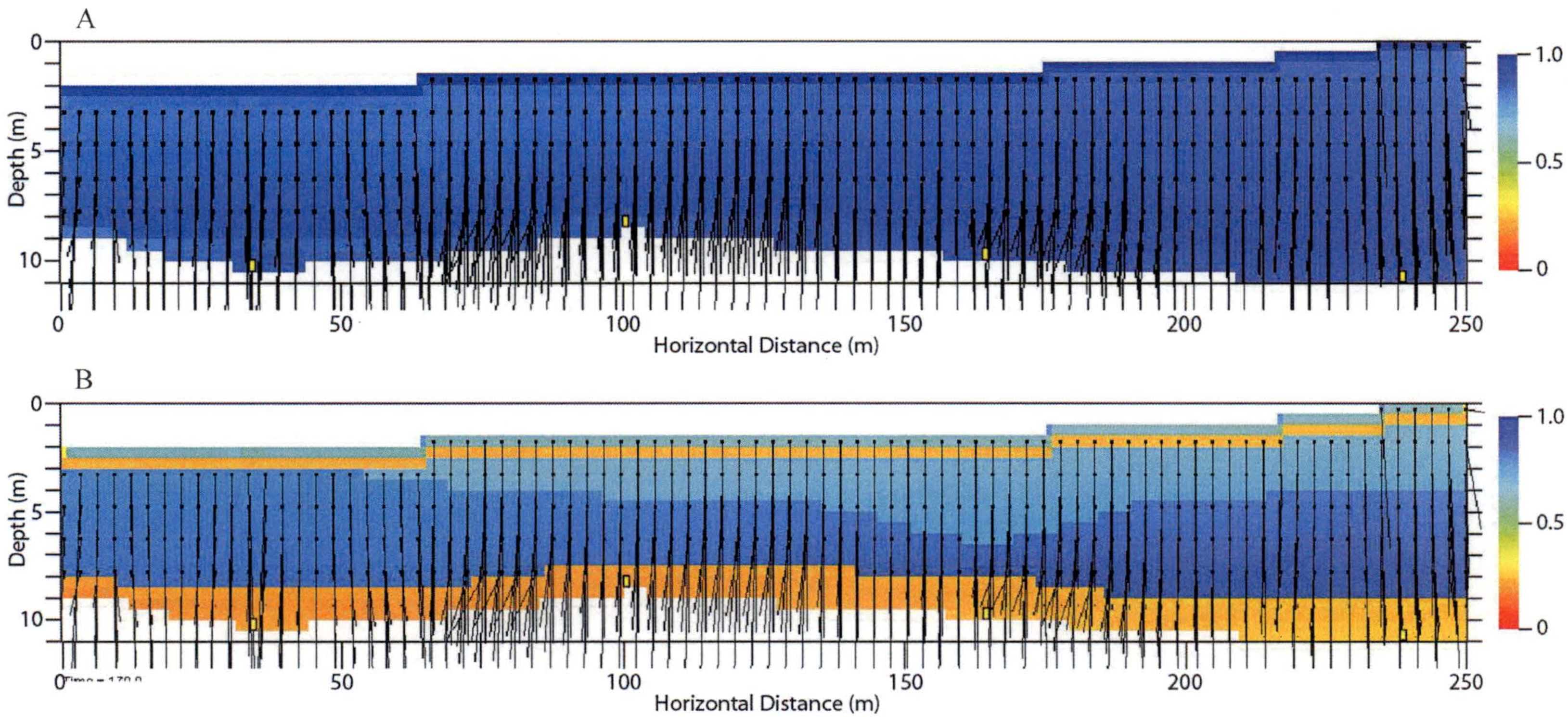


Figure 8. Hydraulic Conditions for Scenario 1, simulation day 170.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

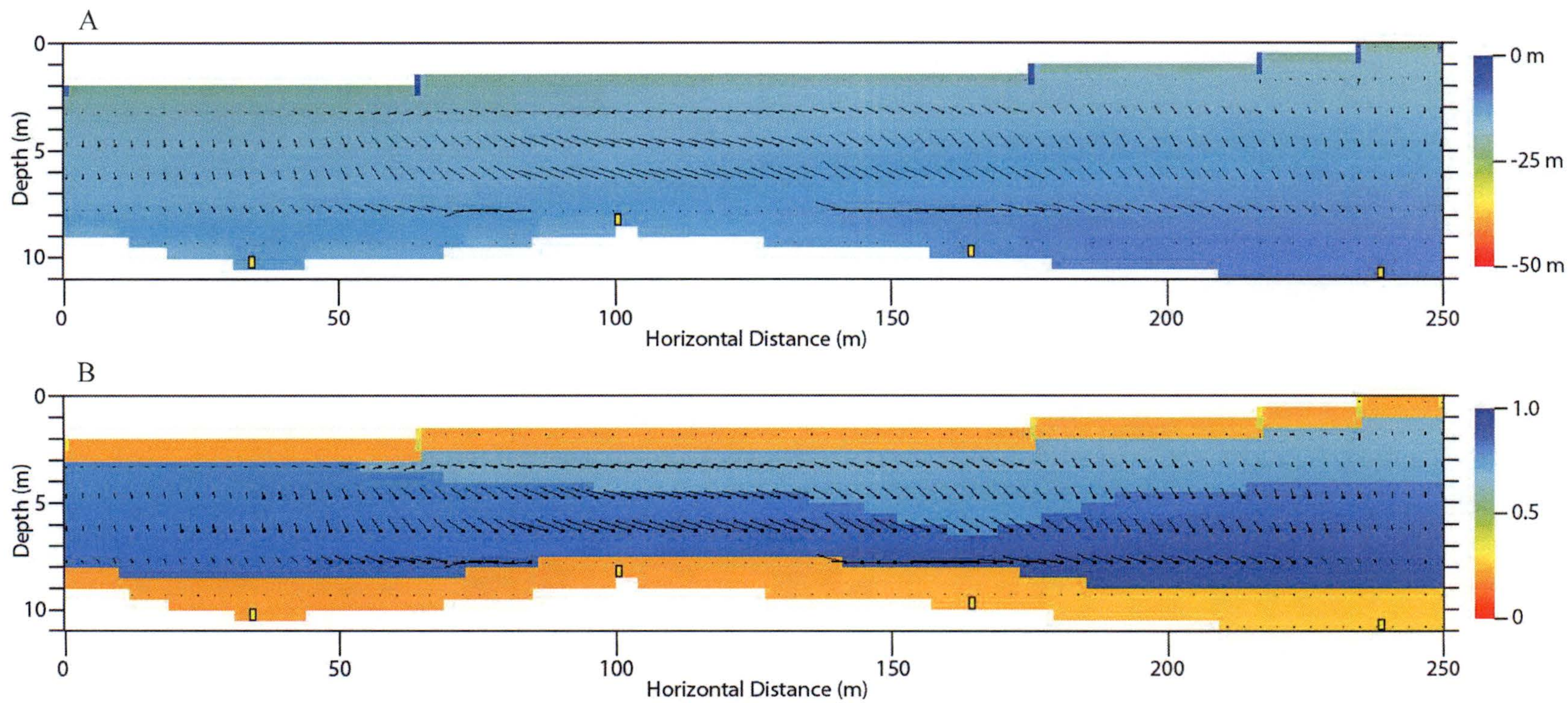


Figure 9. Hydraulic Conditions for Scenario 1, simulation day 177.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

