INTERA Incorporated
6000 Uptown Blvd, NE
Suite 100
Albuquerque, NM 87110
Telephone: (505) 246-1600
Fax: (505) 246-2600

December 9, 2008

Mr. Guy Bralley
Water Administrator
Sandoval County
P.O. Box 40
Bernalillo, New Mexico 87004

RE: Delivery of DRAFT Aquifer Test Report
Rio Puerco Brackish Water Development Project
Sandoval County, New Mexico

Dear Mr. Bralley:

INTERA Incorporated (INTERA) is pleased to submit this Draft report documenting the aquifer testing and analysis which took place over the past several months. We are providing two bound copies which include the paper copies of the main text of the report. A CD is enclosed which contains the entire report in pdf as well as all of the test data in electronic format. We are also delivering paper copies of the project field notes so that you can conveniently refer to field activities during the project.

This report reflects our best professional efforts to conduct the test and analyze the resulting data. It also includes an assessment of the ground water resource potential. Our assessment is based on a number of assumptions which are defined in the document and we have provided a range of potential reservoir capacities, rather than a single number.

We look forward to your review and comment and we are available to discuss any portion of this DRAFT report at your convenience.

Should you have any questions or need additional information, please call me at (505) 246-1600.

Sincerely,

INTERA, Incorporated

R M Sengebush

Robert M. Sengebush, R.G.
Senior Project Manager/Geologist

RMS for

Cynthia Ardito
Program Manager

FILE: SAN-001-01-09

Draft Sandoval County Rio Puerco Basin Water Development Project

Aquifer Test and Analysis Report

Prepared for:

Sandoval County

Prepared by:

INTERA Incorporated
6000 Uptown Blvd, NE
Suite 100
Albuquerque, NM 87110

December 9, 2008

Executive Summary

A 31-day aquifer test in Well 6 was conducted by INTERA, Incorporated (INTERA) on behalf of the Sandoval County Development Department during October and November 2008. The purpose of the test was to determine the aquifer characteristics of a confined, brackish aquifer located over 3,000 feet beneath the Rio Puerco Valley and to estimate the long-term production potential of this aquifer. The target water-bearing units include the Agua Zarca Sandstone, the San Andres Limestone and the Glorieta Sandstone (SAG), as well as other sandstone zones beneath these units. Only the SAG and a small portion of an underlying sandstone zone are open in Well 6; the Agua Zarca would likely contribute to the aquifer potential if it were open to the well.

Data analysis was conducted by two separate methodologies to provide a range of possible results. The resultant ground water production potential is compared to the estimated future demand of 43,200 acre feet per year identified by the Sandoval County Development Department. The following table compares the range of potential ground water production, in acre feet, to the projected demand. The total potential ground water production is defined here as the aquifer parameter of storativity (S) times the area (A) times the change in head (Δh) (Fetter, 2001).

Potential Ground-Water Production and Demand	Analysis A	Analysis B
Total Potential Ground Water Production (acre feet)	2,657,280	576,000
Estimated Total Development Demand (acre feet per year)	43,200	43,200
Years of Water Supply at Estimated Demand Level	62	13

Analysis A, which represents the first data analysis method, indicates a possible total reservoir volume of 2.65 million acre feet, while Analysis B, the second methodology, indicates a capacity of 576,000 acre feet. The range between these estimates is entirely due to a factor of ten difference in the storativity values calculated by the two analyses. Analysis A indicates that the potential water supply is adequate to meet the Sandoval County's estimated total development demand of 43,200 acre feet per year for a period of 62 years. This analysis relied on an aquifer testing tool, nSights that was developed jointly by INTERA Engineering (an affiliate company of INTERA located in Ontario, Canada) and Sandia Laboratories. The nSights analysis yielded a storativity factor which was used, in combination with the other factors of area and decline of head, to derive the total volume of potentially available ground water. In contrast, the Analysis B reservoir volume is 576,000 acre feet, which suggests 13 years of supply at the total demand rate. Both analyses assume a large resource area, approximately 2,000 square miles. The area is defined based on limited petroleum exploration borehole data and geologic inference of the area underlain by the producing formations, extending primarily north from the project area and into the San Juan Basin and the area could be even larger if the producing formations were found to extend further into the San Juan Basin. Land ownership, county boundaries, or other potential surface restrictions are not considered in the area estimate. The potential head decline of 3,000 feet is based on the potential head draw down to the approximate depth of the producing formations. Analysis B is based specifically on the leaky aquifer model (Hantush, 1965), which limits the leaky source to the aquitard directly above the SAG (i.e., the Moenkopi Formation).

It must be emphasized that the projected demand of 43,200 acre feet per year represents the estimated demand at total build-out of all potential developments identified by the County as of the date of this report. Demand during the early years of development in the Rio Puerco Valley would be substantially lower than this total build-out figure and thus the actual demand during the 100 year period could be substantially less. The estimated build-out rate and associated demand increase has been modeled by Sandoval County, but it is beyond the scope of this aquifer test report to incorporate such forecasting into the aquifer potential analysis.

In addition, the presence of the 140-foot-plus thick Agua Zarca Member of the Chinle Formation may provide a substantial additional ground water resource. The Agua Zarca is a recognized reservoir rock in the region (Hawkins, et al., 1977), but was not completed as part of the open interval in Well 6, due to drilling difficulties. Any future exploration or production wells should include completion in this potential aquifer, especially in areas where fracturing is likely, such as near the fault zones. If the Agua Zarca holds a quantity of water similar to that identified in the SAG producing zone within Well 6, the total potential aquifer volume could increase substantially.

The range of volume estimates for the potentially available Rio Puerco ground water resource reflects the uncertainty associated with applying the results of a single test to the characterization of an entire aquifer system. Additionally, as this well was intended for exploration and difficult drilling conditions were encountered, its completion is not ideal for the analysis of resource potential. Sandoval County has undertaken an exploration effort to identify and develop a brackish ground water resource. The results of the geologic and hydrogeologic analysis to date are promising, but additional exploration will better determine the long-term potential of this brackish water resource.

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Acronyms and Abbreviations

1/m	inverse meters
ºF	degrees Fahrenheit
bgs	below ground surface
ft^2	square feet
ft^2/d	square feet per day
ft^3	cubic feet
gpd	gallons per day
gpm	gallons per minute
INTERA	INTERA Incorporated
Kb	kelly bushing
m	meters
m^2	square meters
m^3	cubic meters
mg/l	milligrams per liter
msl	mean sea level
NMED	New Mexico Environment Department
OSE	New Mexico Office of the State Engineer
psi	pounds per square inch
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

1.0 Introduction

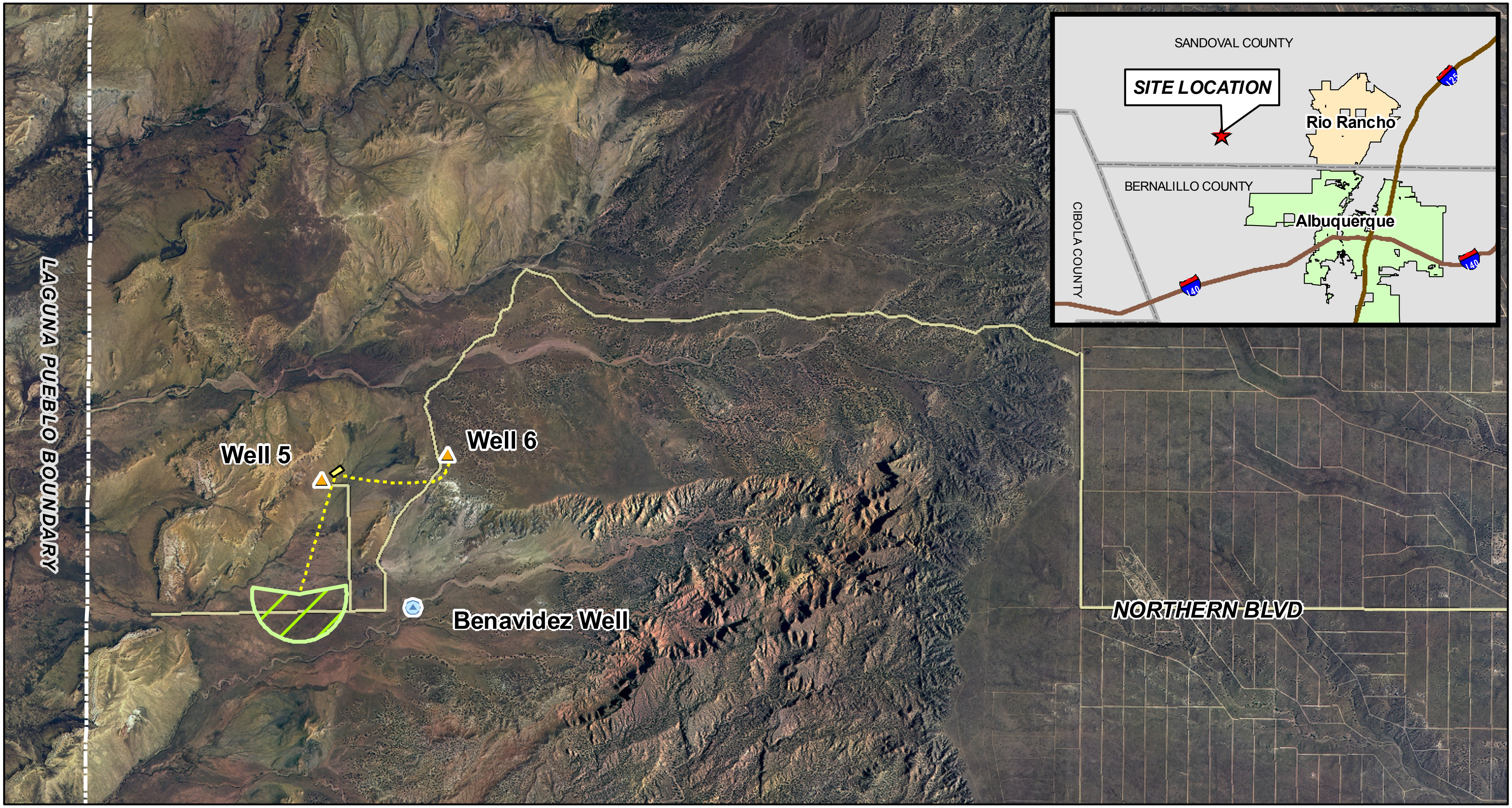
A 31-day aquifer test was conducted by INTERA, Incorporated (INTERA) on behalf of the Sandoval County Development Department (County) during October and November 2008. The purpose of the test was to determine the characteristics of a confined, brackish aquifer located beneath the Rio Puerco Valley and, based on these data, to provide an estimate of the long-term production potential of this aquifer. The test site is located in the Rio Puerco Valley west of the city of Rio Rancho in Sandoval County, New Mexico (Figure 1) and may be found on the U.S. Geological Survey (USGS) San Felipe Mesa, 7.5-minute topographic map. The first well to be drilled, Well 6 (also known as Exp-6), was the flowing well; a later well, Well 5 (also known as Exp-5), was the observation well for this test. The work was authorized under Sandoval County Professional Services Agreement No. 200650694 and subsequent authorized modifications to that contract. All work was conducted according to the *Sandoval County Rio Puerco Basin Water Development Project Aquifer Test and Groundwater Sampling Field Work Plan* dated October 1, 2008 (INTERA, 2008), and/or according to the agreement and approval of Sandoval County management.

This report describes the aquifer test and data analysis methods used as well as the results of the data analysis. Section 1 summarizes the well drilling and construction, the geology and hydrogeology of the area, the results of the 12-hour aquifer test performed in 2007, a hydrogeologic model based on referenced geologic literature and newly acquired data, and an overview of the 2007 aquifer test. Section 2 summarizes the well instrumentation and the phases of the 2008 aquifer test, which consisted of infrastructure preparation, background monitoring, flow period, and recovery period. Section 3 describes two separate analyses of the test data and summarizes the results.

Based on the results of the data analyses, Section 4 provides estimates of the expected long-term reservoir capacity and Section 5 presents INTERA's conclusions and recommendations based on these test results. All Figures referenced in the text are presented in the body of the report. Five appendices include the test data, test operations, the test work plan, field notes and operation field forms, and a photo log of the test operations. Appendices A through D are provided in electronic format on a compact disk in a pocket at the end of this report; Appendix E, the photo log, is included in the paper copy of this report.

1.1 Exploration Drilling and Well Completion

Two exploration wells, Well 6 and Well 5, were drilled in the Rio Puerco Valley of Sandoval County between June and September of 2007. The purpose of these wells was to explore for a potential ground water resource to supply residential and commercial growth in the area. Well 6



Source(s): Aerials – RGIS website; dated 2005;
Water well – OSE database.

Legend

- Center Pivot Irrigation Area (80.32 acres)
- Lined Storage Impoundment
- Water Well
- Sandoval County Well Location
- Pipeline to Storage and Center Pivot
- Access Road

Feet
4,000 2,000 0 4,000

INTERA

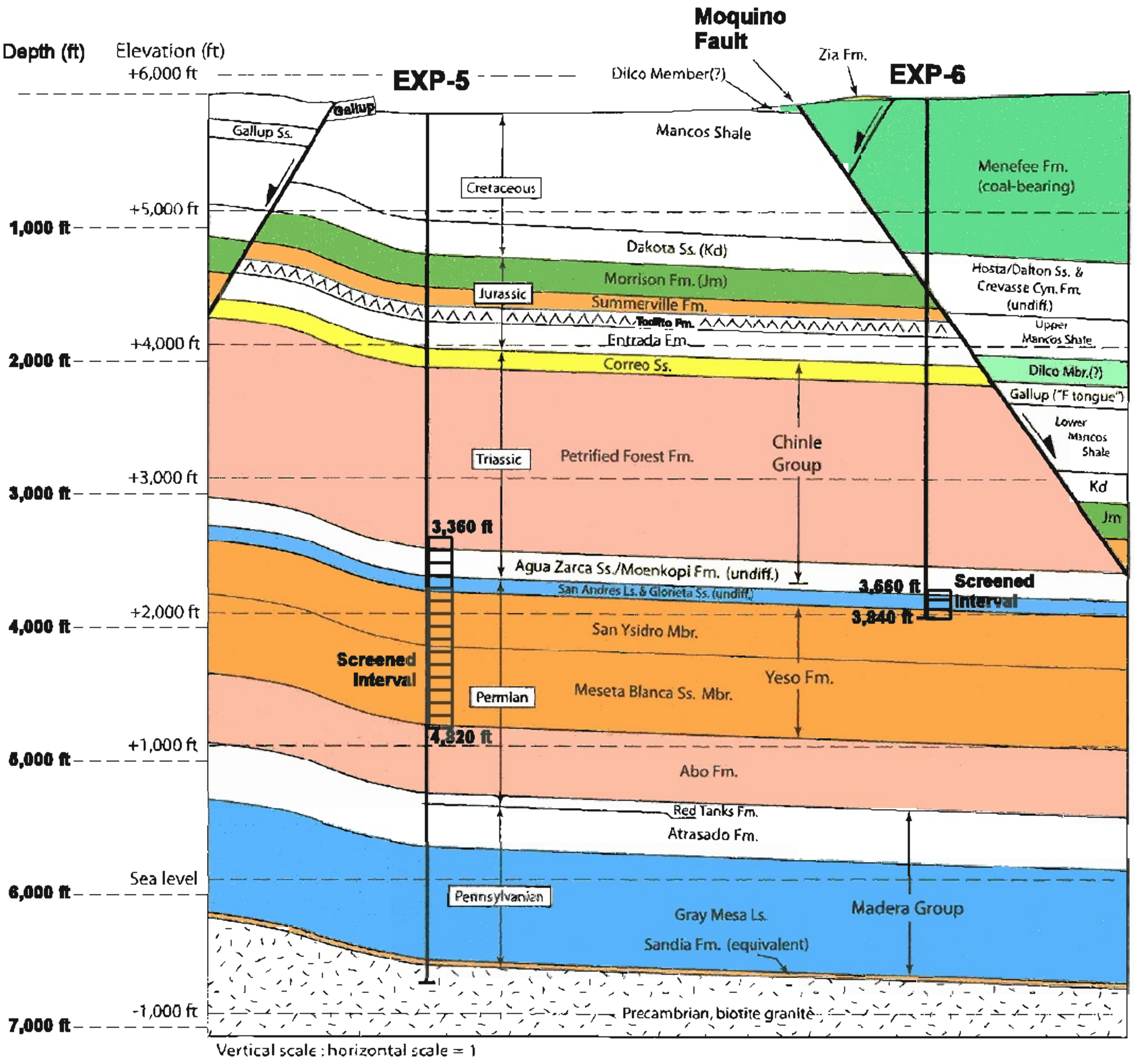
Figure 1
Location Map
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report

S:\Projects\SAN-001_Sandoval County Rio West\Sandoval_County_Rio_West_Evaluation\graphics\Figure1_11-08new.mxd is located at lat 35º17′7.9″N, long 106º54′53.3″ W and Well 5 is located at lat 35º17′0.9″N, long 106º55′34.9″W. The distance between the two wells is approximately 3,450 feet.

Wells 6 and 5 were drilled at the direction of Sandoval County under exploration permits from the New Mexico Office of the State Engineer (OSE). Drilling and completion operations were under the supervision of contractors and consultants under contract to Sandoval County and a developer, Aperion, Inc. The wells are not conventional water production wells, although they might be recompleted as water production wells with larger diameter screens (or with open holes) at some future time. The wells were drilled using a mud-rotary drilling rig typical of the type used to install oil and gas wells. Both wells were cased and the casing cemented to approximately 3,000 feet below ground surface (bgs). The casing and cement were inspected by a representative of the OSE. Well-bore diameter, casing diameter, and screen type and diameter varied between the two wells below depths of 3,000 feet and reflected the drilling needs and materials available at the time of drilling. The screen in the wells varies from conventional wire-wrapped water well screen to slotted liner to hand-slotted casing pipe, depending on the well and the depth. Well 6 is completed in an open hole with a 5-inch diameter slotted liner attached and sealed to the cemented casing. Well 5 is completed in an open hole with a 7-inch diameter screen attached and sealed to the cemented casing. There is no conventional gravel pack in either well.