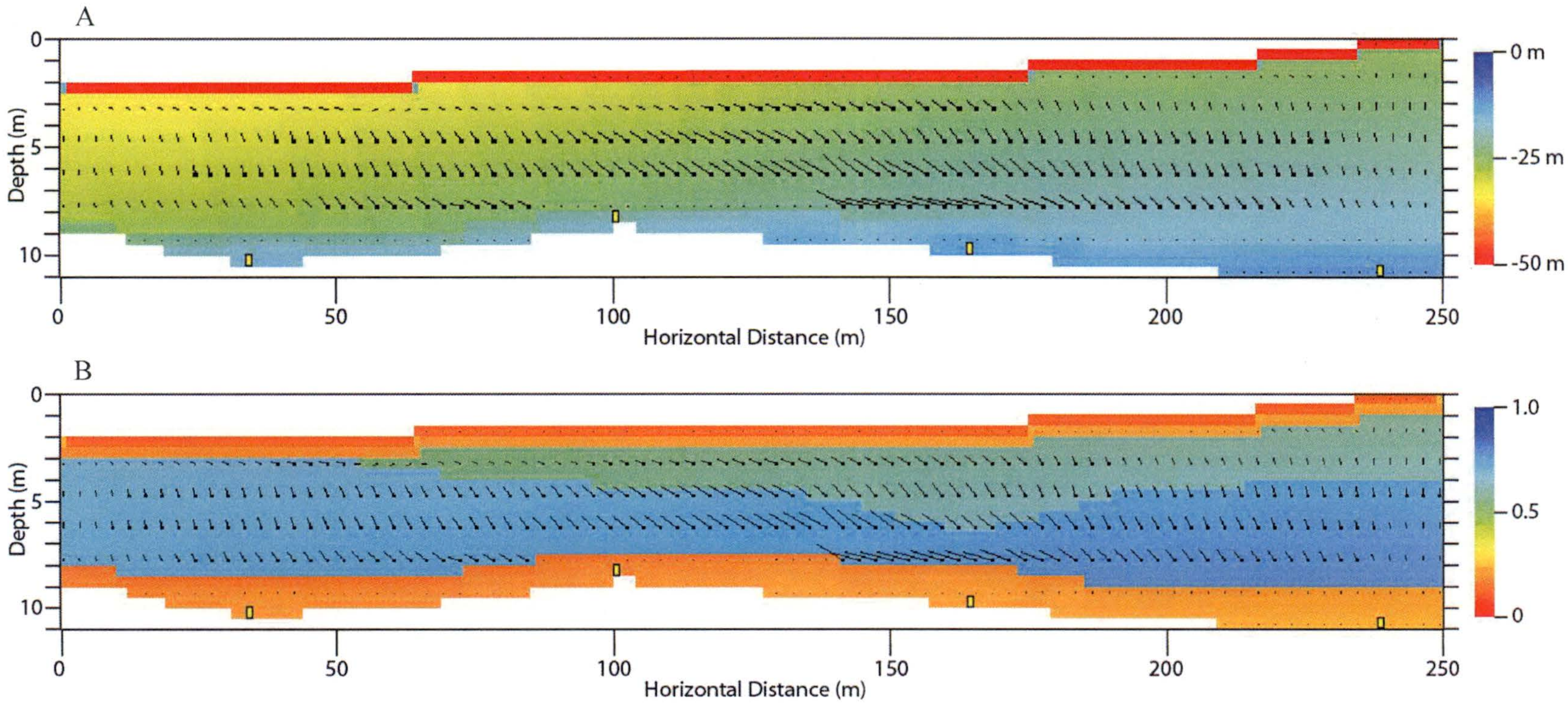


Figure 10. Hydraulic Conditions for Scenario 1, simulation day 242.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

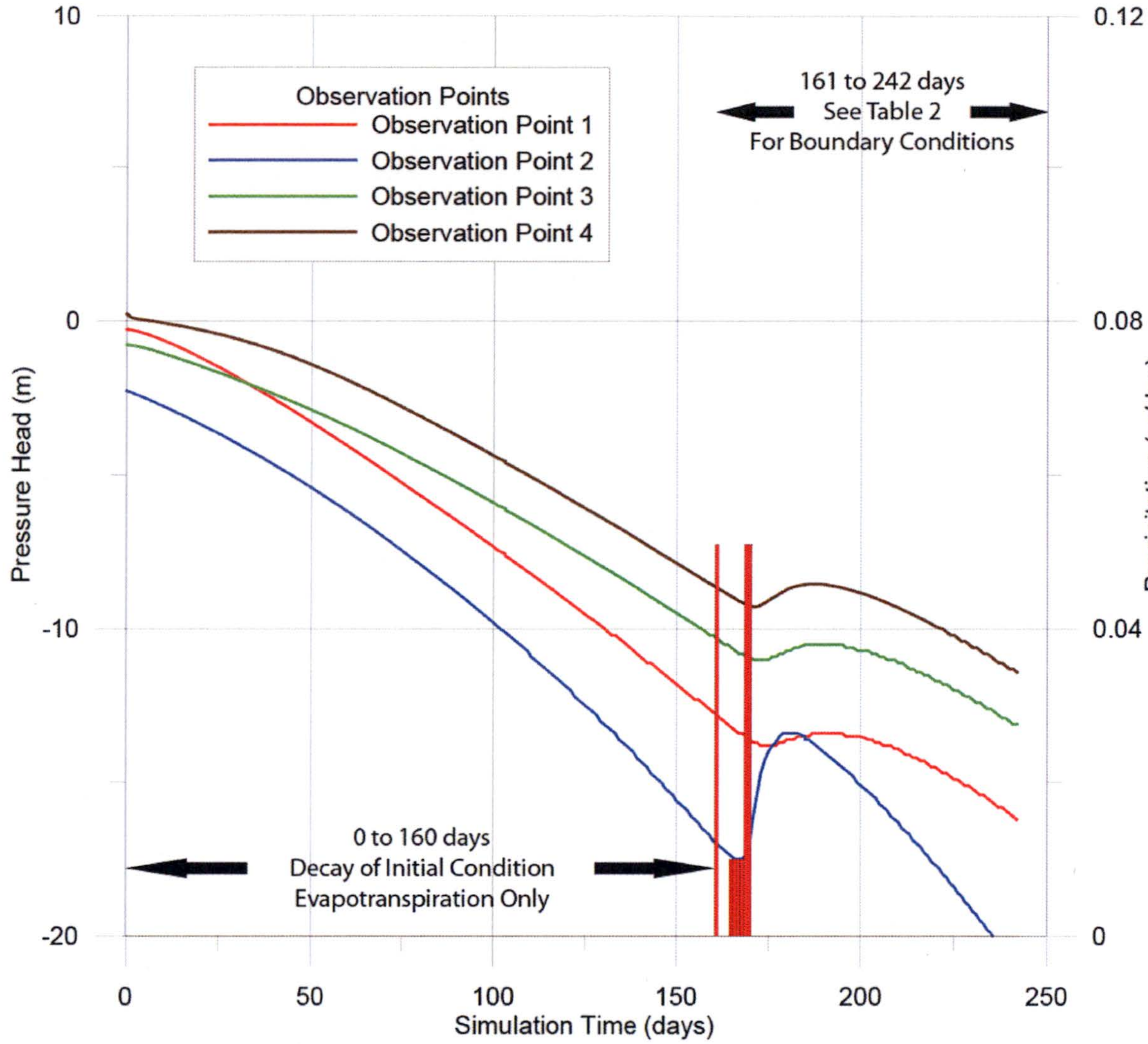


Figure 11. Pressure head and precipitation history for observation points during Scenario 1. Observation point locations are shown in Figure 3. Note that saturated conditions in the OAG are reflected by pressure heads ≥ 0 m.

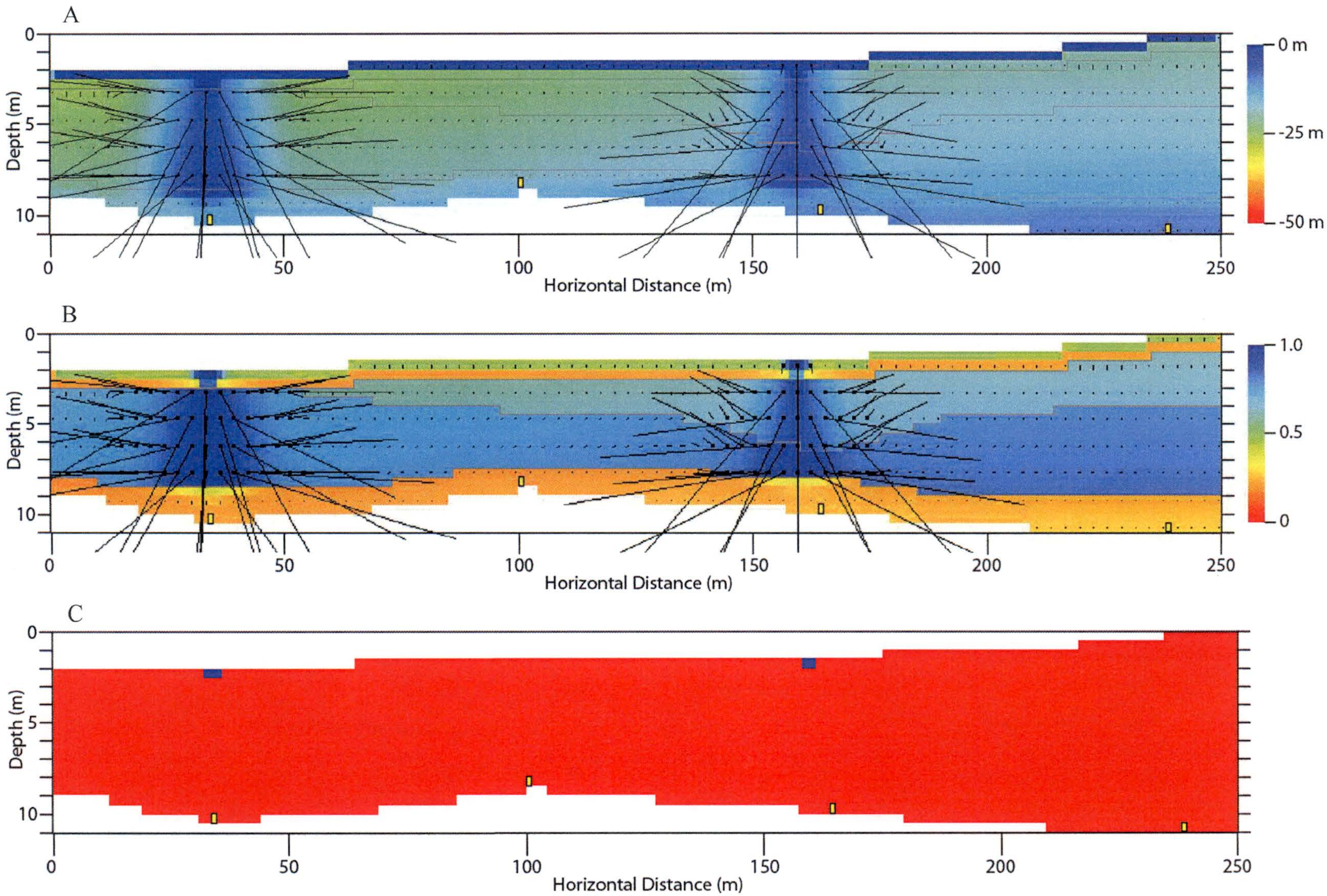


Figure 12. Hydraulic Conditions for Scenario 2, simulation day 161.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

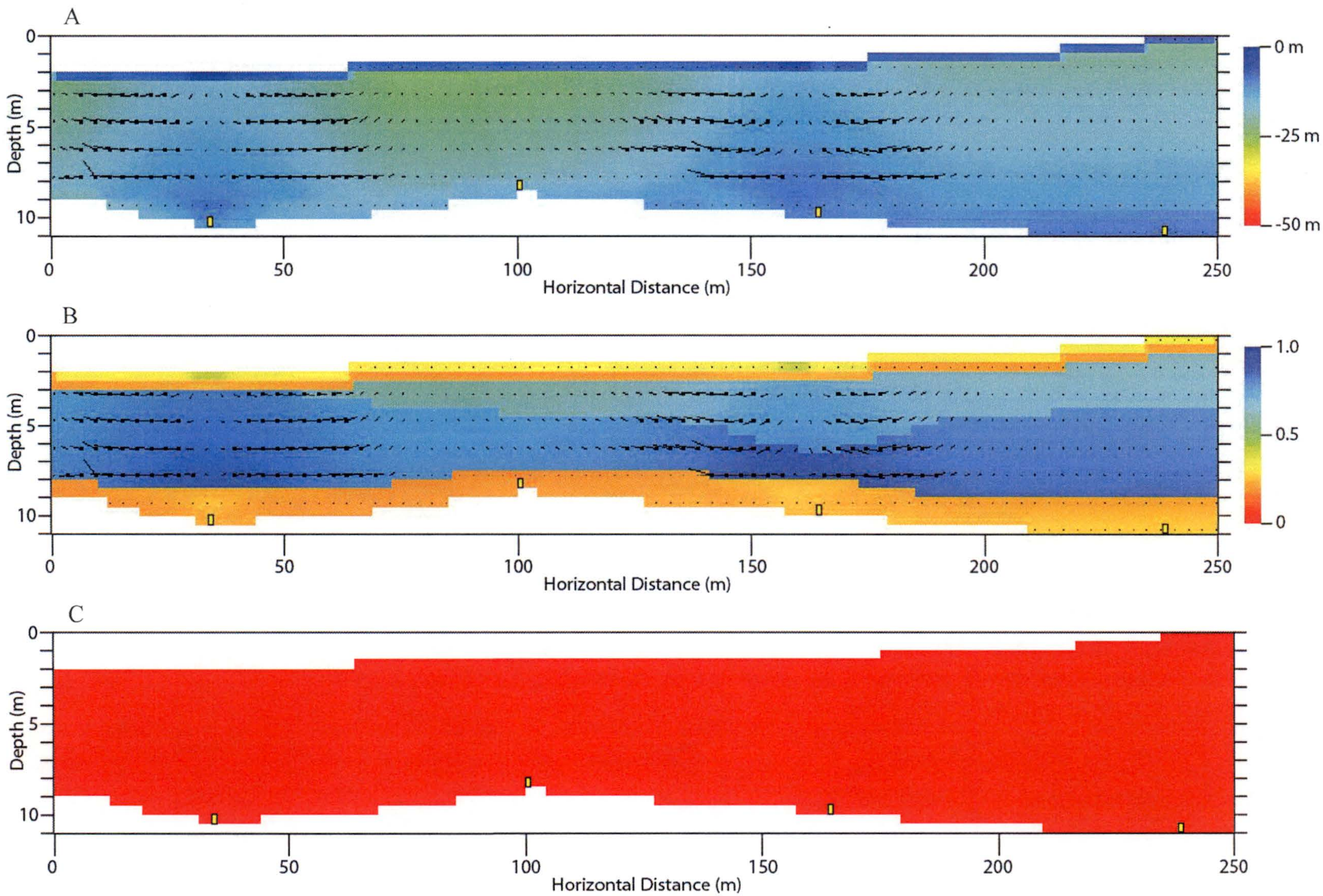


Figure 13. Hydraulic Conditions for Scenario 2, simulation day 164.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

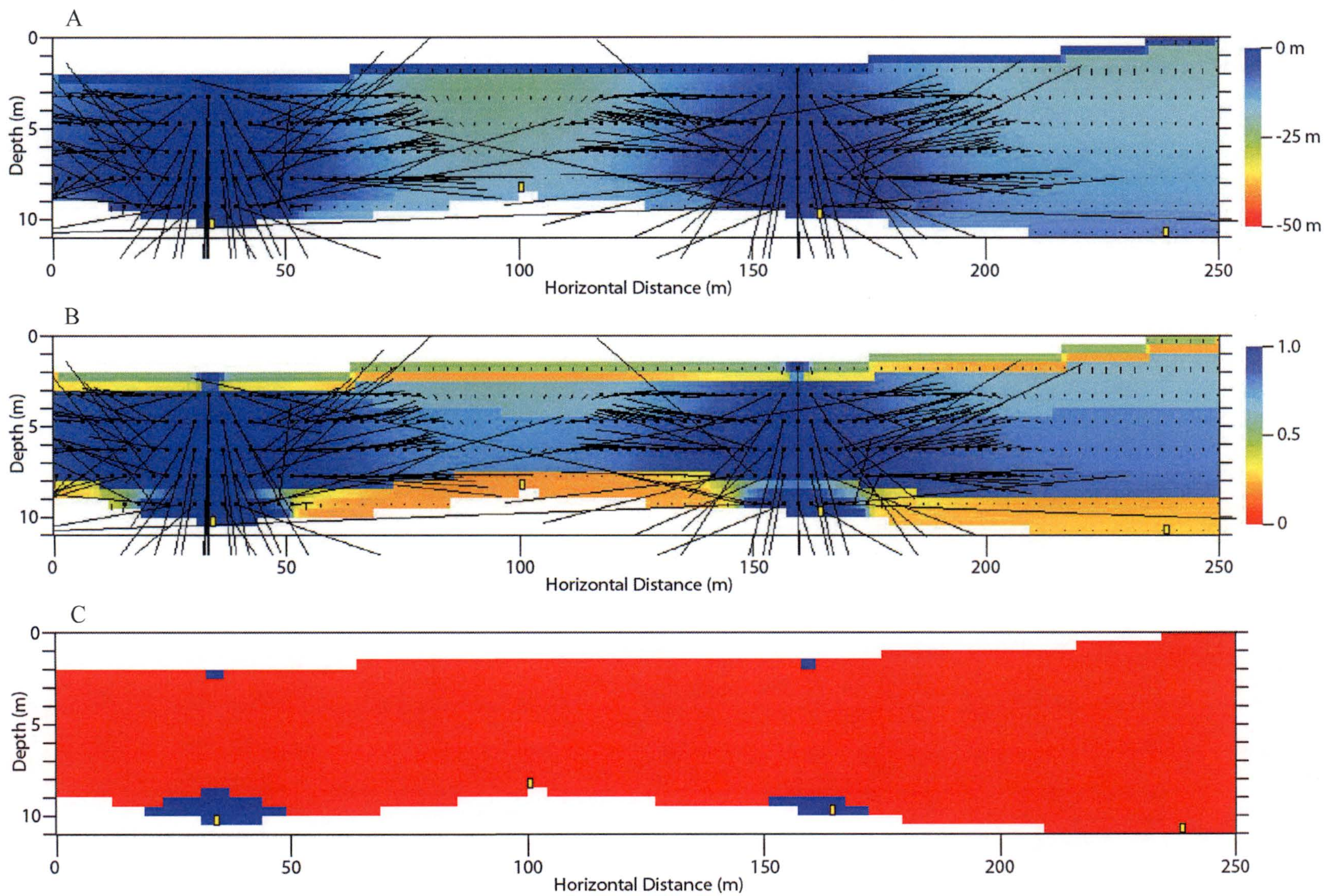


Figure 14. Hydraulic Conditions for Scenario 2, simulation day 168.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