Well 6 began in thin alluvial cover and was drilled to a total depth of 3,850 feet. It is completed with a slotted liner in an open hole between 3,598 and 3,809 feet bgs in mudstones of the Triassic Moenkopi Formation, limestone of the Permian San Andres Formation, and sandstone of the Permian Glorieta Formation. The Triassic Agua Zarca Sandstone, which overlies the Moenkopi Formation, is a recognized aquifer in this region. However, due to drilling difficulties, this zone was cased off and does not contribute to the flow from Well 6. Well 5 was drilled to a total depth of 6,450 feet bgs (reaching the Precambrian basement rock at 6,350 feet bgs) and screened in multiple zones between 3,360 and 4,820 feet bgs.

Based on testing completed to date, Well 6 is capable of producing artesian flow of over 600 gallons per minute (gpm) through a 2-inch diameter valve. Well 5 initially produced only about 20 gpm of artesian flow, but after a commercial fracturing procedure, it flowed at a sustained rate of approximately 150 gpm. Ground water from the wells contains approximately 12,000 milligrams per liter (mg/l) total dissolved solids, 3,100 mg/l chloride, and 4,400 mg/l sulfate. A full suite of geophysical logs was run in both holes to assist with the selection of potentially productive zones. Figure 2 is a geologic cross section showing the rock layers, their relative thicknesses, and the water-producing zones being accessed by these wells. Figures 3 and 4a-c show the construction details in Wells 6 and 5 along with the geologic units that are open to the wells and potentially productive. Table 1 summarizes the drilling and construction information for the two wells.



Adapted from Van Hart, 2007

Figure 2
Schematic Geologic Cross Section
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report

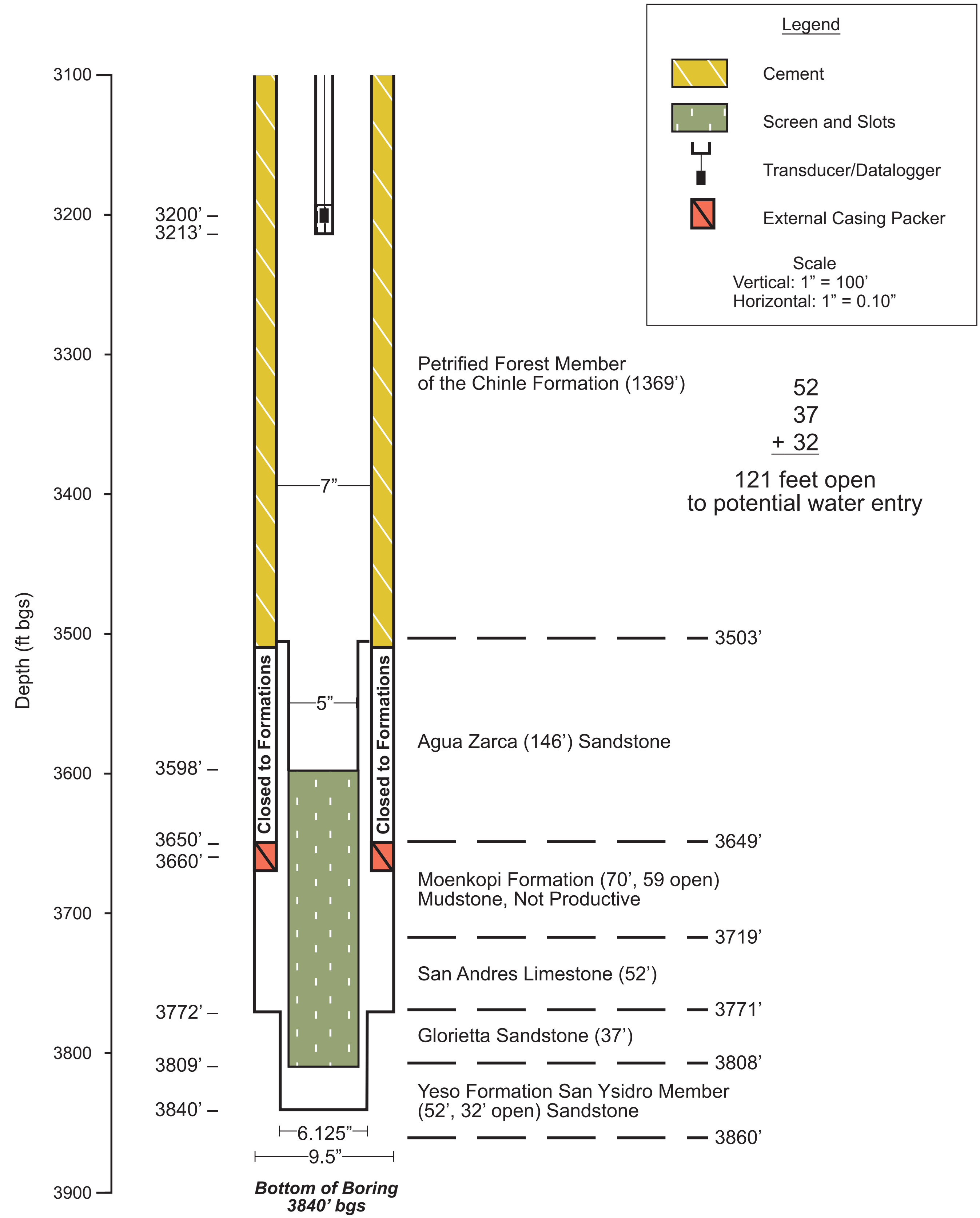
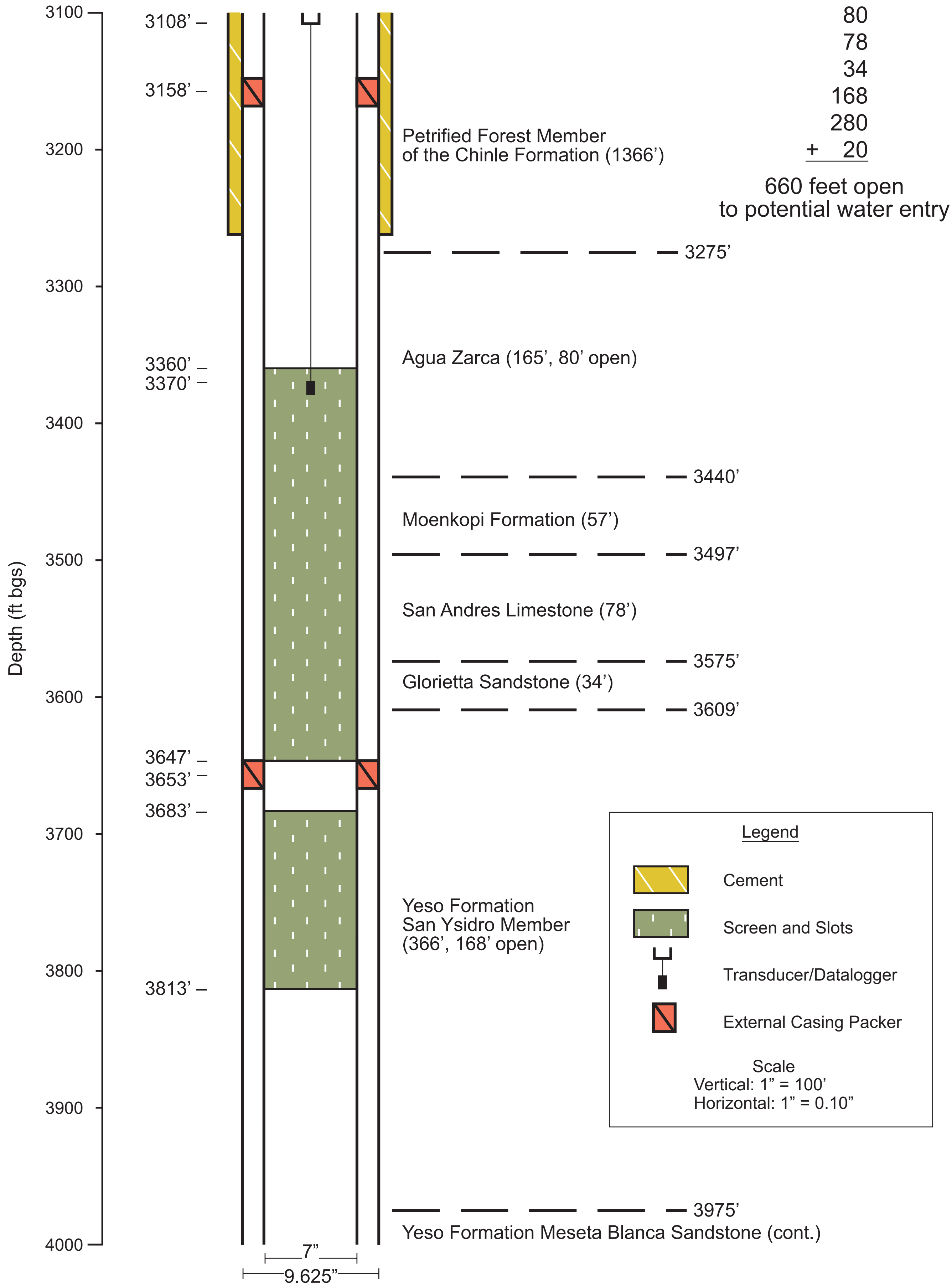


Figure 3
Well 6 Completion Schematic with Geology
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report

INTERA



(cont. on Figure 4b)

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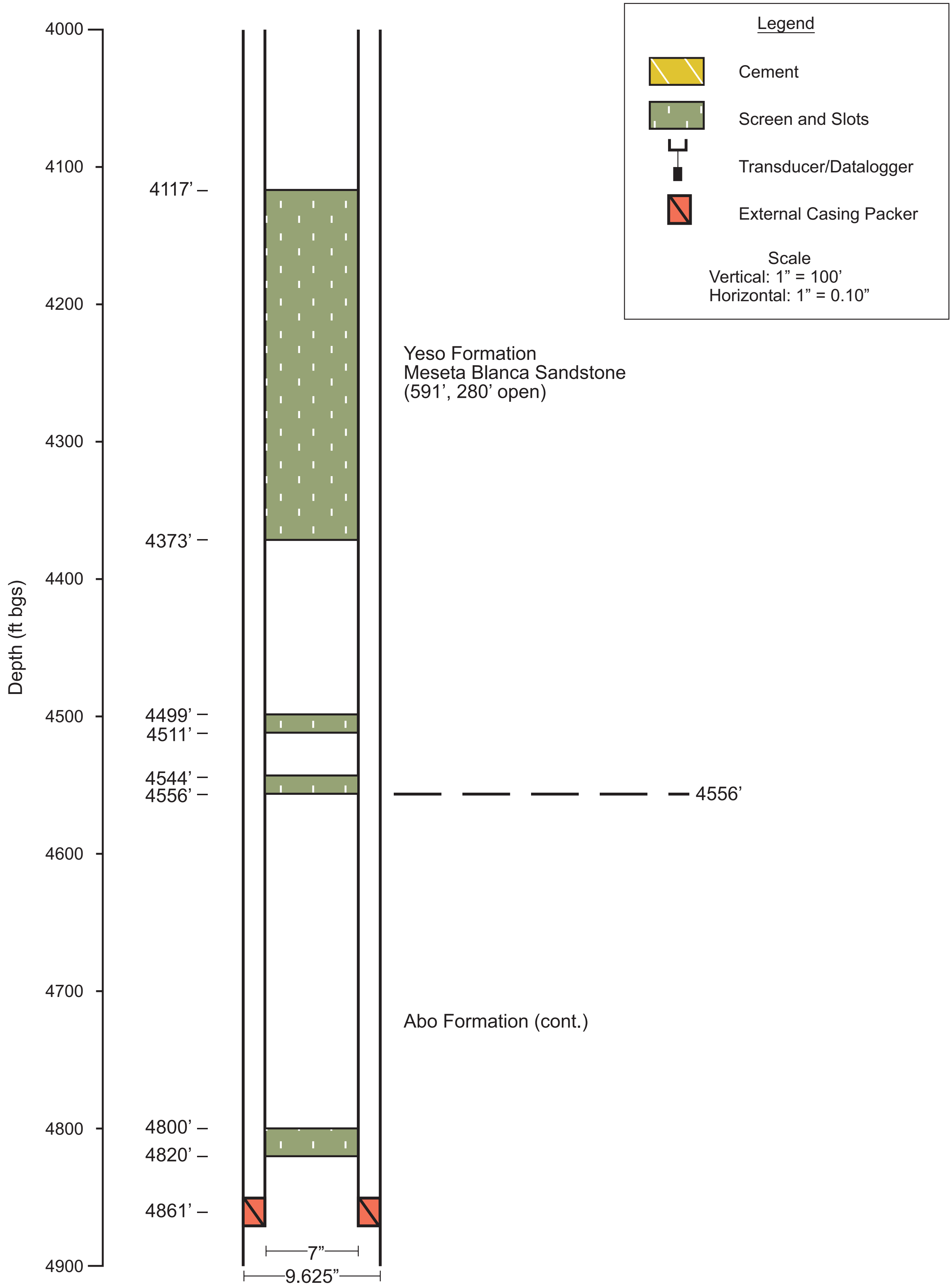
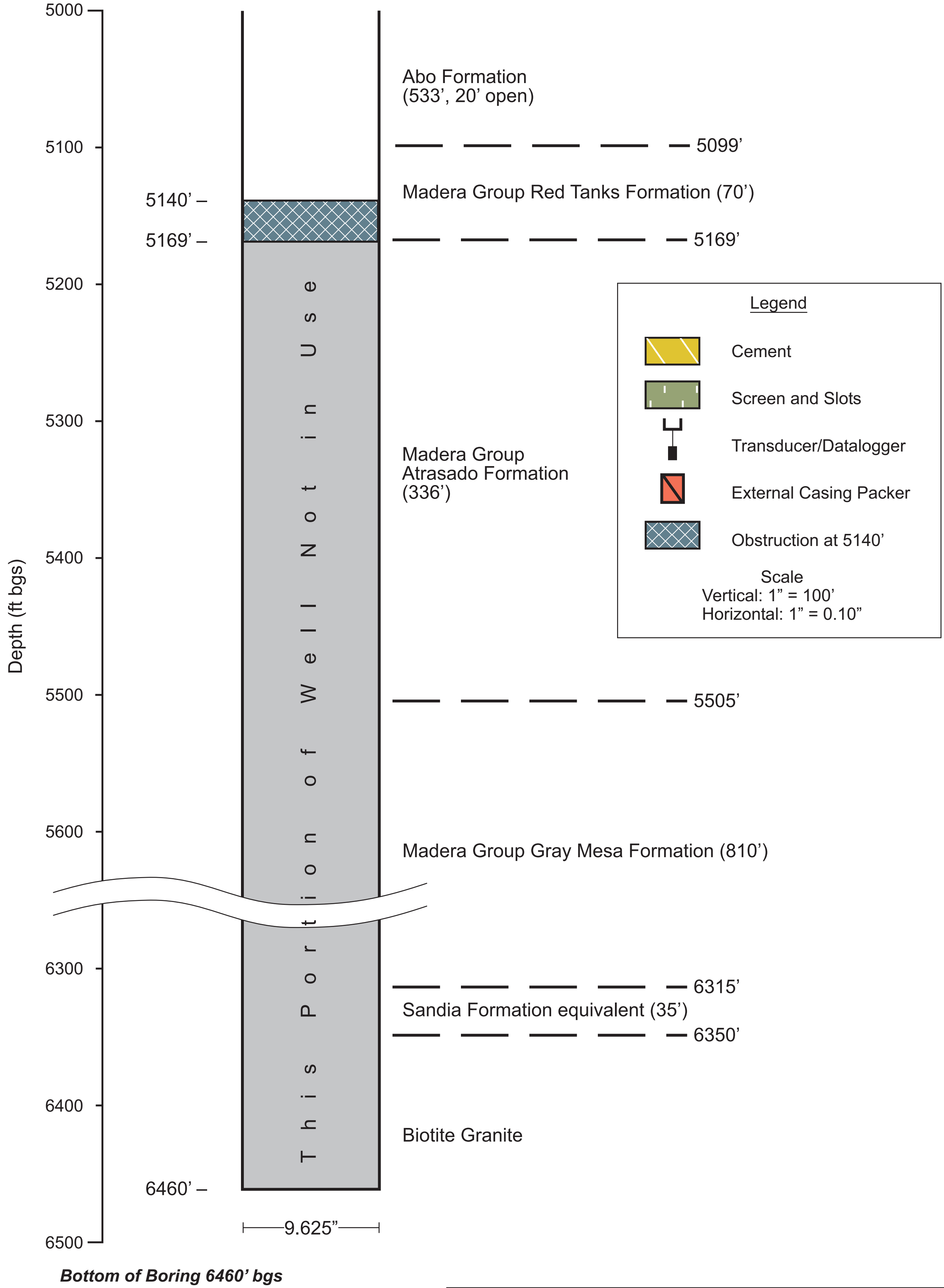
Figure 4a
Well 5 Completion Schematic with Geology
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report



(cont. on Figure 4c)

Figure 4b
Well 5 Completion Schematic with Geology
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report



INTERA

Figure 4c
Well 5 Completion Schematic with Geology
Sandoval County Rio Puerco Water Development Project
Aquifer Test and Analysis Report

Table 1
Summary of Drilling Information for Exploration Wells

Specifications	Well -6	Well -5	Comments
Location	S11, T12N, R1W	S10, T12N, R1W	---
Drilling Dates	June 16–August 8, 2007	July 30–September 1, 2007	---
Well Construction Completion Date	August 10, 2007	September 24, 2007	---
Wellhead Elevation (msl at kb on drill rig)	5,815 (kb 14 ft)	5,715 (kb 15 ft)	Datum for depth to formation tops.
Total Depth, ft	3,840	6,460	---
Screen Interval, ft	5-inch I.D. diameter liner hanger screen; 3,598–3,809 Geologic units completely or partially open to production: Moenkopi 3,660–3,719: 59 ft, not productive San Andres 3,719–3,771:52 ft Glorieta 3,771–3,808: 37 ft Yeso 3,808–3,840: 32 Total 121 feet of geologic units open for potential water entry (see Figure 3)	7-inch diameter screen as a liner hanger; 3,360–4,820 (> 1,460 ft total) Agua Zarca 3,275–3,440: 80 ft open Moenkopi 3,440–3,497: 57 ft, not productive San Andres 3,497–3,575: 78 ft Glorieta 3,575–3,609: 34 ft Yeso 3,609–3,975: 168 ft open Yeso 3,975–4,566: 280 ft open Abo 4,566–5,099: 20 ft open Total 660 ft of geologic units open for potential water entry (see Figure 4)	Obstruction at 5,140 ft in Well 5, due to hole collapse. Drilling in Well 6 ended at a total depth of 3,840 when the well flowed ground water to the surface. Additional exploration at greater depth was decided to be risky.
Actual Screened or Open Hole Zones, ft	3,660–3,840 Total 180 ft open or screened in well	7-inch diameter screen as a liner hanger; 3,360–3,647 = 287 3,683–3,813 =130 4,117–4,373 =256 4,499–4,511 =12 4,544–4,556 =12 4,800–4,820 =20 Total 717 ft screened or open in well	---
Flow Rate, gpm	Est.> 600	20 (before fracture) 150 (after fracture)	---
Down-Hole Water Temperature (ºF)	150	150	---

msl = mean sea level
gpm = gallons per minute
kb = kelly bushing
ºF = degrees Fahrenheit

1.2 Geology and Hydrogeology

The project area lies in a broad valley west of the badland escarpment of the Rio Puerco (Ceja del Rio Puerco) (Tedford and Barghoorn, 1999) within the southeast San Juan Basin and west of the Rio Grande rift boundary. The area is characterized by northeast-southwest trending ridges and valleys formed by outcrops of folded and faulted Mesozoic-age rocks. Exposed rocks along the eastern side of the area near Well 6 are mapped as the Cretaceous Menefee Formation (part of the Mesaverde Group). The older Gallup Sandstone, also part of the Cretaceous Mesaverde Group, crops out in the western part of the area near Well 5. Units within the Cretaceous Mancos Shale, which underlies the Gallup Sandstone, form the valley floor between Wells 6 and 5 (Williams and Cole, 2007).

1.2.1 Stratigraphy

Mesozoic formations ranging from Cretaceous to Triassic in age, were encountered in both wells. The most continuous section of strata was found in Well 5, which penetrated Cretaceous through Precambrian bedrock. All subsurface formations encountered by the two wells are shown on the schematic geologic cross section (Figure 2). The units of most hydrogeologic interest are the Triassic-age Chinle and Moenkopi Formations, and the Permian-age San Andres Limestone, Glorieta Sandstone, and Yeso Formation. Although there are few descriptions of these units in literature that specifically focus on the Rio Puerco Valley (because they occur in the deep subsurface and drilling in this area is rare), investigations by the U.S. Geological Survey (USGS) and others within the region provide the information needed to establish the geologic and hydrogeologic conceptual model. The following descriptions, summarized from various sources, provide lithologic descriptions as well as some hydrogeologic characteristics of the units. They are presented in the order in which they were encountered during drilling.

The Triassic-age Chinle Formation consists of nonmarine, red-brown mudstone and siltstone, and is 1,423 feet thick in Well 6 and 1,517 feet thick in Well 5, excluding the basal Agua Zarca Sandstone (Van Hart, 2007). The clay-rich Chinle is a recognized hydrogeologic confining unit in the region and is interpreted by Sawyer and Minor to form an effective confining layer above the water-producing zones in Wells 6 and 5 (Sawyer and Minor, 2006).

The Agua Zarca Sandstone is the basal unit of the Chinle Formation and consists of white, fine- to coarse-grained, moderately-sorted, moderately-hard, well-consolidated, clean quartzose sandstone with minor feldspar and mica. Well logs and cores from the Las Milpas Gas Storage project, located approximately 16 miles north of the exploration wells, indicate the Agua Zarca is fractured (Hawkins et al., 1977). In the Las Milpas area, the Agua Zarca is fractured uniformly and has an average permeability of 5,000 millidarcies, or transmissivity of 1×10^{-3} m^2/sec (Hawkins, et al., 1977). The Agua Zarca is a potential water-producing unit and is 146 feet thick in Well 6 and 165 feet thick in Well 5 (Van Hart, 2007). None of the Agua Zarca is open to the well within in Well 6, while 80 feet is open in Well 5.

The Triassic-age Moenkopi Formation is a red to dark red to reddish-brown siltstone, silty sandstone, or fine- to very fine-grained sandstone with mudstone and gypsum. In northeastern

Arizona, it is a confining layer above the Kaibab Limestone, which is interpreted to be equivalent to the San Andres Limestone in the project area (Leake et al., 2005). The Moenkopi is 70 feet thick in Well 6 and 57 feet thick in Well 5 (Van Hart, 2007). In Well 6, 59 feet of the section are open; all 57 feet are open to the well in Well 5. The Moenkopi is interpreted to be a confining layer or aquitard in these wells.

The Pemian-age San Andres Limestone consists of limestone with minor dolomite, shale, siltstone, and gypsum. The top of the formation was exposed and eroded during Triassic time (McLemore, 1998; Summers and Kottlowski, 1969). The San Andres is 52 feet thick in Well 6, 78 feet thick in Well 5 (Van Hart, 2007), and is fully open in both wells. Void spaces on the order of a few vertical feet were encountered in this limestone unit during drilling of Well 6.

The Permian-age Glorieta Sandstone is described near Bluewater Lake in the Zuni Mountains, approximately 60 miles from the drilling site, as massive, white to buff to yellow, quartz sandstone. It is typically cross bedded, indicating deposition as eolian dunes and in local stream channels along the shore of the Permian sea that extended across New Mexico (McLemore, 1998.). The Glorieta was deposited along the coast or in shallow water as the seas began to cover the region (USGS, 2005). It is 37 feet thick in Well 6, 34 feet thick in Well 5 (Van Hart, 2007), and fully open in both wells.

The Permian Yeso Formation consists of red sandstone and shale and gray limestone. Gypsum is present in thin beds and as a dispersed material in the sandstone and shale (USGS, 2005). The San Ysidro Member is a major sandstone unit in the Yeso; in Well 6, 32 feet of this unit are open to the well. In Well 5, 130 feet of the San Ysidro are open to the well, while 280 feet of the Meseta Blanca Member of the Yeso are screened. Beneath the Yeso, 20 feet of the Abo Formation sandstone are open in Well 5.

1.2.2 Structural Geology

The project area displays a series of easily discernible, northeast-southwest striking ridges which are interpreted to be the limbs of north-plunging, faulted anticlines and synclines (Tedford and Barghoorn, 1999). In addition to these major folds, minor folds with axes trending roughly west to east are evident in the cliff-forming Gallup Sandstone and overlying Mancos Shale exposed south of Well 5. These minor folds are primarily west of the Moquino Fault (described below). Strata east of the Moquino Fault, especially the Upper Cretaceous Menefee Formation, have a regional dip of a few degrees to the east.

The surface trace of the Moquino Fault, which is down-dropped on the eastern side, cuts the valley from northeast to southwest in the vicinity of Well 6. This fault is recognized as the western structural margin of the northern Albuquerque basin (Tedford and Barghoorn, 1999) and has at least 984 feet (Tedford and Barghoorn, 1999), but probably over 2,000 feet of vertical throw based on published unit thicknesses (Williams and Cole, 2007).

As shown in Figure 2, Well 6 was drilled through the Moquino Fault, which made for difficult stratigraphic correlation until the Jurassic-age Todilto gypsum beds were encountered at approximately 1,685 feet bgs. The stratigraphy of Well 5 correlated with that of Well 6 below a depth of approximately 1,400 feet bgs, the point at which the Salt Wash Member (also known as the Westwater Canyon Member) of the Jurassic Morrison Formation was encountered in both wells (Van Hart, 2007).

The amount of displacement on the Moquino Fault is estimated on the basis of the surface geology on either side of the fault. The Williams and Cole (2007) geologic map shows the Menefee Formation (to the east of the fault) in stratigraphic contact with the Montezuma Valley Member of the Mancos Shale (to the west). According to the map, another fault cuts through the Menefee, but has little apparent displacement. Minor faults were noted near this location in the field. However, the major displacement, interpreted to be the Moquino Fault, must form the contact between the marine shale of the Montezuma Valley and the deltaic, coal-bearing sandstones of the Menefee. Based on published unit thicknesses (Williams and Cole, 2007) a displacement of 2,011 to 2,620 feet with an average of 2,315 feet is necessary to juxtapose the younger Menefee and the Montezuma Valley sediments (Figure 5).

1.3 Hydrogeologic Model

Using published information in conjunction with well log data, INTERA has developed a hydrogeologic model that forms the basis for this aquifer potential analysis. The model considers the location of the units with the greatest water-bearing potential, their structural or stratigraphic boundaries, their estimated areal extent, and the estimated age of the water contained in these units.

1.3.1 Target Aquifers

The target aquifers for the Sandoval County water development project are, from youngest to oldest, the Agua Zarca Sandstone, the San Andres Limestone, the Glorieta Sandstone, the San Ysidro and Meseta Blanca members of the Yeso Formation, and sands within the upper Abo Formation. The Agua Zarca Sandstone is present in Well 6 but is cased off. A portion of the Moenkopi Formation (59 feet) is screened open to Well 6, but is interpreted to be an aquitard based on its lithology of primarily mudstone. The San Andres and Glorieta (SAG) formations were both screened open in Well 6, as was part of the Yeso Formation.

Thickness from top Kmz to top Kme, Williams and Cole 2007 and Van Hart 2007				Thickness from Shell Santa Fe Pacific No. 1 well log, Black and Hiss 1974	
Formation	**Map Symbol**	**Thickness Range, (ft)**	**Average Thickness (ft)**	**Thickness (ft)**	**Formation**
Menefee Formation (Exp-6)	Kme (1111 ft VH)	1111 - 1250	1180.5	734	
Point Lookout Sandstone	Kpl	125 - 300	212.5	142	
Hosta Tongue of the Point Lookout Sandstone and Daltstone Sandstone Member, undivided (incl.as part of the Kcc (Crevasse Canyon Formation undivided including the Dilco Coal Member (Kcdc) and Khd	Khd	220 - 370	295	400	
Satan Tongue	Kms	240 - 440	340	775	Crevase Canyon
Mulatto Tongue Mancos	Kmm	380 - 500	440	400	Niobrara
Gallup Sandstone	Kg	60 - 60	60	331	Sanostee
Montezuma Valley Member Mancos (Exp-5 start top Kmz)	Kmz (165 ft)	0 - 0	0		
Subtotal		2136 - 2920	2528		
Subtract PL included in Khd		-125 - -300	-212.5		
Range of thickness between units on either side of fault		**2011 - 2620**	**2315.5**	**2782**	

Source: Sengebush, 2008

Figure 5
Moquino Fault Displacement Table
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1.3.2 Ground Water Flow Boundaries

According to Kernodle (1996):

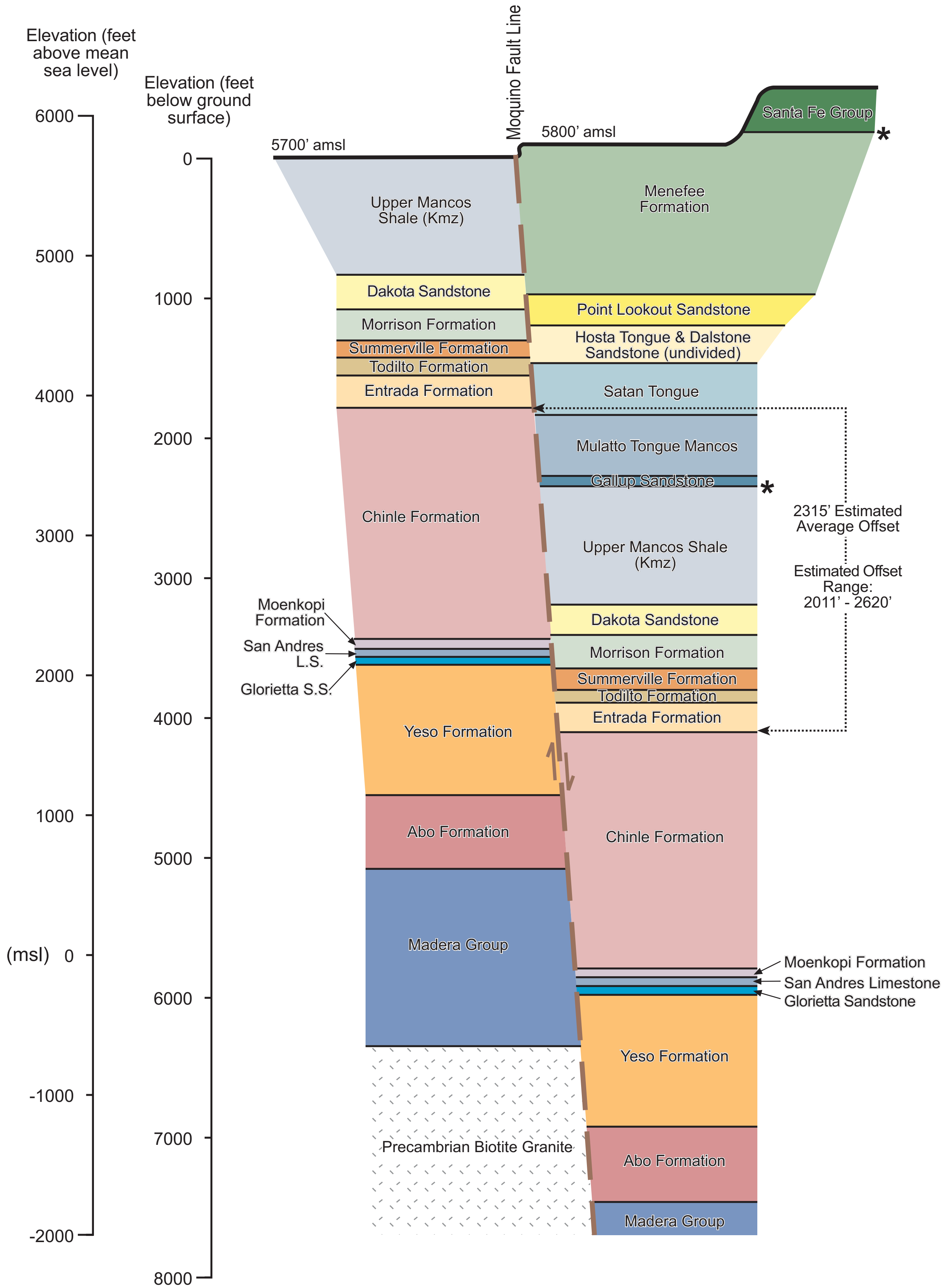
> "A ground-water-flow boundary is any physical feature or mechanism that alters the movement of water in the ground-water-flow system, or is a sink or source of water to the system. The San Juan Basin, as defined for this investigation, is a virtually self-contained ground-water-flow system whose boundaries generally are clearly defined."

Wells 6 and 5 are within the southeastern portion of the San Juan Basin as defined by Kernodle. The boundaries of the target aquifers are interpreted as described below.

Overlying and underlying boundaries. The target aquifers are regionally-extensive geologic units which are known to be present beneath the central San Juan Basin and in the project area. The aquifer zones are bounded above by the Triassic Chinle Formation (Petrified Forest Member), which is approximately 1,500 feet thick in the project area and is a recognized barrier to ground water flow (Sawyer and Minor, 2006). The aquifers are bounded below by thick mudstones of the Permian Yeso and Abo Formations.

Eastern boundary. On the regional scale, the Nacimiento Uplift and related faulting to the south form the eastern boundary of the San Juan Basin. The Pajarito Fault (Woodward, 1972) and the Nacimiento Fault (Pollock et al., 2004) have displacements of several thousand feet, placing Precambrian granite against younger sedimentary rocks and creating the eastern boundary of the ground water flow in the San Juan Basin (Kernodle, 1996). The Moquino Fault and related north-south trending, down-to-the-east faults align with the eastern boundary of the San Juan Basin as defined by Kernodle (1996); this is also interpreted to be the western structural margin of the northern Albuquerque basin (Tedford and Barghoorn, 1999). The Moquino Fault is located within a few hundred feet east of Well 6 at the producing depth interval and may act as a boundary due to the low permeability gouge within the fault zone. Well-developed fault gouge has been observed in outcrop on the project site during field reconnaissance in the vicinity of the surface trace of the Moquino Fault.