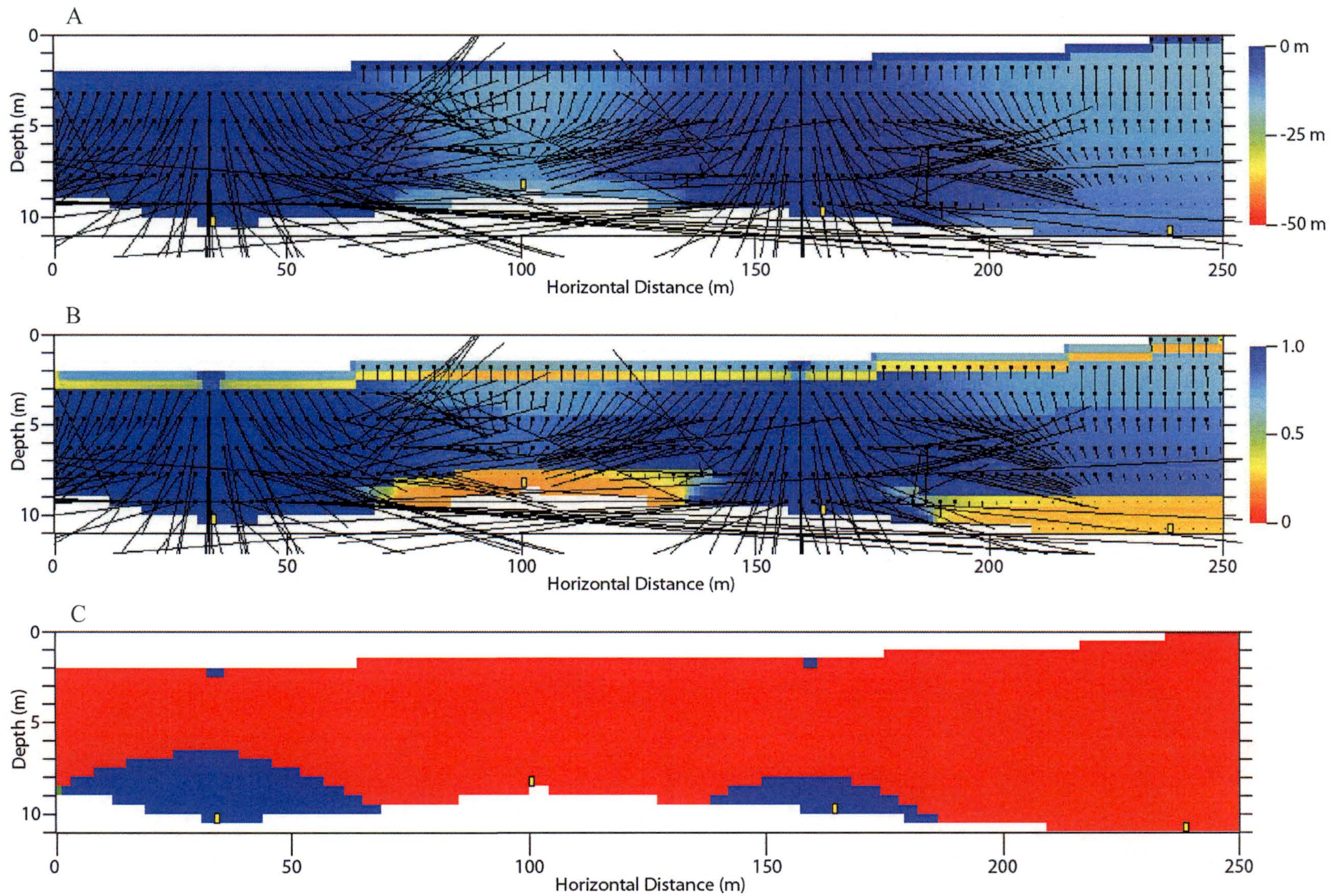


Figure 15. Hydraulic Conditions for Scenario 2, simulation day 170.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

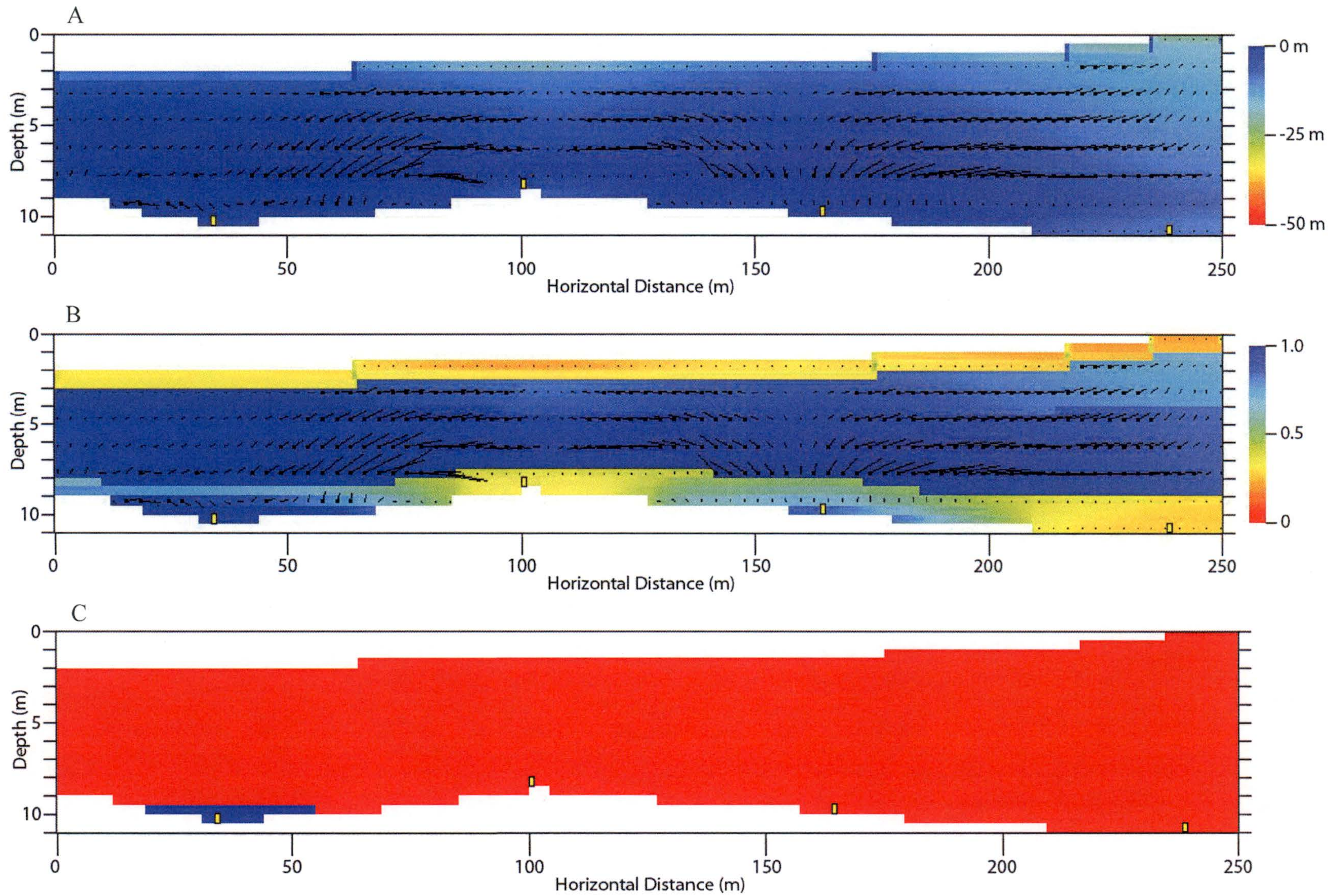


Figure 16. Hydraulic Conditions for Scenario 2, simulation day 177.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

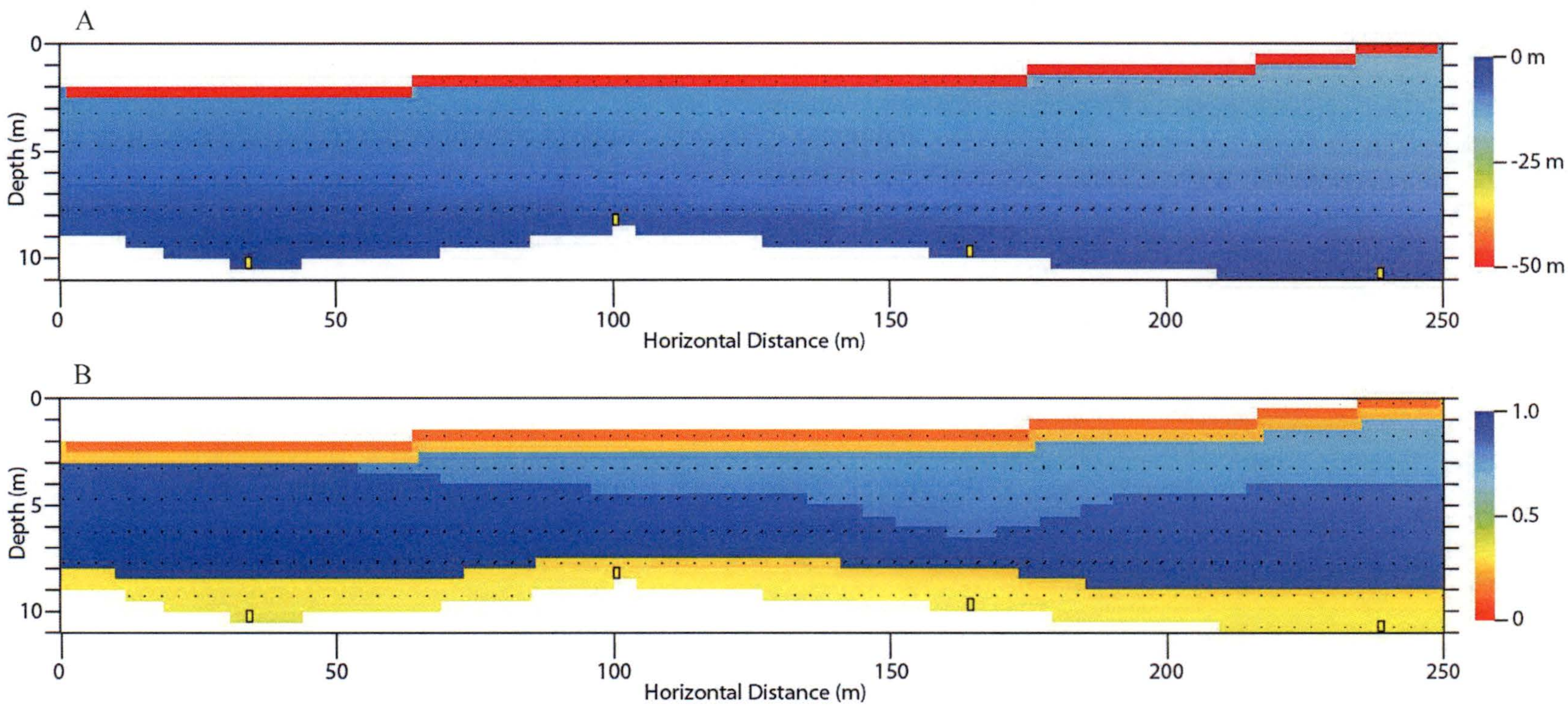


Figure 17. Hydraulic Conditions for Scenario 2, simulation day 242.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

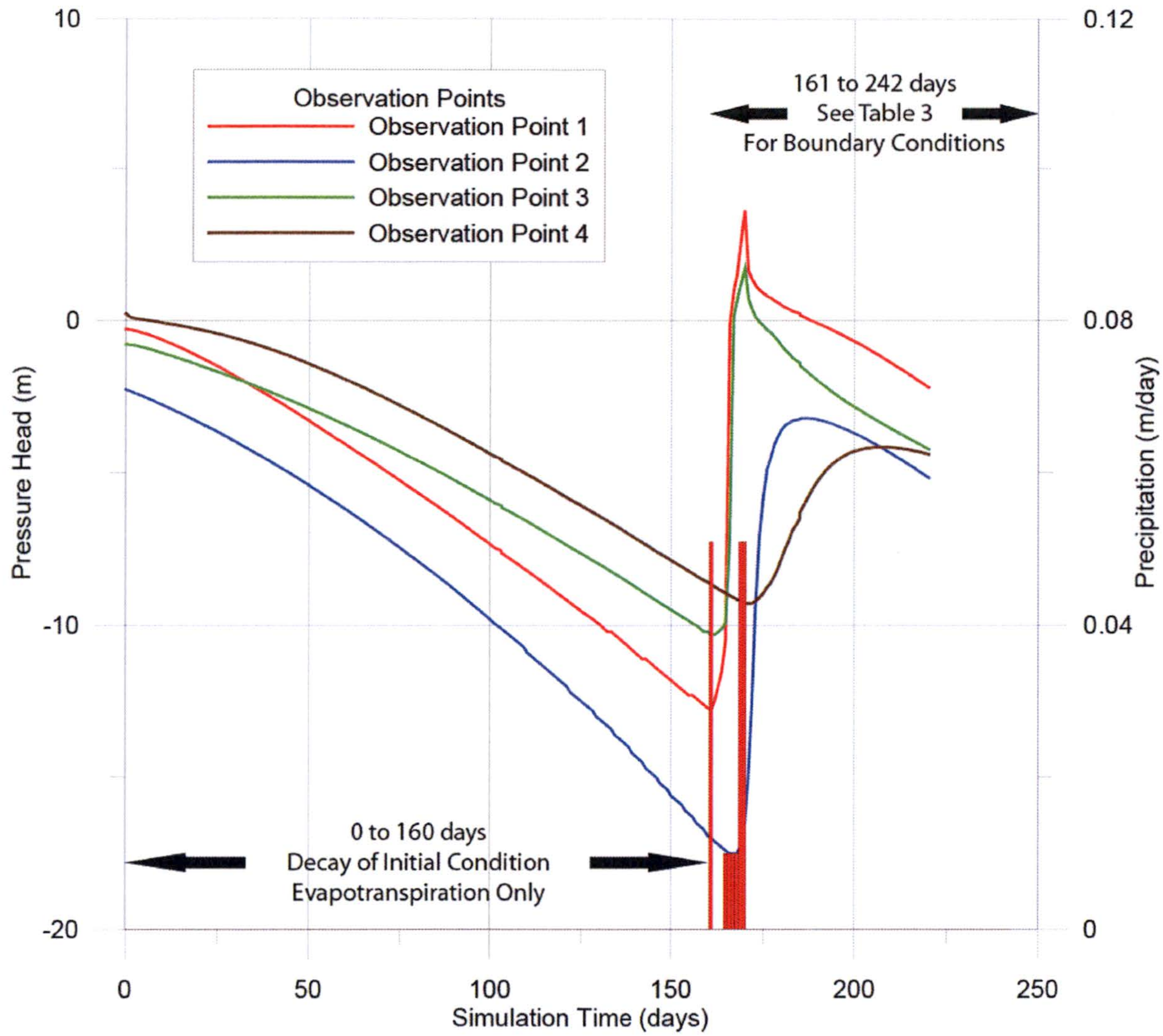


Figure 18. Pressure head and precipitation history for observation points during Scenario 2. Observation point locations are shown in Figure 3. Note that saturated conditions in the OAG are reflected by pressure heads ≥ 0 m.