The vertical throw of the Moquino Fault identified during the drilling of Well 6 is interpreted to be on the order of 2,300 feet (Sengebush, 2008) but may range between 2,011 and 2,620 feet (Figure 6). This amount of throw is consistent with published unit thicknesses of the Menefee Formation and the Montezuma Valley (Williams and Cole, 2006), which crop out on the east and west sides of the fault, respectively. This fault displacement places the target aquifers on the western, or foot wall, of the fault block possibly against units of the Jurassic Morrison Formations on the eastern, or hanging wall. Considering the potential range of offset, the adjacent units on the hanging wall could consist of any of the units between the Dakota and the



* Thickness from base of Gallup Sandstone to top of Menefee Formation from:

Williams & Cole, 2007
Van Hart, 2007
Sengebush, 2008

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Figure 6
Estimated Vertical Offset on Moquino Fault
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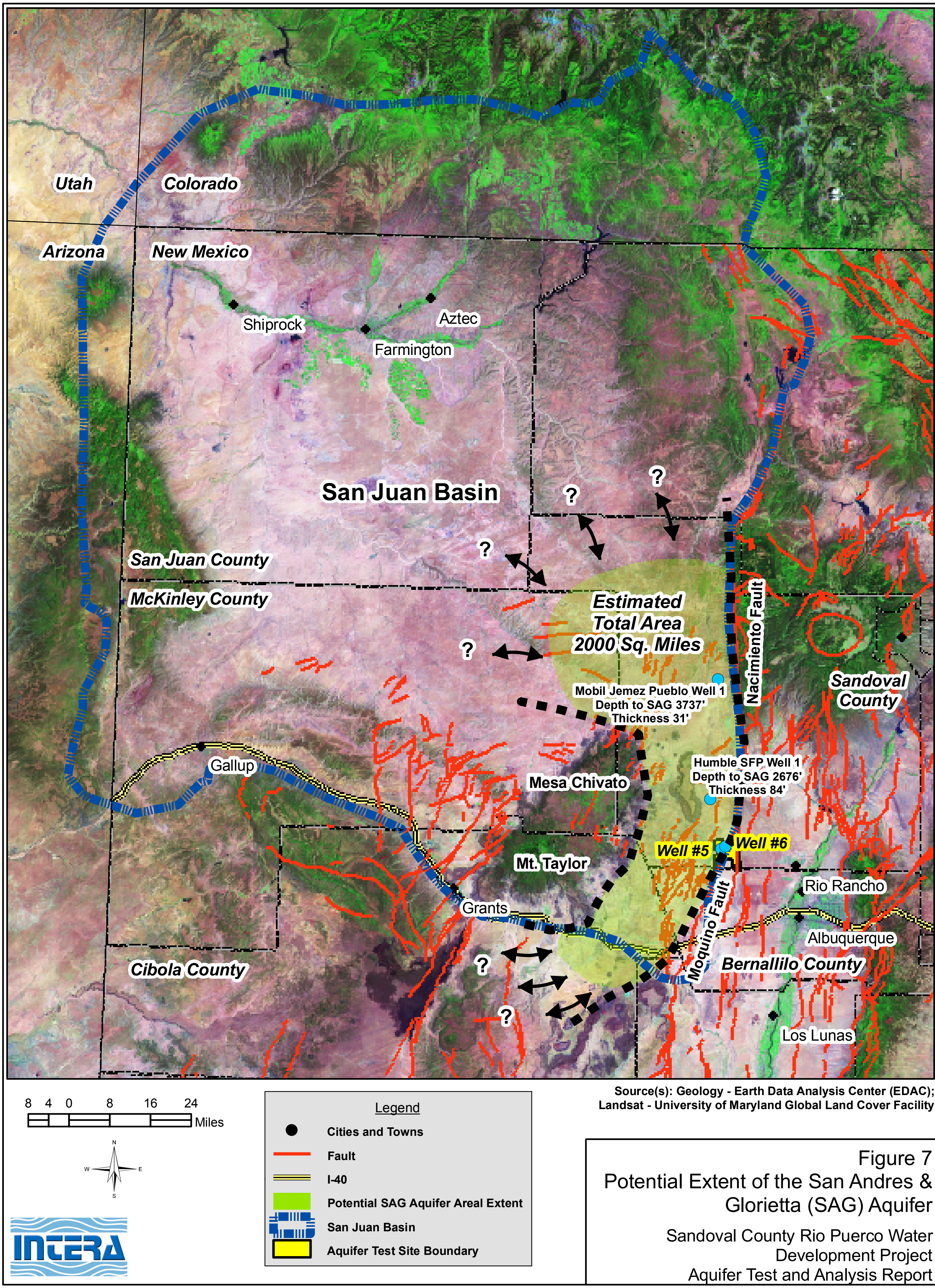
Entrada. The section of Mancos Shale on the east side of the fault is juxtaposed against the Petrified Forest Member of the Chinle Formation on the west side of the fault; together, these units create a continuous confining unit over the potential aquifers (Figure 6).

Western boundary. The western boundary of the brackish Rio Puerco aquifer is interpreted to be the Mt. Taylor volcanic center which forms a southwest to northeast-trending volcanic intrusion approximately 17 miles west of the project area. The roots of Mt. Taylor and related volcanic vents seen on the surface of Mesa Chivato to the north of Mt. Taylor (Dillinger, 1990) suggest a major structural break interrupting the westward extent of the target aquifers. A conservative interpretation of this structural feature is that it forms a barrier boundary to ground water flow. The Puerco fault zone is also present a few miles west of the project area, but these Laramide-age faults are interpreted to have a vertical offset of only several tens to a few hundred feet, which is insufficient displacement to completely offset hydrostratigraphic units over a large distance (Kernodle, 1996). In fact, the Puerco fault zone may increase the permeability and porosity of the target aquifers, if the faults penetrate to the required depth. As noted by Kernodle (1996), "Faulting also can cause nearby fractures in friable rock, leading to a local increase in permeability and porosity."

Northern and southern boundaries. Analysis of available geologic maps and literature suggest that geologic units beneath the project area may continue uninterrupted into the central San Juan Basin to the north and into the Acoma Sag to the south. To the north, a corridor of Cretaceous and younger rocks crop out at the surface, intruded by the occasional volcanic neck, such as Cabezon Peak. Few if any wells tap the target aquifers within the central San Juan Basin because these units are considerably deeper than the typical oil and gas reservoirs in the basin; however, the target aquifers are inferred to be present at depth beneath the San Juan Basin. This inference is supported by the presence of the SAG and other units in two petroleum test wells north of the project site: the Humble SFP1 and the Mobile Jemez Pueblo 1 (Figure 7). The structure is less certain to the south, but no major fault displacement is evident, based on surface geology, that would significantly impact the continuity of the aquifers.

1.3.3 Total Area Occupied by Target Aquifers

The total area occupied by the potential Agua Zarca, San Andres, Glorieta, and deeper aquifers can be defined based on the structural boundaries presented above. Figure 7 is a regional aerial photograph showing the potential area underlain by the aquifers described previously. This area is bounded by structures on the east and west, but open on the north to the central San Juan Basin and on the south to the Acoma Sag. For the purposes of this aquifer potential analysis, INTERA projects that a 2,000-square-mile region is underlain by the target aquifers, as illustrated on Figure 7.



Source(s): Geology - Earth Data Analysis Center (EDAC);
Landsat - University of Maryland Global Land Cover Facility

Figure 7
Potential Extent of the San Andres & Glorietta (SAG) Aquifer

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1.3.4 Ground Water Age Dating

Sandoval County conducted a study of the ground water age using radiocarbon and isotopic analysis. As of the date of this report, Sandoval County had received the results of a water age dating study consisting of radiocarbon analysis, and the analysis of stable isotopes of oxygen 18 (^{18}O), deuterium (^{2}H), and various anions and cations. Water was collected at depth from Well 6 during the flowing portion of the test and also from the Benavidez well water tank (the Benavidez well is a nearby stock well, total depth 114 ft) for comparison with the deep ground water sample from Well 6. The age determined by this type of analysis is a "mean residence time" because it indicates the average residence time in the aquifer of each molecule of water.

The uncorrected radiocarbon age for the Well 6 sample is 29,350±210 years. In comparison, the radiocarbon results for the Benavidez well indicate that its uncorrected residence time is 1,880±40 years. This preliminary age date for the deep brackish water suggests it is not connate water that was present in the rock when the sediments were deposited in the Permian sea (although this is a possibility that will be evaluated by an analysis for tritium, which is pending); such water would be more saline and would likely have a residence time of millions of years. These results suggest that the water collected from Well 6 may have entered the rock within the past 29,000 years.

1.3.5 Hydrogeologic Model Summary

In summary, the hydrogeologic model that forms the basis for this aquifer potential analysis covers a 17-mile-wide east-to-west corridor that spans over 80 miles long north to south and has an area of approximately 2,000 square miles. The corridor is bounded on the east and the west by geologic structures, but open to the north to the central San Juan Basin and to the south to the Acoma Sag. The water resides in confined aquifers of Triassic and Permian age that consist of fractured sandstones and limestones with potential interconnections or "leakyness" across relatively thin mudstone units (such as the Moenkopi Formation between the Agua Zarca and the San Andres). The aquifer zone is bounded above by the Chinle Formation and below by mudstones within the Yeso and Abo Formations. The aquifers are interpreted to be bounded on the east by the Moquino Fault and on the west by the Mt. Taylor volcanic region. Fracturing within the aquifers near the Moquino Fault and in the Puerco fault zone may have enhanced the porosity and permeability of the rock. Limestone dissolution along these fractures may have resulted in large-scale fracture flow. The uncorrected ground water age of 29,000 years suggests ground water in this zone has migrated into the basin.

This hydrogeologic model provides a working model, or hypothesis, under which exploration may proceed. It is supported by a synthesis of published geologic literature, field observations, geologic and geophysical logging of Wells 6 and 5, and the results of the 2008 aquifer test and will be revised as additional data become available.

1.4 Summary of 2007 Aquifer Test

A 13-hour, constant-flow-rate draw-down and recovery test was conducted in Well 6 during November 2007 (Balleau Groundwater, Inc., 2007). The water temperature at the surface during the later portions of the test was approximately 151ºF. During the test, the well was allowed to flow at over 400 gpm. This resulted in a water-level decline of 83 feet (measured as change in pressure) in Well 6 and a water-level decline of 1.5 feet in Well 5.

Conclusions from this test are as follows:

- Well 6 and Well 5 are hydraulically connected.
- The draw-down response in Well 6 shows that the local flow system is a highly transmissive (thousands of square feet per day [ft^2/d]) fracture system with nearly one-dimensional flow. The aquifer within a mile of the test well has a transmissivity of hundreds of ft^2/d, which approaches radial flow.
- Late time recovery indicates a regional aquifer with transmissivity near 100 ft^2/d and leakage in a three-dimensional flow system.

2.0 2008 Aquifer Test

The 2008 Sandoval County aquifer test consisted of flowing Well 6 for a period of 31 days (October 1 through October 31, 2008) followed by a recovery period which lasted approximately 60 days. Approximately 30 days of recovery data were used in the analysis documented in this report. Field operations were conducted from a job-site trailer rented by Sandoval County and supplied with power from a rented 25-kilowatt generator. A communications cable was wired directly from the well data logger into the trailer to facilitate the test data monitoring.

The initial flow rate from Well 6 was approximately 150 gpm over a period of 17 days (October 1 through October 17). The flow rate was increased to approximately 250 gpm on October 18 for the duration of the test (the final 14 days). The well was shut at approximately noon on October 31, 2008. Data was collected every two hours from Well 6 and once per day from Well 5 for the duration of the flowing period. Recovery data was collected from both wells approximately every two to four days during the 30-day recovery period.

Water from the flowing well was piped to a 9.5 acre-foot capacity lined storage lagoon, located approximately 3,400 feet west of Well 6. The water in the lagoon was pumped approximately 3,650 feet to a center pivot irrigation system and sprayed over an area of approximately 80 acres.

Flow rate to the irrigation system varied from 350 to 400 gpm and typically took place for 8 to 10 hours per day. This discharge was conducted under New Mexico Environment Department (NMED) Ground Water Quality Bureau Discharge Permit No. DP-1682 and the overall discharge from the irrigation system was within the limits of the discharge permit. A pre- and post-soil and vegetation testing program, as well as flow monitoring and sampling, was conducted by INTERA in compliance with the discharge permit. These permit compliance activities are continuing during the test recovery period.

2.1 Well Instrumentation and Operational Equipment

Well 6 is equipped with two 2-inch-diameter outlets at the pressurized wellhead, each controlled with a gate valve. The two outlets are manifolded to a 4-inch-diameter pipe equipped with a gas trap and gas release valve, a CLA-VAL Rate of Flow Control Valve Model 640G-01ABKC, a series of in-line pressure gauges, two flow meters, and two flow control gate valves. A plumbing and instrumentation diagram is presented in Figure 8. Flow downstream from the valve splits through a tee fitting to two 4,000-foot lengths of 2⅝-inch inside diameter high-density polyethylene pipes that conduct the flow west to the lined water storage pit near Well 5. The gate valve and the flow control valve controls the flow rate through the polyethylene pipe.

Both Wells 6 and 5 are constructed with a main portion (the “backside”) and a smaller diameter center tubing inside the main casing (see well diagrams, Figures 3 and 4). The purpose of the center tubing is to equipment (such as the transducer and data logger) to be introduced into the main well. To insert equipment into the center tubing, the artesian well pressure must be overcome by adding a mixed brine to “kill the well.” The well is then accessible for a period of time before the main pressure from the backside returns to the center tubing. Well 6 was instrumented in 2007 with a GeoKon vibrating wire piezometer set at 3,200 feet bgs to measure pressure and temperature and a temperature probe at 120 feet bgs. During the 2008 test, the data logger recorded the pressure and temperature at 3,200 feet bgs, the temperature at 120 feet bgs, the flow rate, the barometric pressure and the temperature at the wellhead. The logger was programmed to take a reading whenever the pressure at 3,200 feet bgs changed by a specified amount; 0.1 or 0.3 pounds per square inch (psi), or at a maximum specified time interval of 3 to 10 minutes, depending on the phase of the test. The logging interval was more frequent during the early flow (draw-down) period and during the early recovery period. A 50-watt solar panel was employed to support the battery supporting the data logger and transducer.

A logging transducer system identical to the one in Well 6 was installed in Well 5 on September 27, 2008 at approximately 3,370 feet bgs, adjacent to the top of the intake screen. Well 5 was killed on August 26, but when the tubing was opened on September 27 to install the equipment, the pressure had returned and the well flowed from the center tubing. Well 5 was opened to flow

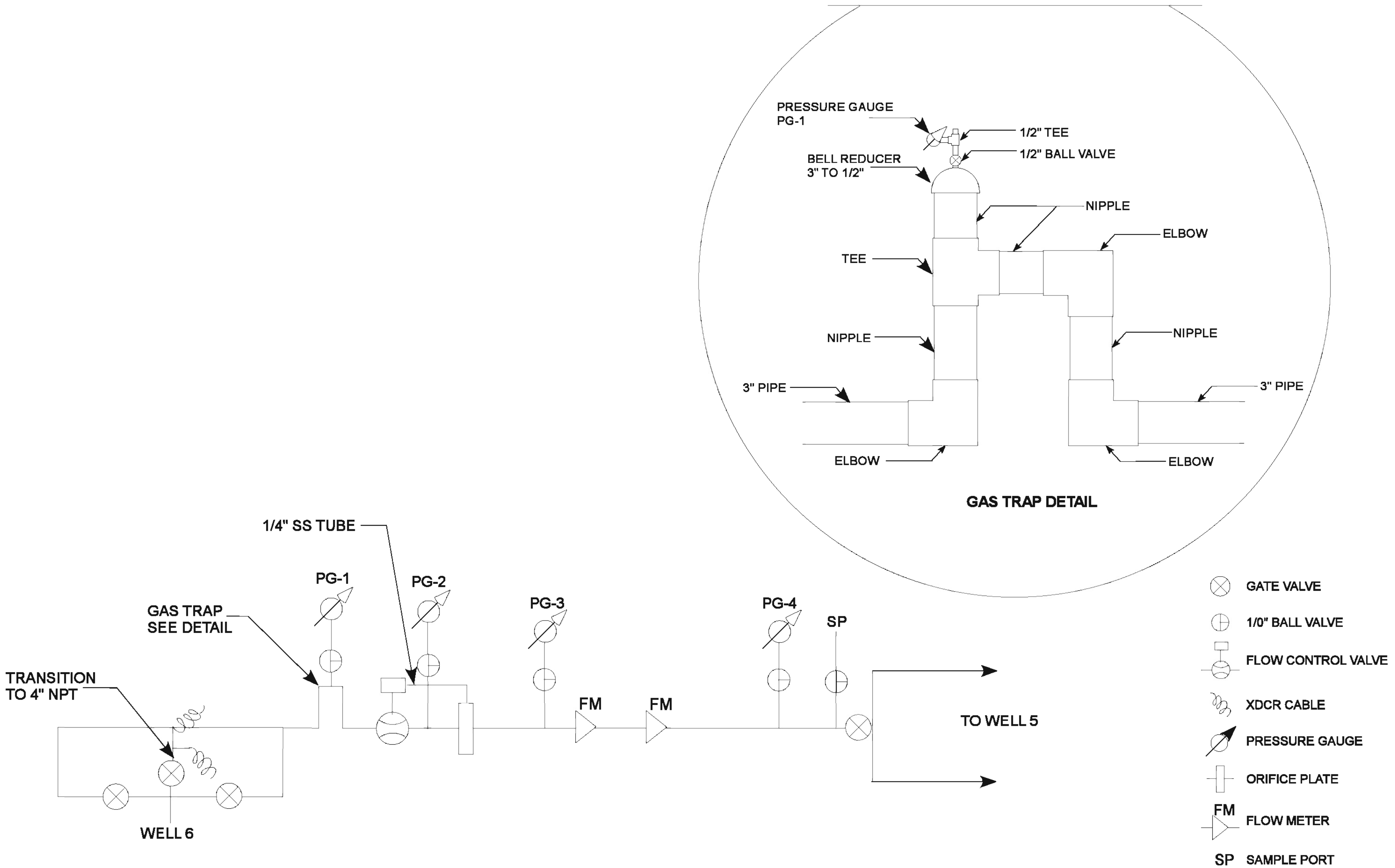

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Figure 8

Well 6 Surface Completion Valves and Flow Meters

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from the backside of the well for approximately one half hour in order to reduce the pressure in the center tubing enough to install the logging equipment.

The measurements recorded by data loggers were augmented by pressure gauges that monitored the pressure at the wellhead and on either side of the control valves (at Well 6) in order to record the pressure drop across the flow control valve and across the other valves in the line.

Atmospheric pressure and temperature were measured at the surface near Well 6 with a barometer placed in the instrument vault.

The Well 6 surface piping was instrumented with a totalizing flow meter with an electronic signal output to the data logger. A second flow meter was used as a backup and was positioned in line downstream of the electronic flow meter.

A sampling port and valve were located in the surface piping at Well 6 to collect water quality parameters and water samples. Water quality measurements for pH, electrical conductivity, oxidation and reduction potential, and dissolved oxygen were made using a flow-through cell and water samples for laboratory analysis were collected three times during the flow test period. The water was cooled to approximately 95ºF before parameters were measured to prevent damage to the measurement probes. The analytical results from these sampling events will be presented in a separate report.

Water from the lined storage pit was pumped through a 6-inch-diameter, centrifugal, diesel-powered pump, located at approximately 3,300 feet bgs, to a Zimmatic center pivot irrigation system, which was installed on the project site for the specific purpose of discharging the produced water onto the ground surface. The irrigation system was selected to prevent pooling of the discharge water and to prevent any runoff into nearby arroyos. This discharge method was approved by the NMED under Ground Water Discharge Permit No. 1682 dated May 29, 2008. The discharge volume and the depth of infiltration was monitored during irrigation, in compliance with the discharge permit (INTERA, 2008). Additional discharge permit requirements included soil sampling and analysis, soil moisture monitoring, water sampling near the point of discharge (irrigation system sampling port), and vegetation surveys before and after the discharge. Results of these studies will be compiled and presented to NMED, per the permit requirements under separate cover.