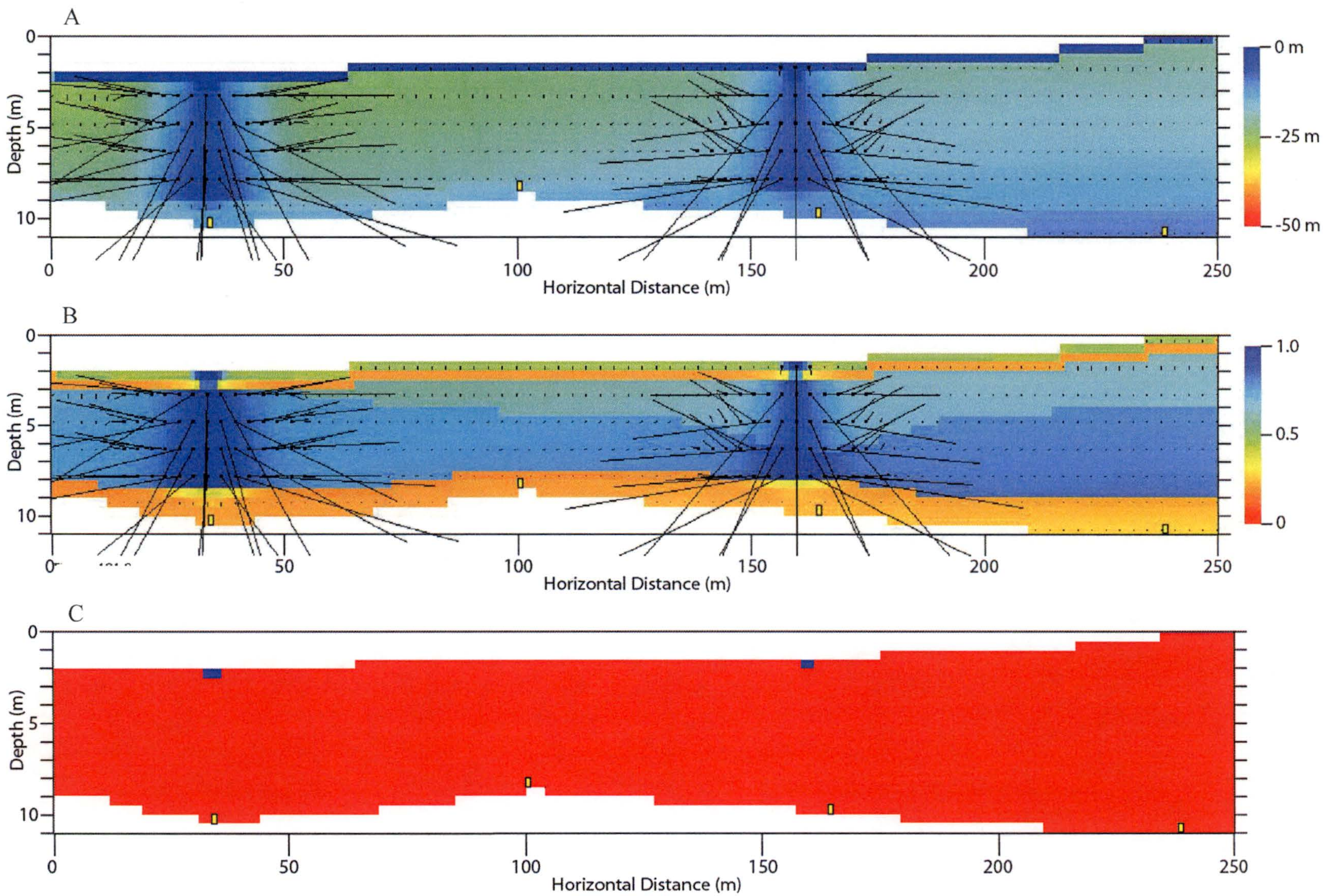


Figure 19. Hydraulic Conditions for Scenario 3, simulation day 161.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

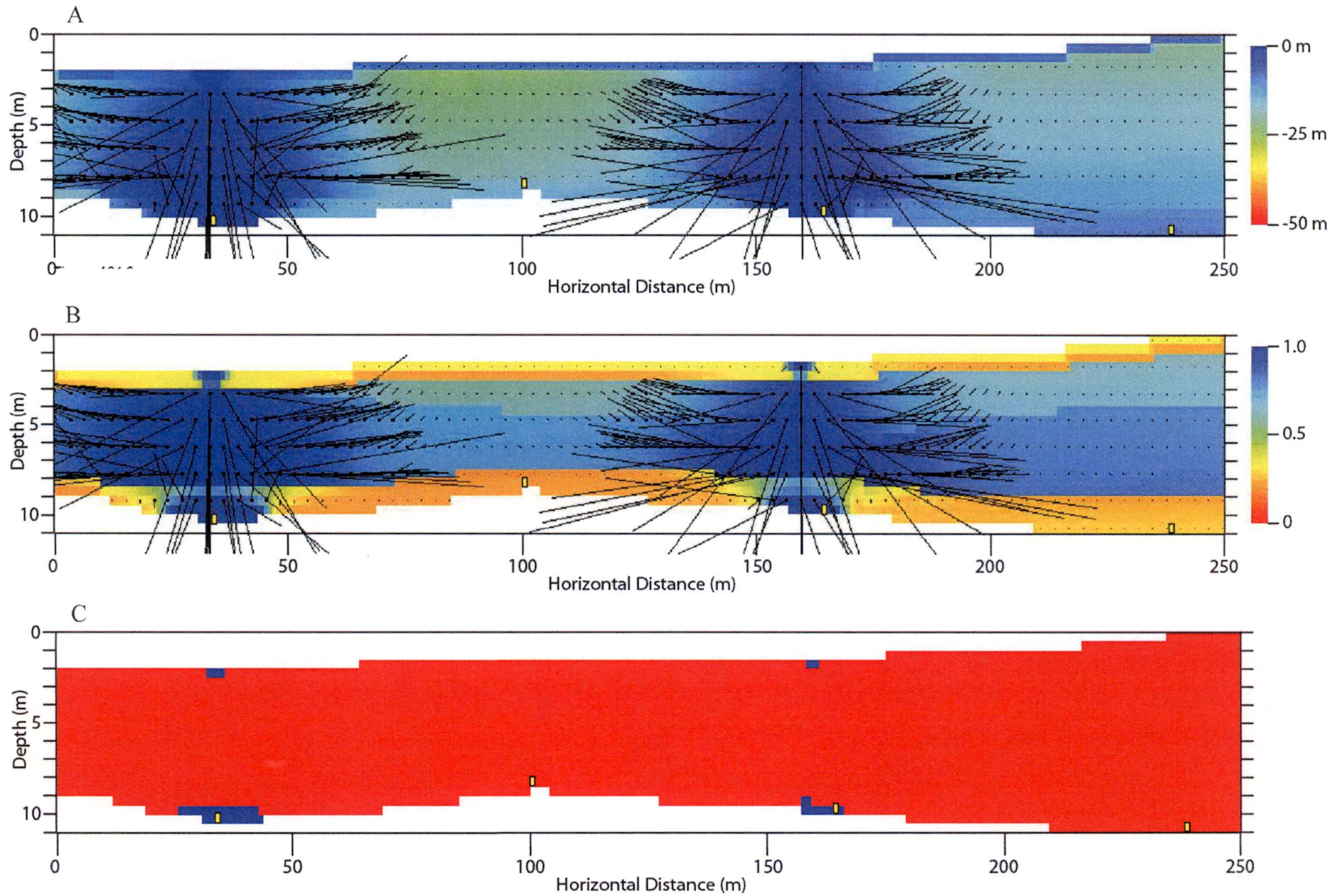


Figure 20. Hydraulic Conditions for Scenario 3, simulation day 164.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

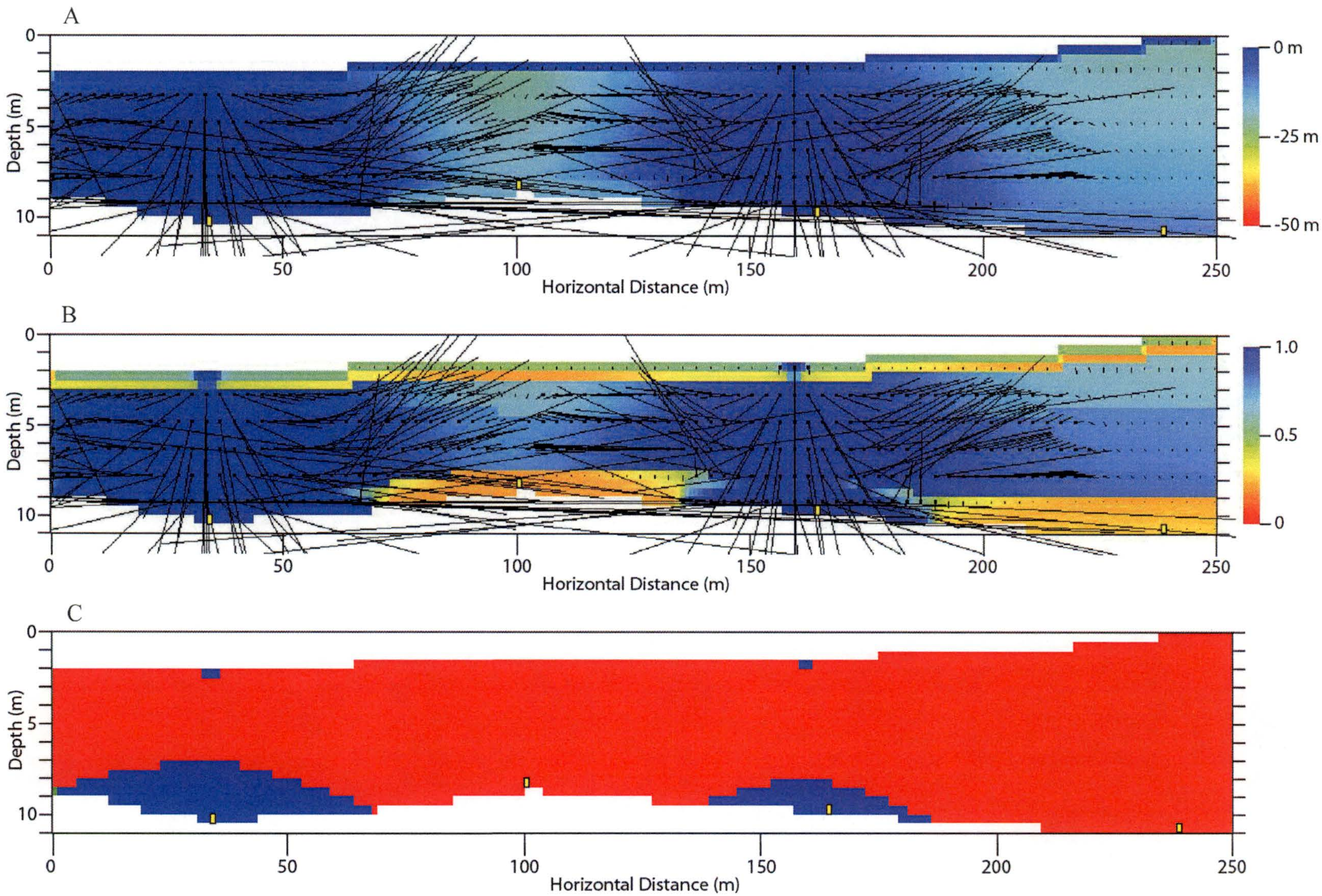


Figure 21. Hydraulic Conditions for Scenario 3, simulation day 168.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

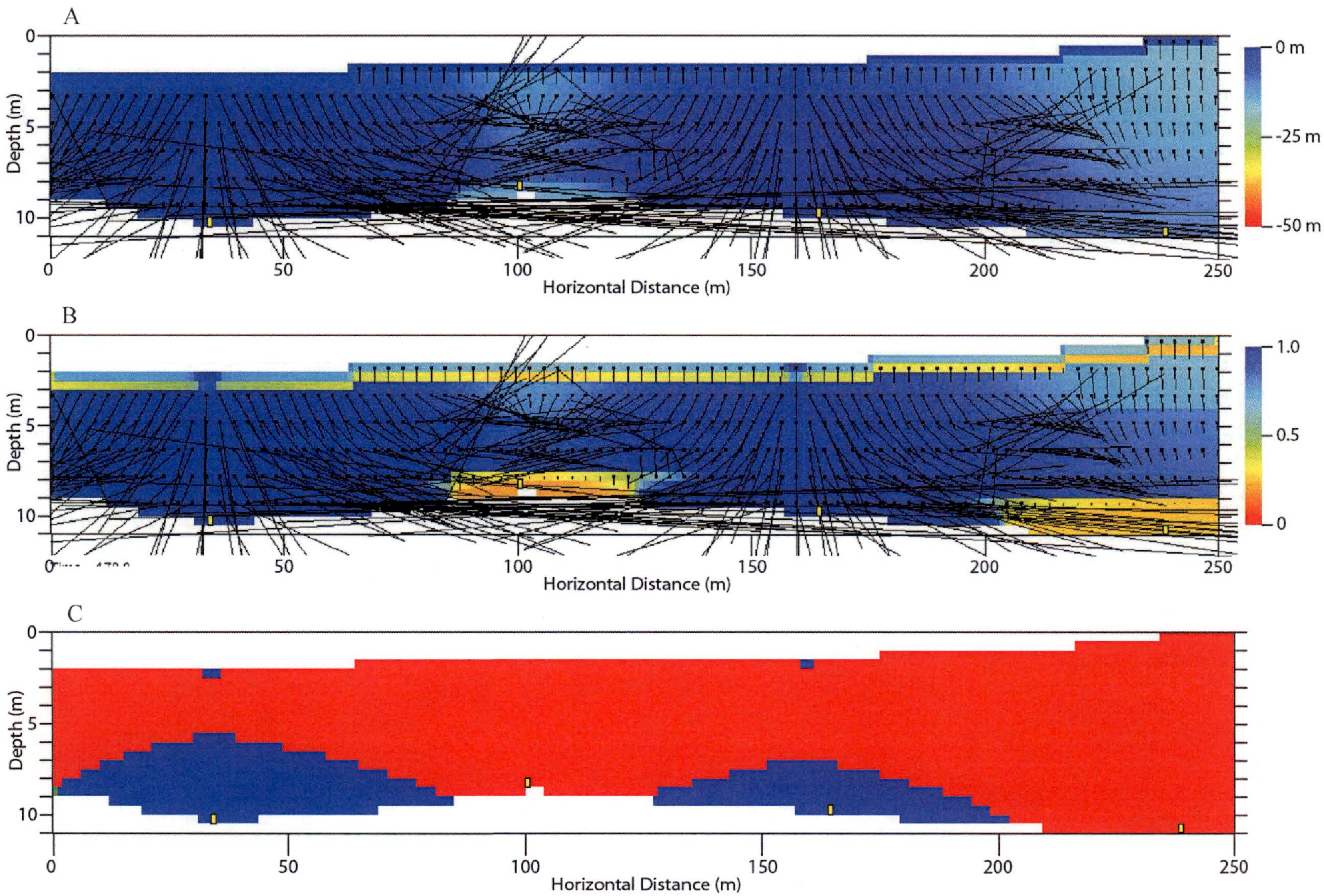


Figure 22. Hydraulic Conditions for Scenario 3, simulation day 170.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

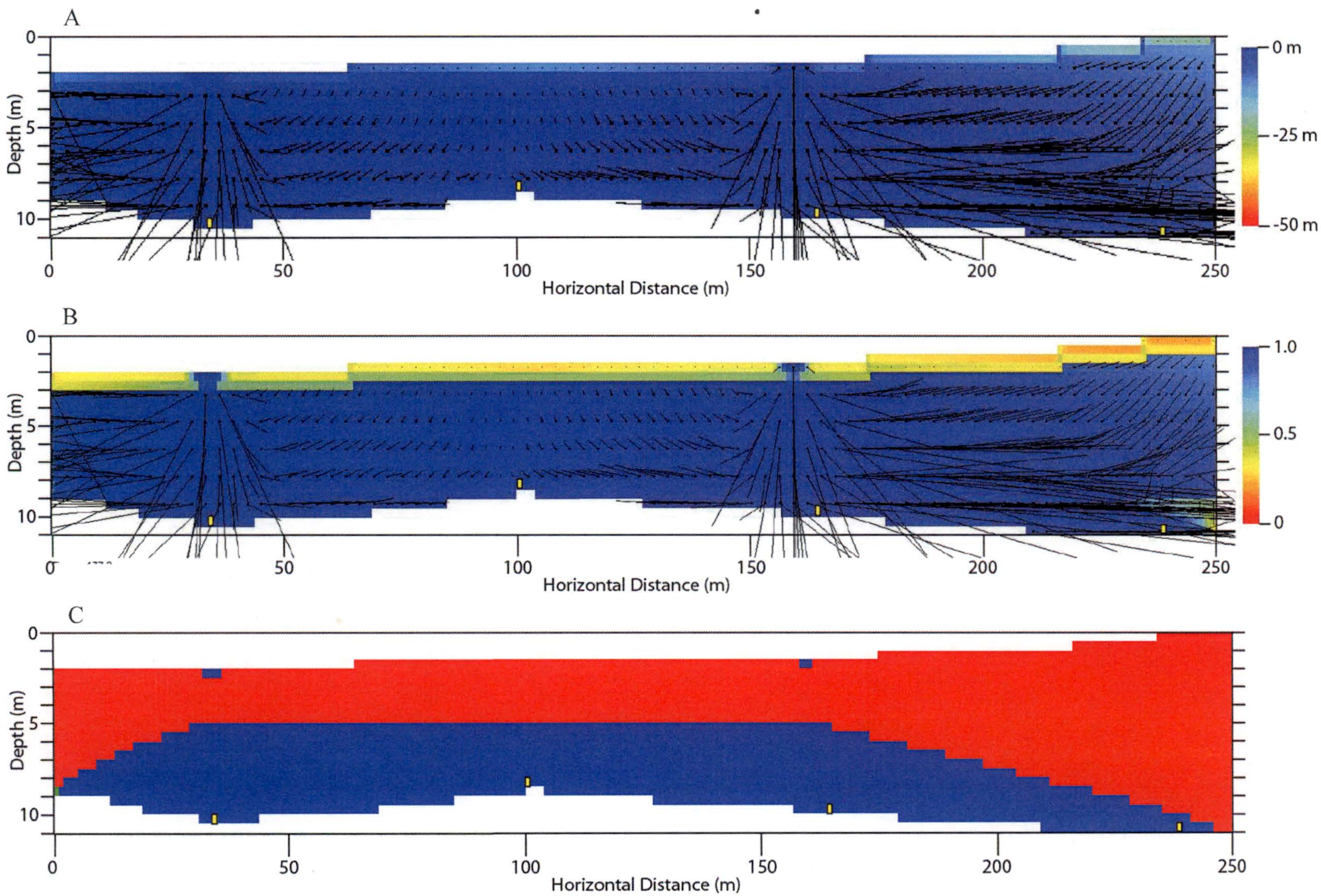


Figure 23. Hydraulic Conditions for Scenario 3, simulation day 177.0: A) pressure head, B) saturation, and C) saturated regions (blue). Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