2.2 Aquifer Testing Method

The 2008 aquifer test was a constant-rate draw-down and recovery test. A unique aspect of this test was that the water in Well 6 is under artesian pressure, thus no pump was required in the test well and the water level was monitored in terms of pressure, instead of depth to water.

Aquifer tests are performed to provide an estimate of hydraulic properties of a formation, identify changes in the hydraulic properties, and to identify aquifer boundaries. A number of well testing techniques exist including slug or pulse tests, constant pressure tests, and constant rate tests. For all types of testing, the estimated hydraulic properties will be an average of the properties within the tested volume of the formation. Single-well, constant-flow-rate tests may indicate the presence of boundaries and other heterogeneities. In general, a constant-rate test with one or more observation wells provide the best estimate of the hydraulic properties. The actual extent of the formation that is tested depends on the well spacing, the formation properties, and the duration of the test.

In a constant-rate test, water is produced from the test well at a constant rate and the pressure response is recorded in the test well and in observation wells, if present. The pressure response in the test well is determined by the formation properties and the properties of the well itself. The response in the observation well depends on the pressure response of the formation at the test well and the properties of the formation between the test and observation wells.

The pressure response of the test and observation wells can be analyzed either by fitting the data to a specific theoretical response or by using a numerical simulator to match the data; numerical simulators allow more flexibility. In either case, assumptions must be made about the flow regime in the formation. The flow regime can be evaluated by comparing the pressure response to known theoretical responses for different conditions. The pressure derivative diagnostic plot (the mathematical derivative, or change in slope within a very small portion of the plotted pressure curve) is particularly useful for this purpose because it accentuates the visible changes in the slope of the plotted curve, allowing a diagnostic interpretation of aquifer characteristics.

Two analysis (A and B) were conducted for the interpretation of the test data. Analysis A was completed by an independent hydrogeologic consultant under contract to INTERA using the numeric well test simulator known as nSights, an analytical tool developed jointly by INTERA Engineering (an affiliate company of INTERA located in Ottawa, Canada) and Sandia National Laboratories. nSights provides state-of-the-art well-test capabilities for analyzing aquifer test data in complex environments. Some of the distinguishing features of this code include:

- Implementation of multiple conceptual models (e.g., dual porosity, leakage from above or below)
- Numeric simulator which allows for analysis of data from non-ideal test results (e.g., pumping rate changes)
- Optimization (inverse modeling) which allows for automatic fitting and advanced statistical applications

As is discussed in detail in this document, the aquifer regime for this aquifer test is complex and both methods chosen to evaluate these data were done so with this complexity in mind.

Analysis B was conducted by senior INTERA scientists using techniques based on Gringarten et al. (1974) for flow to a well penetrating a vertical fracture to analyze early-time data, Theis (1935) for flow to a well under infinite-acting radial flow, and Hantush (1965) for flow to a well in a leaky aquifer to analyze late-time data. The leaky aquifer analysis at late time assumes leakage from an overlying aquitard. Both analyses were conducted using international units, therefore units of length, area, and volume are expressed first in meters with approximate equivalents in feet.

The aquifer test phases consisted of (1) infrastructure preparation, (2) pre-test flow and recovery, (3) pre-test background monitoring, (4) primary test flow, and (5) primary test recovery. All phases are described briefly below, although the focus of this report is on the flow and recovery period data obtained from phases 4 and 5.

2.2.1 Infrastructure Preparation

Preparation for the test included a number of on-site facility installations and improvements, as follows:

- Gas trap, flow control valve, and two flow meters at Well 6.
- Solar panels to charge the batteries controlling the data loggers and transducers in both wells.
- Communication cable from Well 6 well instrument control vault to the project trailer.
- Gravel pad around Well 6.
- Six-foot high chain-link fences and gates with signage around the well and trailer at the Well 6 area and around the water storage lagoon and well at the Well 5 area.
- Water storage lagoon leak detection system under the liner with seven monitoring stations on the lagoon berm.
- Plastic liner (20millimeters thick) in the water storage lagoon near Well 5.
- Generators (25 kilowatts each) at the trailer at Well 6 and at the center pivot irrigation system south of Well 5.
- Aluminum pipe (3,650 feet with an 8-inch inside diameter) with valves and a water bridge over the road between the water storage lagoon and the center pivot irrigation

system and two 6-inch centrifugal pumps (one primary and one as reserve) to move water from the storage lagoon to the center pivot irrigation system.

- Concrete pad for the center pivot anchor point and installation of a 1,300 foot long, electric, Zimmatic center pivot irrigation sprinkler and control system.
- Diesel fuel tanks with secondary containment adjacent to both generators.
- Concrete instrumentation vault adjacent to Well 5.
- Geokon vibrating wire transducer and data logger at approximately 3,300 feet in Well 5.

2.2.2 Pre-Test Flow

This aquifer test phase consisted of several days (approximately 72 hours) of flow at a rate of approximately 150 gpm. The purpose of this phase was to test all of the equipment in the system, including the plumbing, flow control valve, pressure gauges, flow meters, sampling ports, and water delivery system to the water storage lagoon. An additional purpose of this pre-test flow period was to partially fill the water storage lagoon in order to weight the plastic liner. This phase allowed INTERA personnel to examine the data recorded by the data logger and graph the data to determine the quality of the flow control valve operation.

2.2.3 Pre-Test Background Data Logging

This test phase consisted of collecting water level data (pressure data) from the down-hole data loggers to develop an understanding of natural ground-water-level fluctuations. A steady pressure of approximately 1,500 psi at depth and 150 psi at the surface was observed in Well 6 after the recovery from the pre-test flow period. In Well 5, pressure at depth was 1,625 and at the surface was 200 psi, but the pressure appeared to be decreasing in this well at the start of the main test. The reason for this declining pressure is not evident but may have been related to the need to flow the backside of Well 5 to install the data logger through the center tubing on September 27, four days prior to the start of the flow from Well 6.

2.2.4 Draw-down Test Start-Up

This phase coved the initial seven-day period of the test during which the operations were staffed full time by INTERA personnel. The staffing took place in three shifts: a late night shift from midnight to 8:00 a.m.; a day shift from 8:00 a.m. to 4:00 p.m.; and an evening shift from 4:00 p.m. to midnight. This level of effort ensured a constant rate of discharge from the wellhead. During the late night and early morning hours, the flow rate was recorded every two hours. A checklist for wellhead observations was used by personnel on each shift to document the pressures and flow rates from instrumentation at the wellhead. In addition, an on-site computer, which was connected directly to the data logger in Well 6, was set up in the project trailer for monitoring of the pressures, temperatures, and flow rate. The center pivot irrigation system was operated during the day to discharge the water onto the ground.

2.2.5 Draw-down Data Logging and Maintenance

This phase lasted for 24 days following the initial 7-day period, concluding the 31-day draw-down period. Two shifts were staffed during this time, a midday shift from 8:00 a.m. to 4:00 p.m. and an evening shift from 4:00 p.m. to midnight). A late-night shift was not necessary because the system was found to be stable and reliable. Irrigation continued during this period through the day shift and partially into the evening shift.

The draw-down portion of the test was divided into two periods: flow period 1 at approximately 150 gpm and flow period 2 at approximately 250 gpm. The change in the flow rate took place on October 18 at 2:30 p.m. The reason for the change in the flow rate was that the well had essentially stabilized at the 155 gpm rate with a down-hole pressure of approximately 1,471 psi after approximately 10 days (the first reading of 1,471 psi was on October 10 at 11:55 p.m.) and the technical team, with approval of Sandoval County Management, decided to increase the flow rate by approximately 100 gpm to establish a second draw-down curve in Well 6. In addition to the change in Well 6, Well 5 also showed a steepening of the pressure response.

The flow portion of the test was terminated at 12:04 p.m. on October 31, 2008, with the closing of both main wellhead valves at Well 6.

2.2.6 Recovery Period

A recovery period lasting until pressure stabilization was reached followed the draw-down test. This phase began with the shutting in of Well 6. Pressure recovery was seen in Well 6 immediately after flow ceased. Wells 6 and 5 were monitored daily for several days, then every two to four days thereafter until the pressure stabilized.

2.3 Test Observations

Table 2 summarizes the pressure response in Well 6 for flow periods 1 and 2.

Table 2
Downhole Pressure Response Summary for Well 6

Flow Period 1, psi				Flow Period 2, psi			
Start	End	Δ Pressure	Equiv. Δ, ft of H2O at 2.31 ft/psi	Start	End	Δ Pressure psi	Equiv.t Δ, ft of H2O at 2.31 ft/psi
1,501.43	1,471.35	30.08	69.48	1471	1447	24	55.44
Total Drawdown, Flow Period 1 + Flow Period 2						54.08	124.92

3.0 Aquifer Test Analysis and Results

The draw-down and recovery data from the 31-day flow test and subsequent recovery period were successfully recorded and adhere to established quality assurance procedures (INTERA, 2008). The Well 6 data show an expected pressure decline and stabilization during flow periods 1 and 2, followed by recovery. Well 5 data show an expected pressure decline and recovery. The pressure decline in Well 5 during flow period 1 may have been compromised due to the fact that the pressure in Well 5 was decreasing when flow began in Well 6. Consequently, it is difficult to establish the exact response time of Well 5 pressure to the Well 6 flow during flow period 1. The reason for the pre-flow decline in pressure at Well 5 may have been the result of the brine fluid added to the tubing to kill the well when the instrumentation was inserted; however, the additional pressure decrease in Well 5 resulting from the increased flow in flow period 2, as well as the pressure increase during the recovery portion of the test, are useful indicators of the hydraulic connection between Well 6 and Well 5. The complete draw-down and recovery data set for both wells is provided in electronic format as Appendix A of this report.

As discussed previously, two separate analyses of the draw-down and recovery data were conducted by INTERA. Each analysis relied on different but reasonable assumptions regarding aquifer characteristics and flow dimensions within the constraints of the hydrogeologic model presented in Section 1.3 of this report. Each analysis began by creating diagnostic plots of the data and interpreting these plots in terms of physical aquifer characteristics which are known to produce specific curve slopes and shapes (Kruseman and de Ritter, 1991; Walker and Roberts, 2003). Following these interpretations, each analysis used various methods to determine aquifer parameters based on fitting type curves over the actual data plots, resulting in aquifer parameter values for hydraulic conductivity, transmissivity (T), and storativity (S).

3.1 Analysis A

This analysis used the down-hole pressure response data to develop the diagnostic and analysis curves. The initial flow period (F_01) had a nominal flow rate of 150 gpm and resulted in a pressure decline of 30.08 psi or 69.48 feet (of water, based on 2.31 ft/psi). The second flow period (F_02) had a nominal rate of 250 gpm and resulted in an additional drawdown of 24 psi or 55.44 feet. Figure 9 shows the measured and simulated flow rates for both periods and the curve that was used to input the measured flow rate into the nSights model.

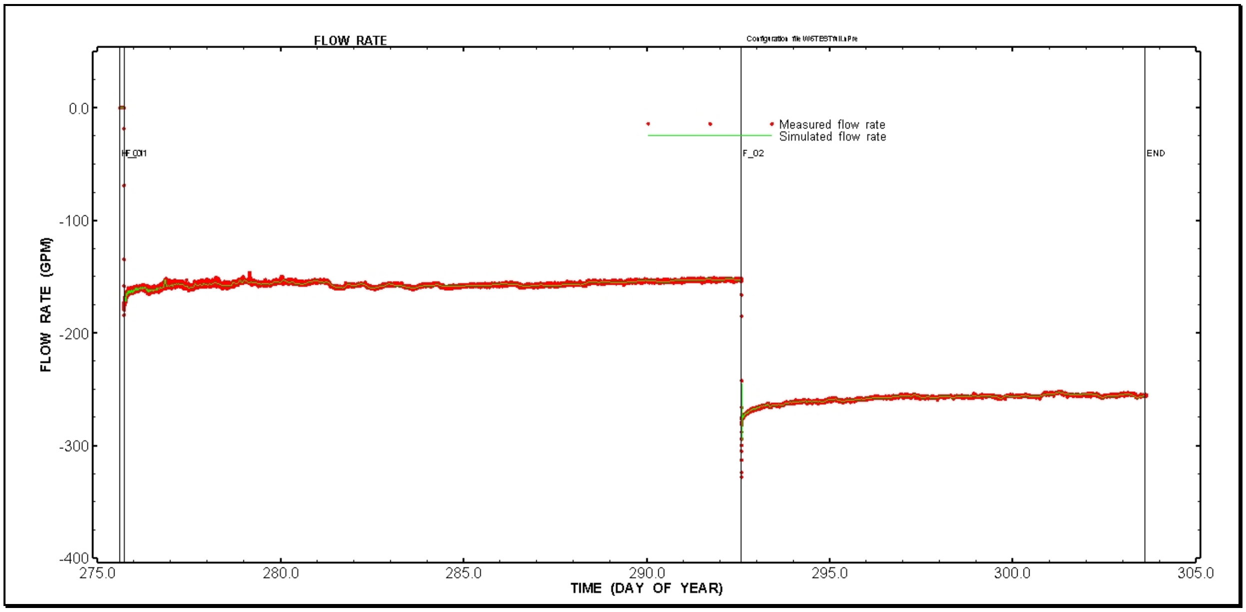

Figure 9. Well 6 Measured and Stimulated Flow Rate

The pressure derivative curve is used as a diagnostic tool to evaluate the flow geometry in the aquifer. Figure 10 shows the pressure derivatives for each of the two flow periods. The derivative for the second flow period has been adjusted using the Agarwal superposition technique (Agarwal, 1980) to compensate for the effects of the first flow period.

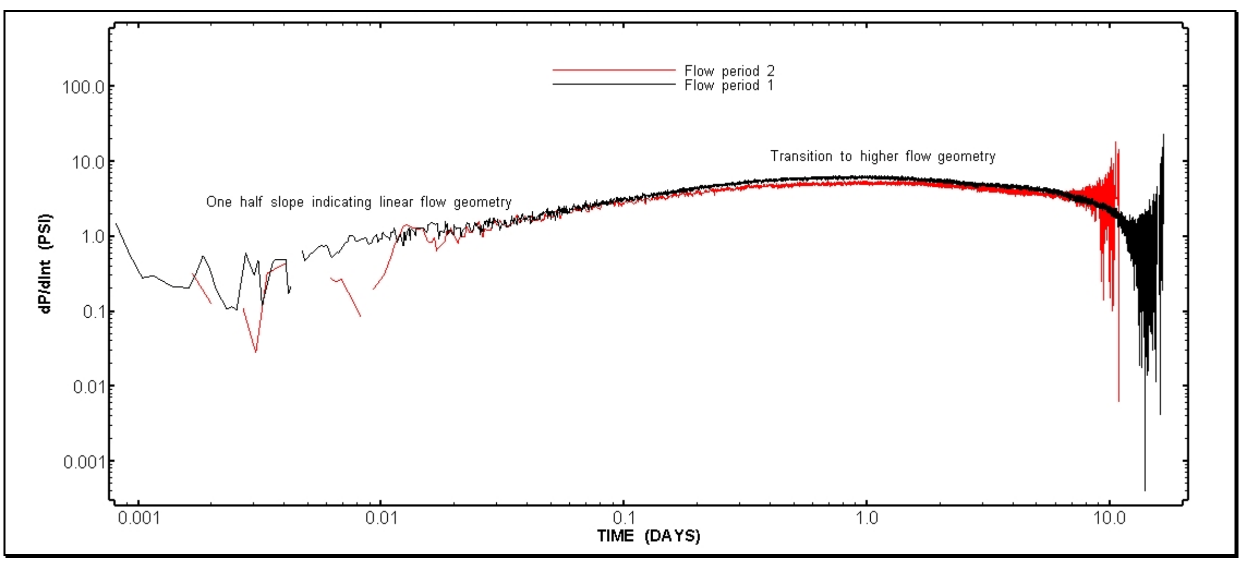

Figure 10. Well 6 Pressure Derivative Plots for Flow Periods 1 and 2

Both derivative plots have similar shapes with an initial period having a slope of ½ followed by a flattening period and then a downward trend. The initial half slope indicates linear flow conditions that correspond to a pipe or a fracture system which does not branch out into other fractures. The flattening and downward trend indicates a transition to a higher flow dimension. This may indicate that the fracture branches out into a two- or three-dimensional pattern or it might indicate water moving in from another system (e.g., leakage).

Following the diagnostic plot evaluation, formation parameters were estimated using nSights. The nSights simulator describes the well and formation properties using a set of parameters. In optimization mode, selected parameters are adjusted to obtain the best fit between the simulation and the measured data. For the purpose of this simulation, the contributing aquifer thickness (b) was assumed to be 121 ft (~37 m) based on the potential producing zones open in Well 6.

Based on the pressure derivatives interpretations discussed above, the simulation was configured with two flow dimensions. The flow dimension nearest the well was fixed to a value of 1. The flow dimension beyond 1,000 m was selected for optimization. Preliminary analysis showed that the distance-to-change in flow dimension could not be accurately determined from the data and had only a small effect on the other parameters. Values for the distance-to-change in flow dimension varied from 500 meters (m) to 1500 m (1,640 feet to 4,921 feet); as a result, it was fixed at 1,000 m (3,280 feet) for the rest of the optimization runs. The other parameters selected for optimization were hydraulic conductivity and specific storage.

Five different estimation strategies were tested. In the first strategy, the parameters were optimized to provide the best overall fit to the entire Well 6 pressure curve (Figure 11). The second strategy optimized the parameters to provide the best fit to Well 6 pressure curve only during the F_01 flow period. In the third strategy the pressure for Well 6 was fixed to the measured pressure during the F_01 flow period. The parameters were then optimized to provide the best fit to the Well 6 pressure curve during the F_02 flow period. For the fourth strategy the pressure for Well 6 was fixed to the measured pressure for the entire test and the parameters were optimized to match the drawdown in observation Well 5. The fifth strategy was the same as the fourth except that radial flow (flow dimension 2) was used for the entire formation.

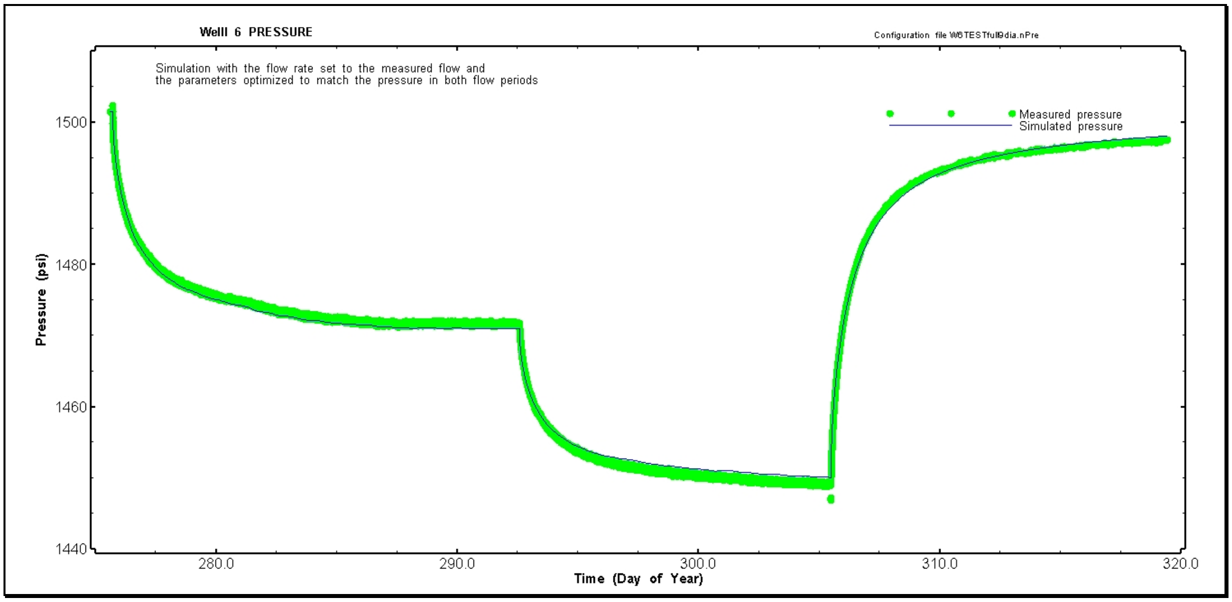

Figure 11. Well 6 Pressure Response

3.1.1 Parameter Values Based on Simulations

Table 3 summarizes the results of Analysis A and Figures 12 to 14 show examples of the simulation results from the first strategy. All of the simulation strategies had equally good fits to the data.

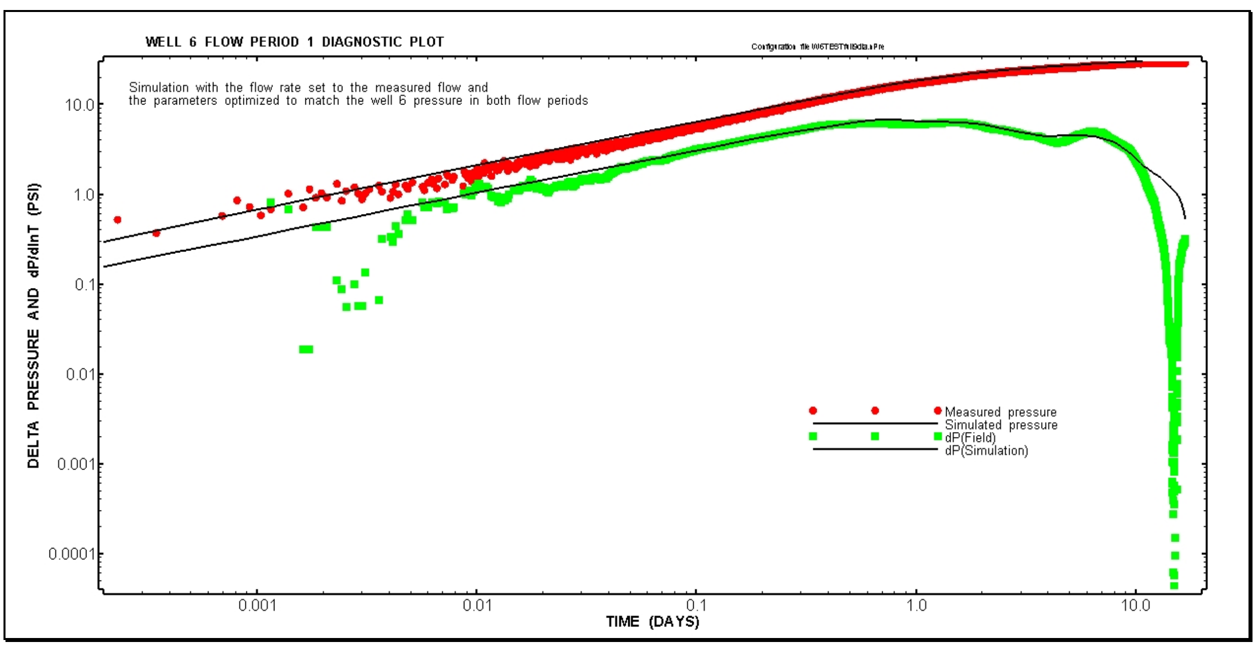

Figure 12. Well 6 Flow Period 1 Diagnostic Plot

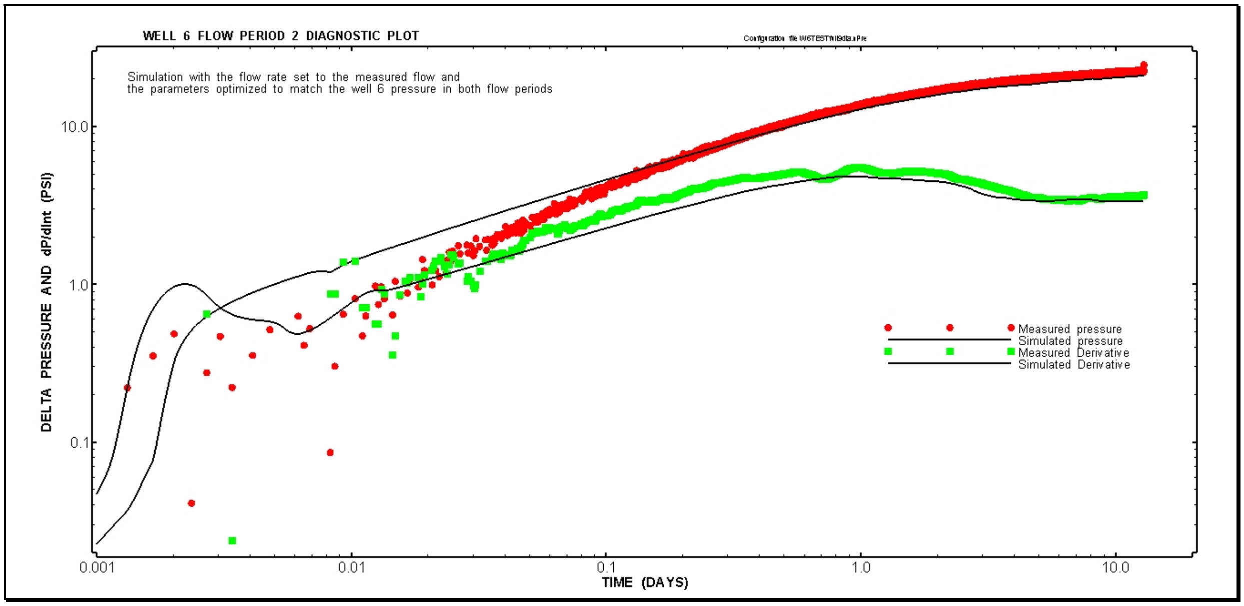

Figure 13. Well 6 Flow Period 1 Diagnostic Plot

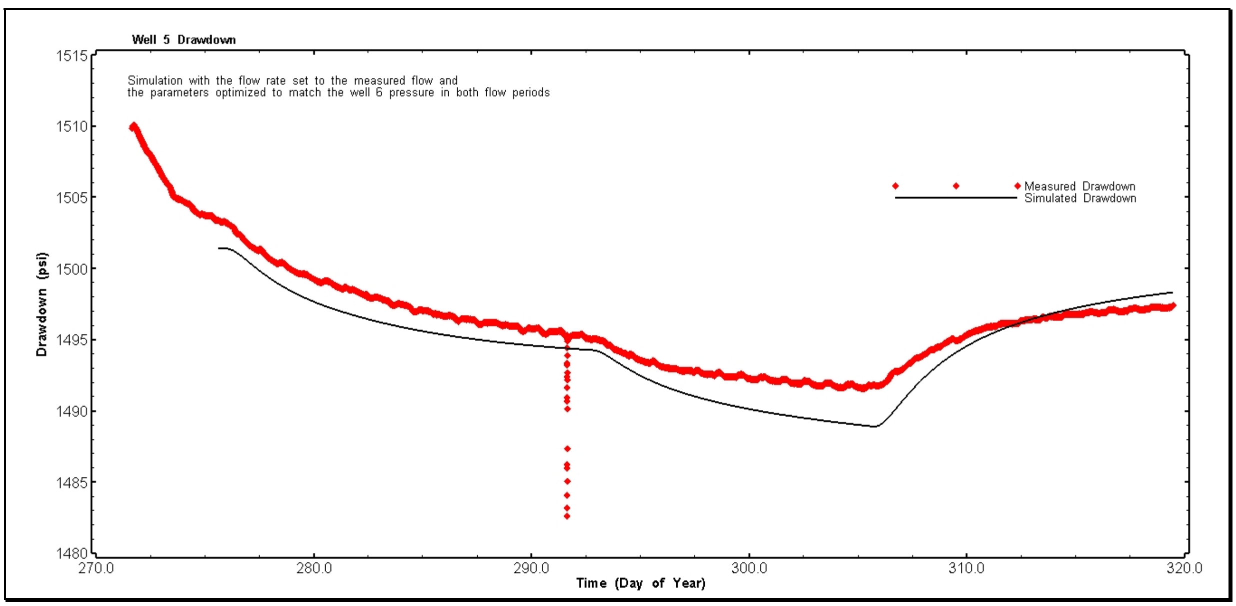

Figure 14. Pressure Response and Simulation Plot

As shown in Table 3, the analysis strategies provided generally similar results. The results for strategy 4, the best fit for Well 5, show the greatest variation from the other results. This is not surprising because the response in Well 5 reflects the connection between Well 6 and Well 5, whereas the Well 6 response is to the entire aquifer. The fact that a good fit to the Well 5 data was obtained using radial flow (strategy 5) indicates that Well 5 is probably beyond the influence of the non-radial flow effects.

Table 3
Summary of Analysis A Results

Estimation Strategy	Transmissivity (m^2/s)	Storativity (unitless)	Flow Dimension 2
1: Well 6, best overall fit	6.80E-01	1.73E-01	2.57
2: Well 6, best fit to F_01 flow	6.99E-01	1.65E-01	2.57
3: Well 6, best fit to F_02 flow	6.69E-01	1.62E-01	2.59
4: Well 5, best fit	8.13E-01	2.01E-01	3.03
5: Well 5, best fit, radial flow	1.47E+00	1.25E-01	NA

3.1.2 Effective Formation Storativity Based on Analysis A

Because of the complicated flow geometry factors involved (linear flow, transitioning to radial flow, transitioning to partial spherical flow from a pressure support, or head boundary), the storativity results shown in Table 3 cannot be used to directly calculate the amount of water that is potentially available from the aquifer. The best-fit values shown in Table 3 are more typical of unconfined aquifer parameters rather than the deep, fractured bedrock, confined water-bearing zones encountered in Wells 6 and 5. The difference is a result of the complexity of the formation and the aquifer response as the flow transitions from linear flow, to radial flow, then to partial spherical flow, with inputs of water from some additional source(s).

For these reasons, it is not appropriate to use the high storativity values derived from the nSights analysis in the total volume calculation. For the “linear flow” portion of the analysis, nSights assumes that the area orthogonal to the flow remains constant and is equal to the area of the well screen. This results in a simulated formation volume that is much smaller than the volume of the total formation, calculated by multiplying the area of the formation by the formation thickness. The actual volume of the formation that is contributing to the flow is unknown, but it is probably closer to the value for the total formation. In order to obtain a more generally-applicable number the storativity needs to be scaled to the total formation volume (Vf) using the ratio of the simulated formation (Vs) volume to the total volume (Vs/Vf).

The area of the formation used to calculate the volume of the formation needs to be calculated from the radius of influence of the test. The two main factors that determine radius of influence are the duration of the test and the diffusivity. Diffusivity is a measure of how quickly a pressure signal will propagate through the aquifer and is defined as the Transmisivity divided by the storativity. The match of the simulation to the Well 5 data is good, as shown in Figure 14. Using the same parameters, a profile of the pressure in the formation was generated at the end of the second flow period and is shown in Figure 15. From this profile the radius of influence was determined to be 15 km (49,200 ft).

Assuming a formation thickness of 36.88 m (121 ft) and a radius of influence 15 km the total formation volume is 2.61×10^{10} m^3. The formation volume from the simulation is 1.06×10^8 m^3. Multiplying 1.73×10^{-1}, the storativity determined from estimation strategy 1, by the scale factor 4.07×10^{-3} (Vs/Vf) yields an effective formation storativity of 6.92×10^{-4}. Once again assuming a formation thickness of 36.88 m (121 ft) the effective formation specific storage would be 1.88×10^{-5} 1/m.

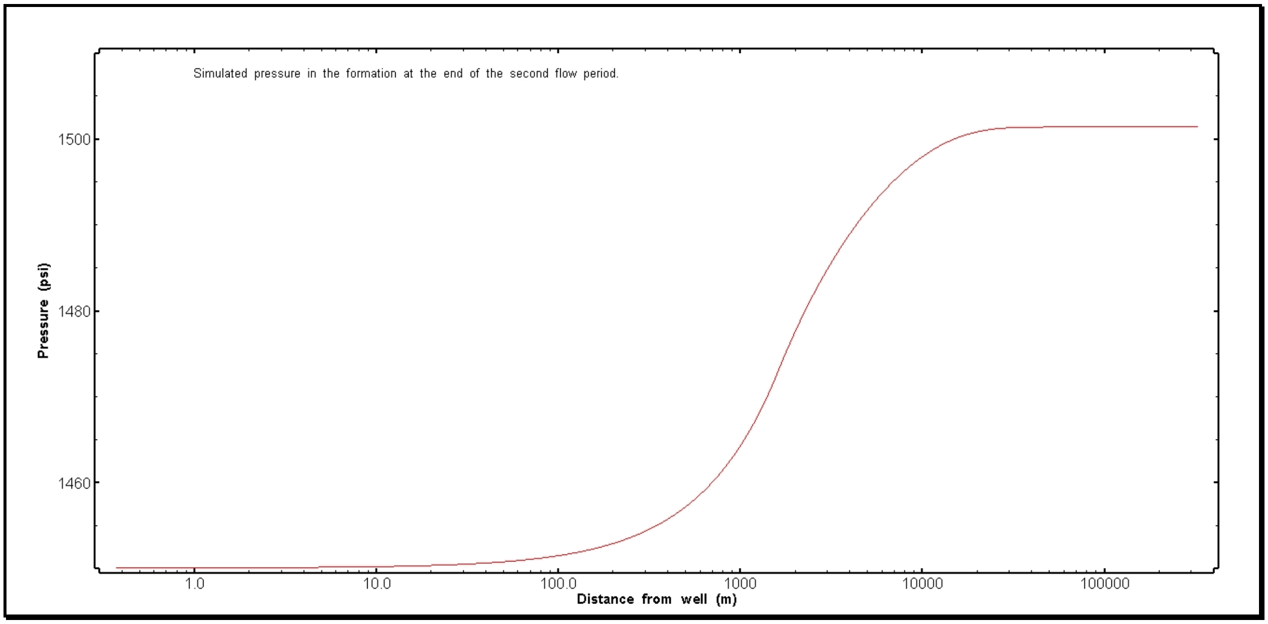

Figure 15. Simulated Pressure Profile

3.2 Analysis B

Analysis B was conducted independently of analysis A using the same data set. The draw-down time data for Well 6 were analyzed to infer a flow model and formation parameters consistent with this model. These model parameters, along with assumptions regarding the aquifer geometry, were then used to make predictions about long-term aquifer response to high-volume water extraction.

Diagnostic plots of drawdown versus elapsed time were used to identify the well-aquifer flow model for each of three test sequences, as follows: flow period 1 (F_01) at approximately 150 gpm), flow period 2 (F_02) at approximately 250 gpm), and a shut-in period. These diagnostic plots displayed the following characteristics:

- A half-slope line in both pressure and derivative plots at early times, up to approximately 0.5 days, indicating linear flow behavior (possibly due to a linear flow channel such as a vertical fracture plane).
- Stabilization in the derivative plot at approximately 0.5 to 2.0 days, indicating the attainment of infinite-acting radial flow (i.e., unrestricted formation flow).
- Decrease in the derivative plot after approximately 2.0 days, indicating pressure support due to fluid influx (possibly due to vertical leakage).