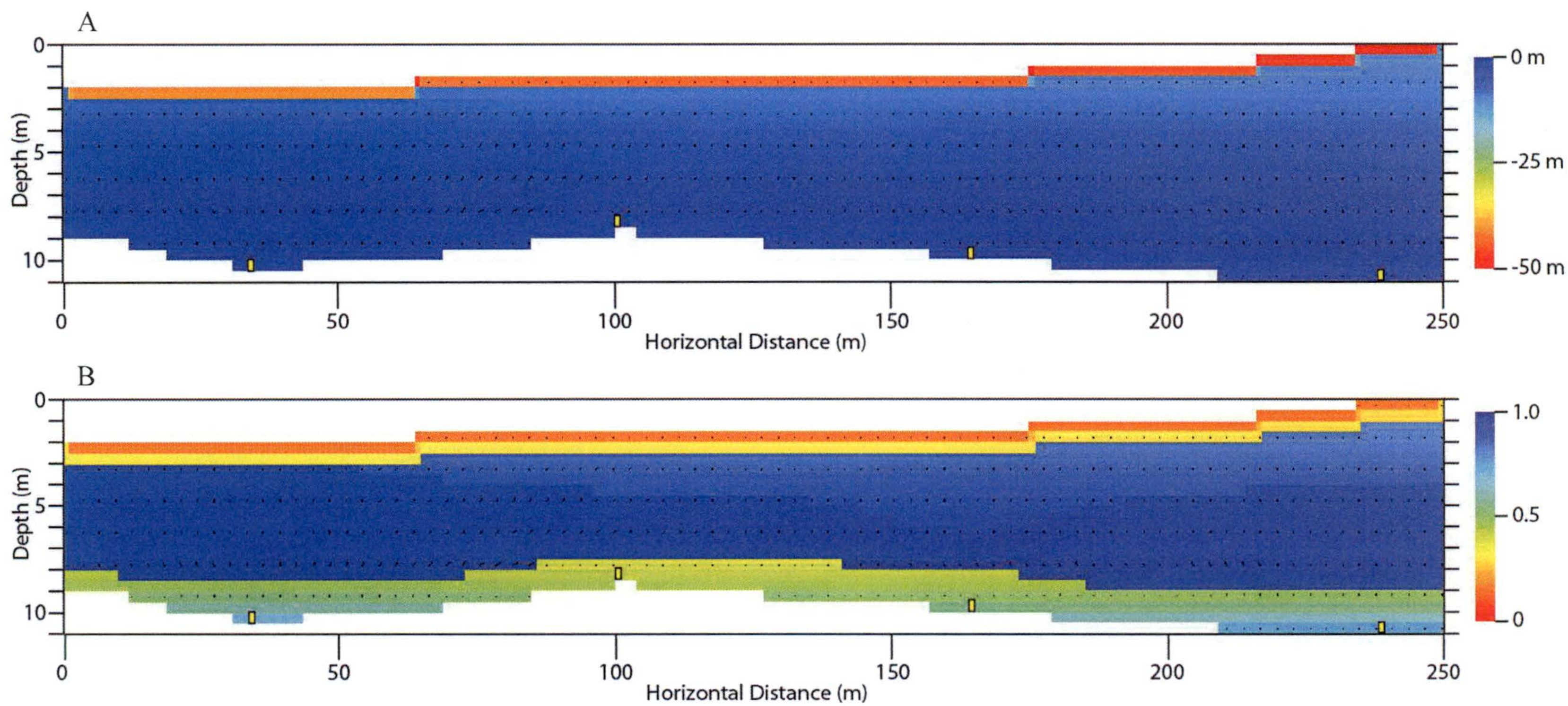


Figure 24. Hydraulic Conditions for Scenario 3, simulation day 242.0: A) pressure head and B) saturation. No saturated regions exist. Flow vectors not to scale. Note that observation points 1 – 4 are depicted from left to right, respectively, in yellow rectangles.

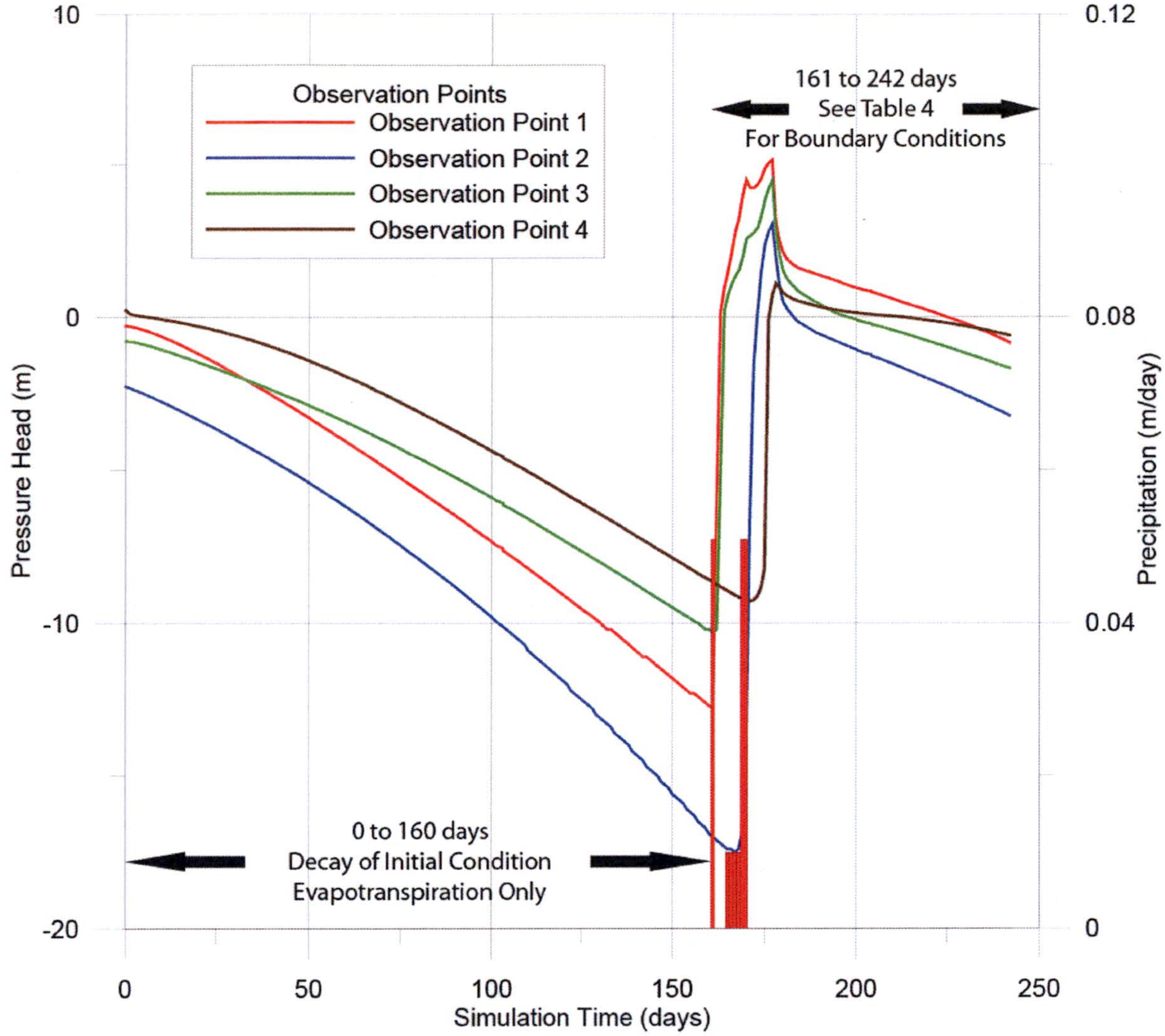


Figure 25. Pressure head and precipitation history for observation points during Scenario 3. Observation point locations are shown in Figure 3. Note that saturated conditions in the OAG are reflected by pressure heads ≥ 0 m.

ATTACHMENT 1
VS2DTI INPUT AND OUTPUT FILES
(On enclosed CD)