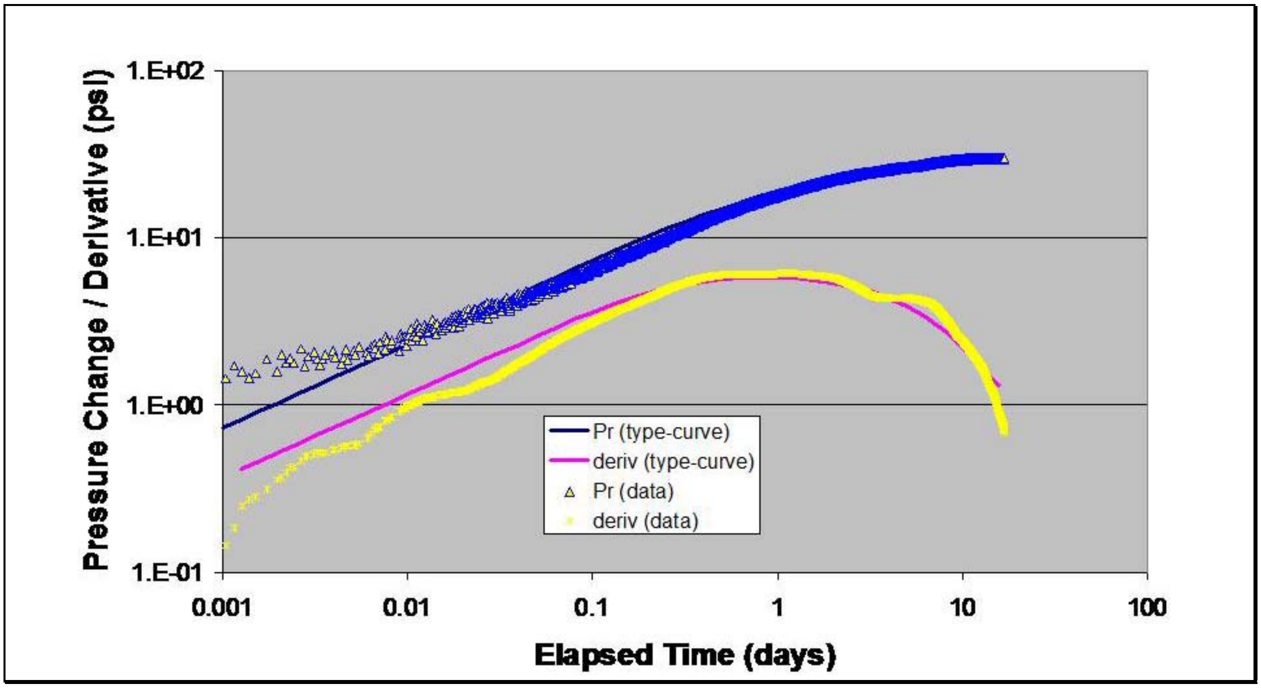

Figure 16. Log-log Fit – Flow Period 1 (RW1)

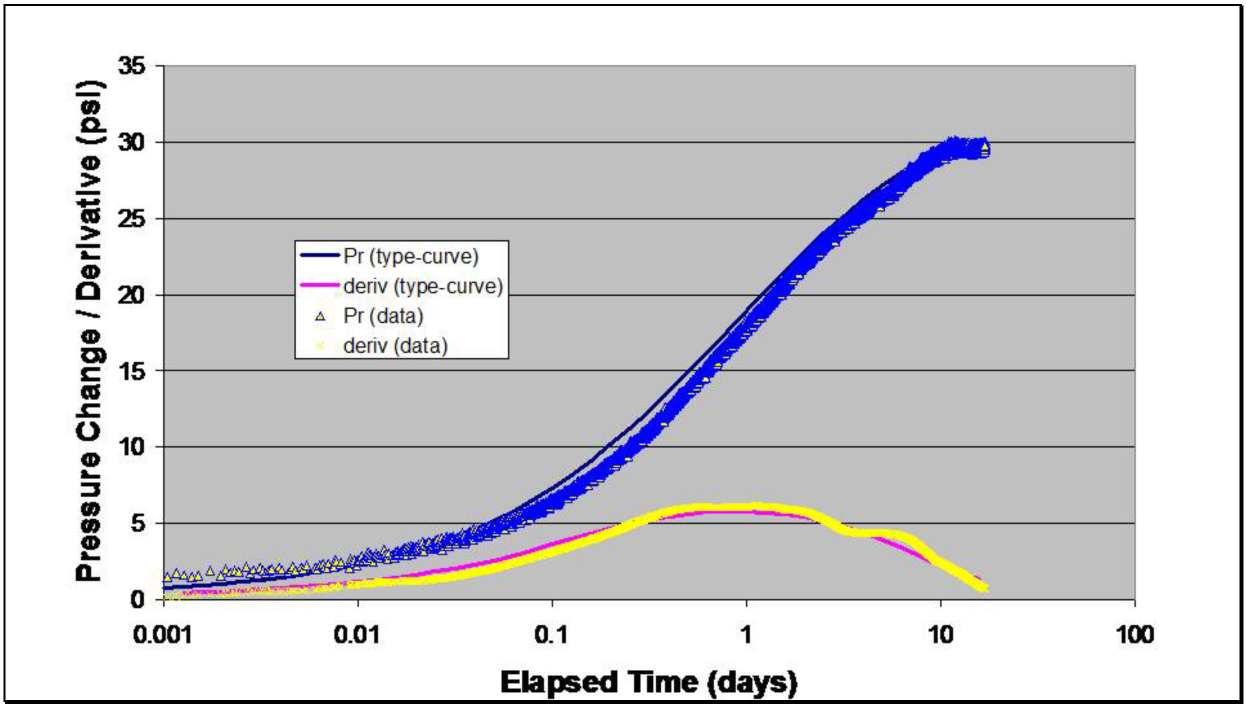

Figure 17. Semi-log Fit – Flow Period 1 (RW1)

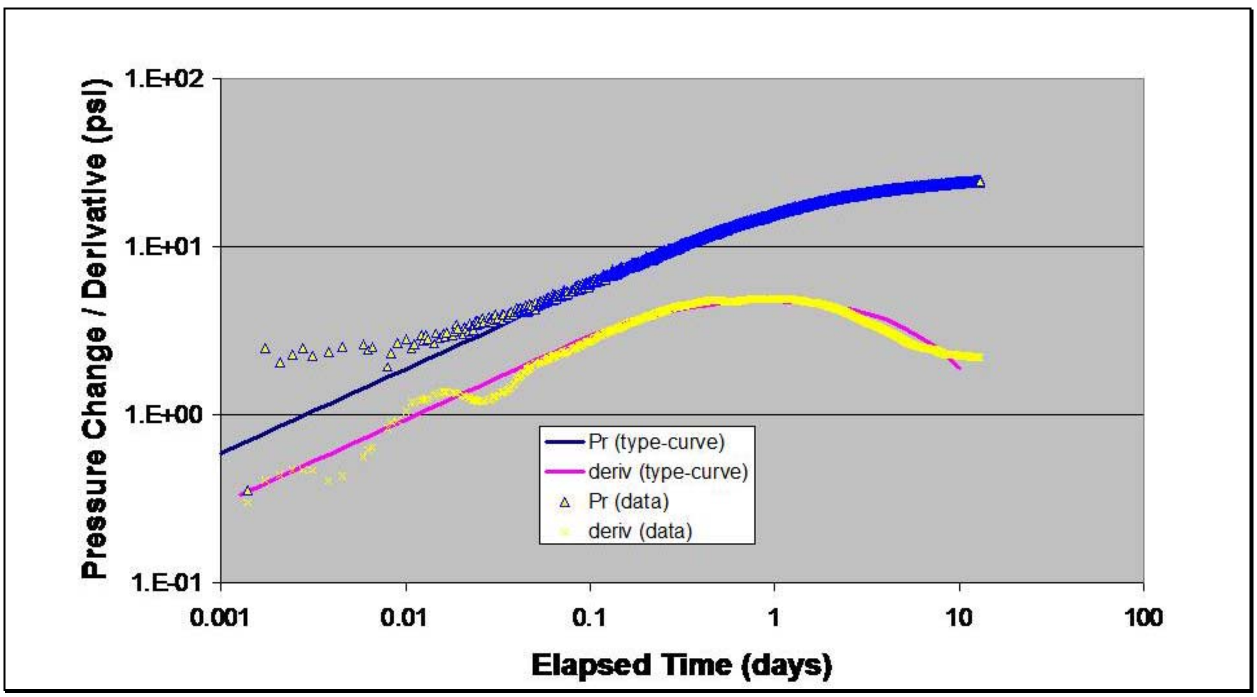

Figure 18. Log-log Fit – Flow Period 2 (RW2)

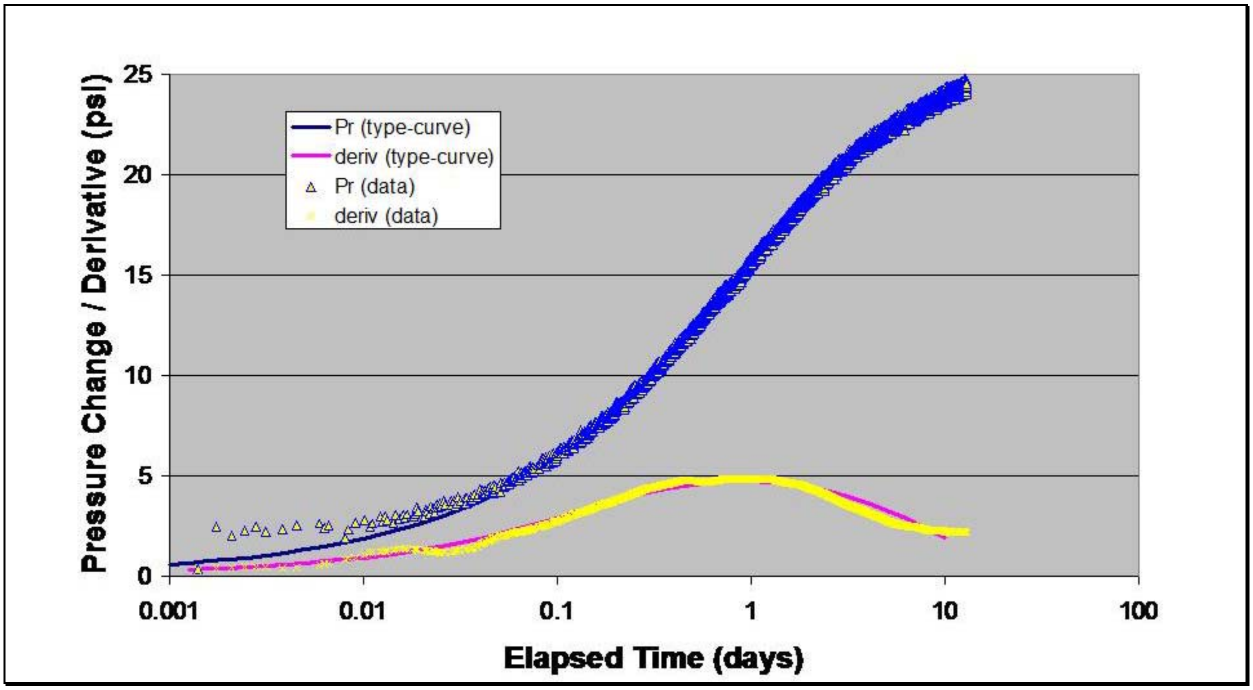

Figure 19. Semi-log Fit – Flow Period 2 (RW2)

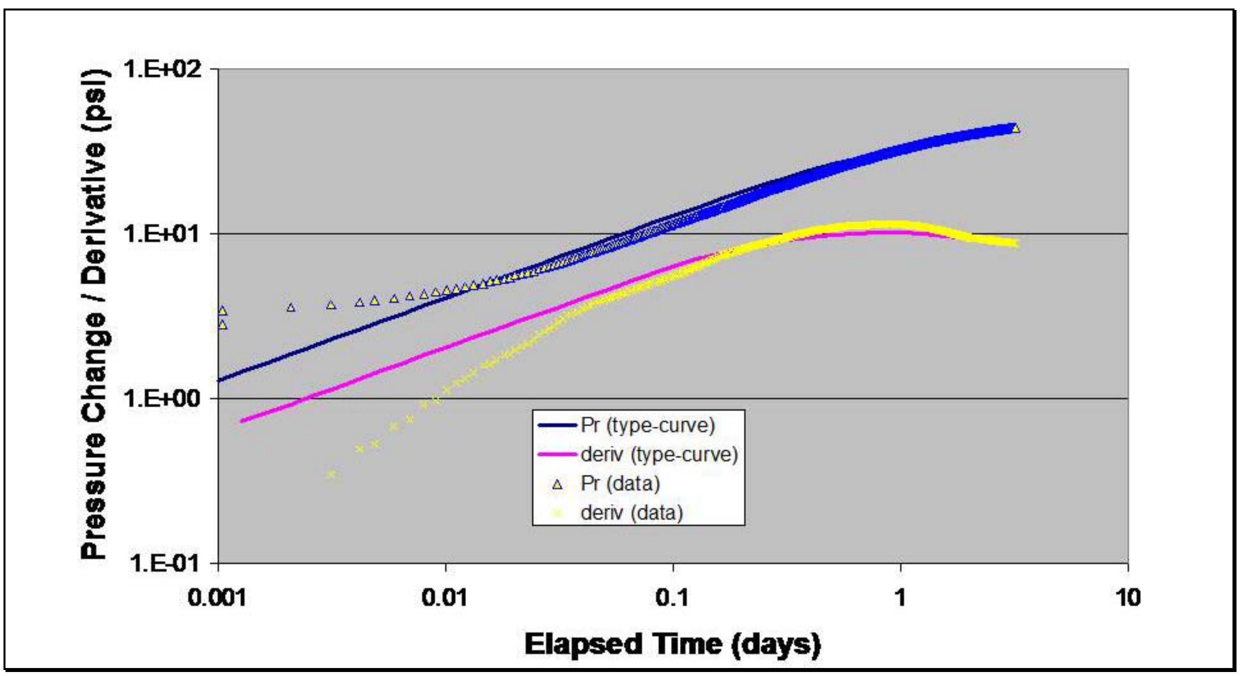

Figure 20. Log-log Fit – Shut-in Period (RS)

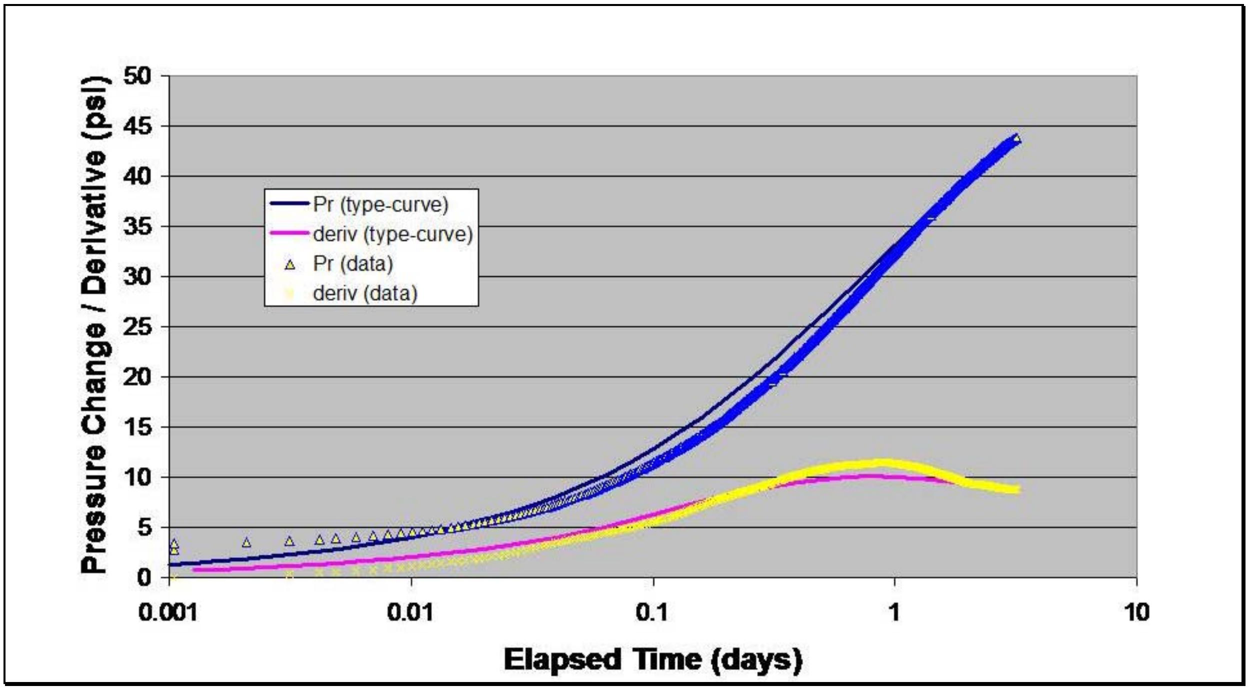

Figure 21. Semi-log Fit – Shut-in Period (RS)

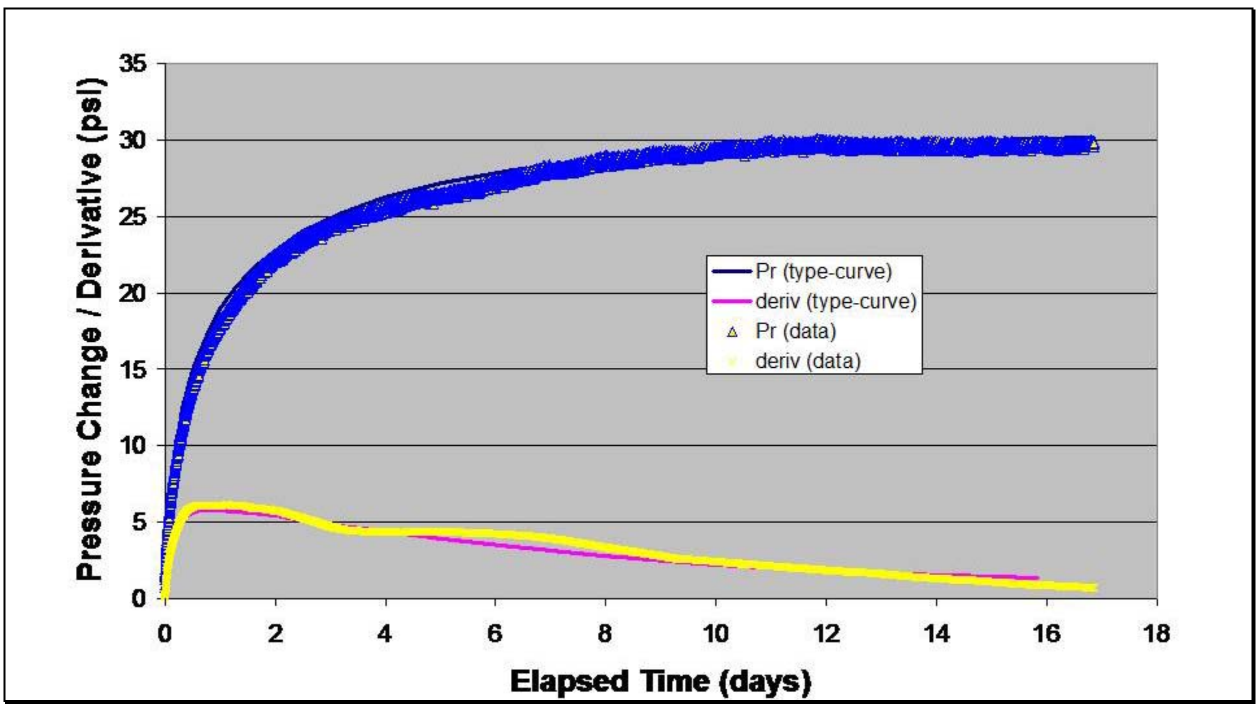

Figure 22. Cartesian Fit – Flow Period 1

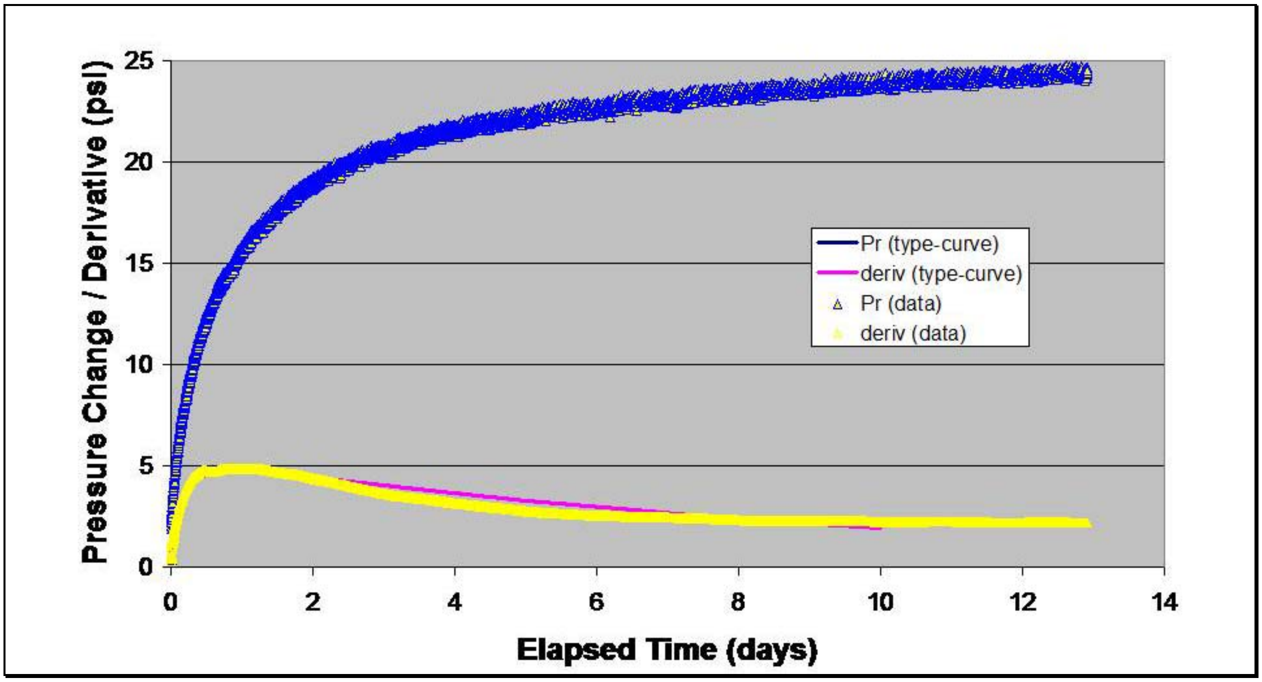

Figure 23. Cartesian Fit – Flow Period 2 (RW2)

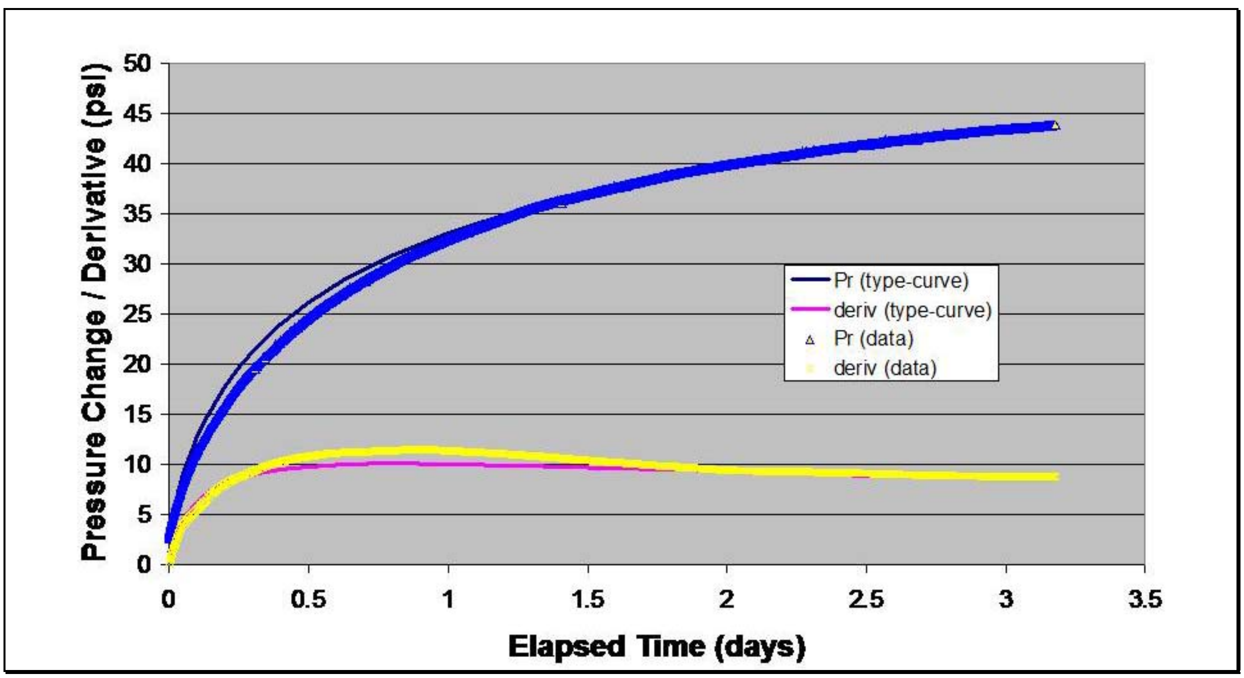

Figure 24. Cartesian Fit – Shut-in Period (RS)

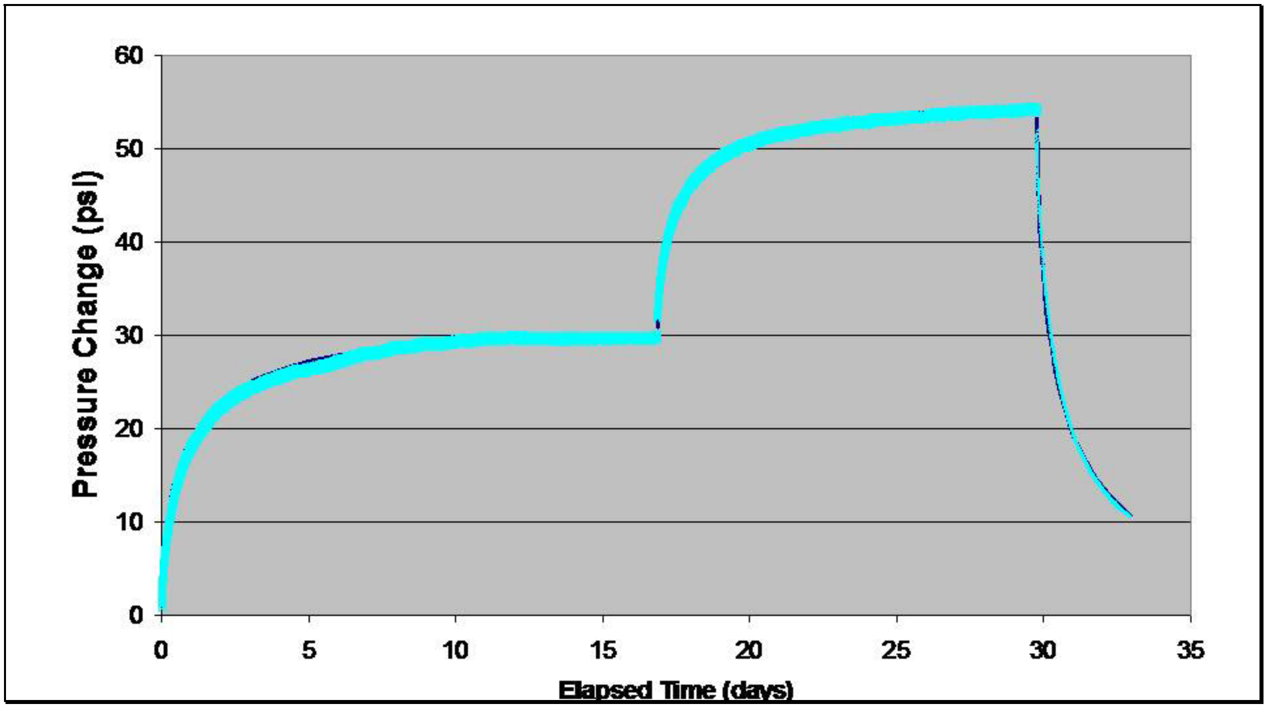

Figure 25. Cartesian Fit – All Sequences

These characteristics suggest a complex flow model that does not fit any of the available standard models. Therefore, a customized dimensionless solution (type curve) was developed by combining the following solutions from the literature:

- Flow to a well penetrating a vertical fracture (Gringraten et al., 1974)
- Flow to a well under infinite-acting radial flow (Theis, 1935)
- Flow to a well in a leaky aquifer (Hantush, 1956)

The Hantush leaky aquifer analysis assumes leakage entirely from an aquitard overlying the primary aquifer zones. This aquitard could be the Moenkopi Formation, as identified in the well logs and on Figures 2 and 3 of this report. The leaky analysis does not include potential input from the Agua Zarca Sandstone, which may have aquifer parameters similar to those of the San Andres and Glorieta formations.

3.2.1 Parameter Values Based on Type Curve

The unknown parameters include formation transmissivity (T), storativity (S), fracture half-length (x_f) and dimensionless leakage parameter (β). These were estimated by manual adjustment to obtain an acceptable visual match between the type curve and the observations. It should be noted that T, S and x_f were determined from the response of the first and second characteristic periods as noted above (i.e., half-slope line and stabilization of derivative). The β parameter was determined from the late-time period (corresponding to the decrease in the derivative plot). The best-fit parameters are as follows:

- $T = 3.2 \times 10^{-4}$ m^2/s
- $S = 1.5 \times 10^{-4}$
- $x_f = 500$ m
- $\beta = 2.7$

3.2.2 Forward Prediction Based on Analysis B

Using these parameters, a forward simulation was carried out to determine the drawdown response in one well over a 100-year period. The production well was assumed to be located at the current coordinates of Well 6 and pumping at a rate of 1,000 gpm. Sealing barriers were placed immediately to the east of the well (coincident with the Moquino Fault), and 17 miles to the west, coincident with Mt. Taylor. The effect of these sealing faults was simulated by adding four rows of image wells on either side of the pumping well. The corresponding draw-down response is shown in Figure 27. Drawdown first increases and then stabilizes after about 0.3 years due to the effect of vertical leakage. Thereafter, drawdown continues to increase because of the restrictions in the drainage area due to the sealing barriers to the east and west.

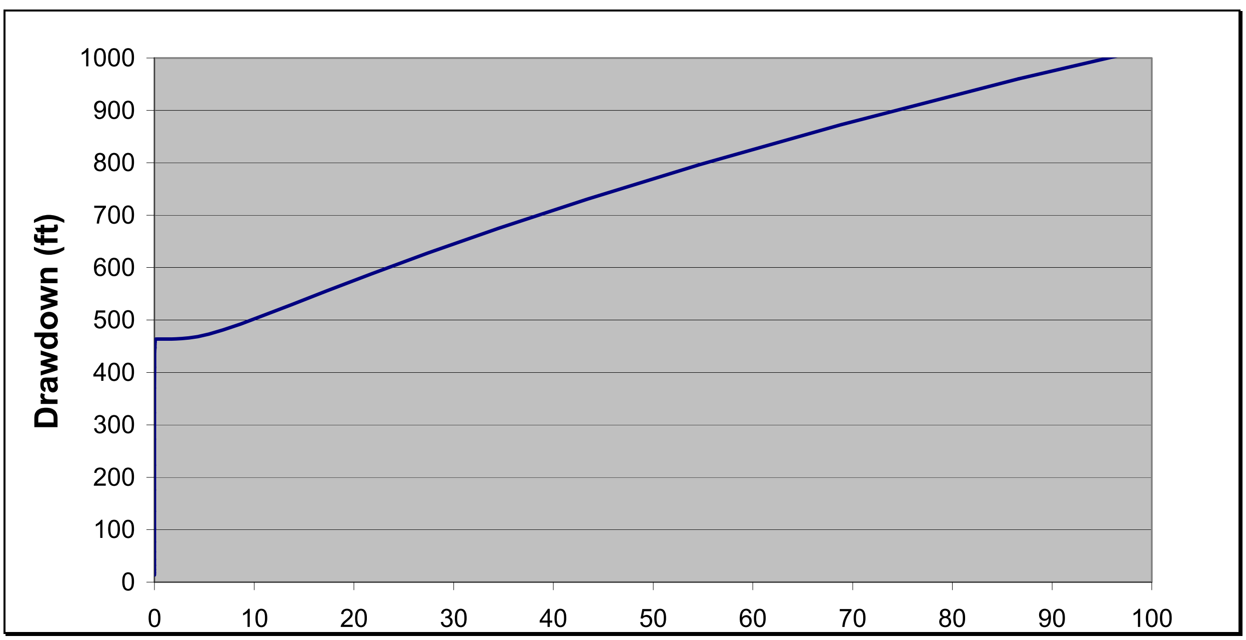

Figure 26. Barriers Adjacent to Well and 17 Miles to the West

This prediction shows a drawdown of approximately 1,000 feet from one well pumping at 1,000 gpm for 100 years.

4.0 Conclusions and Recommendations

4.1 Reservoir Capacity

The results of the aquifer test were used to estimate reservoir capacity. Analyses A and B both provide estimates of the parameters needed to calculate the reservoir capacity as well as predictions of potential aquifer behavior over time, assuming a given amount of pumping. The following discussion describes the calculated reservoir capacity in terms of total volume of water potentially available in the aquifer.

Based on Fetter (2001), the equation used to calculate the potential quantity of water in the aquifer is as follows:

$$Vw = S \times A \times \Delta h$$

where,

Vw = volume of water drained (ft^3, m^3, or acre-feet)
S = storatvity (dimensionless)
A = the surface area overlying the drained aquifer (ft^2, m^2, or acres)
Δh = the average decline in head (ft or m)

Among the factors of this equation, the storativity, S, strongly controls the result because it is a small number, ranging from 6.92×10^{-4} (Analysis A) to 1.5×10^{-4} (Analysis B).

The value for area, A, is based on the area defined in the hydrogeologic model discussed in Section 1.3 of this report. Accordingly, this has a value of 2,000 square miles (1,280,000 acres), which includes the assumed northward extension of the aquifer into the central San Juan Basin. Both analyses assume a large resource area, approximately 2,000 square miles. The area is defined based on limited petroleum exploration borehole data and geologic inference of the area underlain by the producing formations, extending primarily north from the project area and into the San Juan Basin and the area could be even larger if the producing formations were found to extend further into the San Juan Basin. Land ownership, county boundaries, or other potential surface restrictions to drilling are not considered in the area estimate.

The average decline in head, Δh, varies based on the draw-down prediction from Analysis A and on the possible or desired pumping depth in the production wells. This factor has been set at 3,000 feet because of the more than 3,000 feet of head from ground surface to the top of the producing zones.

Table 4 presents the range of factors and the range of possible reservoir capacities based on the results of the 2008 aquifer test. Analysis A indicates a possible total reservoir volume of 2.6 million acre feet, while Analysis B indicates a capacity of 576,000 acre feet. This difference is based entirely on the difference in the storativity values from the two analyses, which vary by nearly an order in magnitude. The Analysis A calculation indicates adequate potential water supply to meet Sandoval County's expected demand after 100 years (43,200 acre feet per year for 62 years). Analysis B suggests 13 years of supply at the projected demand rate. The long-term ground water potential, as evaluated under Analysis B is based specifically on the leaky aquifer model (Hantush, 1965), which limits the leaky source to the aquitard directly above the SAG (i.e. the Moenkopi Formation). This does not account for input to the Moenkopi and thus to the SAG from the Agua Zarca Sandstone which overlies the Moenkopi, or from some as-yet unidentified constant head boundary within the aquifer system.

Table 4
Estimated Potential Available Ground Water
Sandoval County Rio Puerco Water Development

Parameter	Analysis A	Analysis B
Storativity, S	0.000692	0.00015
Areal Extent of Aquifer (acres) [a], A	1,280,000	1,280,000
Average Decline in Head, Δh (ft) [b]	3,000	3,000
Estimated Volume of Aquifer (acre feet) [c]	3,840,000,000	3,840,000,000
Total Aquifer Capacity, (acre feet) [d] = $S \times A \times \Delta h$	2,657,280	576,000
Estimated Total Development Demand (acre feet per year) [e]	43,200	43,200
Years of Water Supply at Estimated Demand Level	62	13

[a] Based on an areal extent of 2,000 square miles (640 acres per mi^2)
[b] Estimated based on the height of the total water column to the top of the Agua Zarca Sandstone (3,275 ft).
[c] Calculated as area (acres) × Δh (ft).
[d] Estimated aquifer volume × S
[e] Based on Sandoval County demand estimates from Rio Rancho and potential developers of the Rio Puerco Valley.

It must be emphasized that the projected demand of 43,200 acre feet per year represents the estimated demand at total build-out of all potential developments identified as of the date of this report. Demand during the early years of development of the Rio Puerco Valley would be substantially lower. The estimated build-out rate and associated demand increase has been modeled by Sandoval County but is beyond the scope of this aquifer test report to incorporate such forecasting into the aquifer potential analysis.

In summary, Sandoval County has undertaken a ground water exploration effort in for a deep, brackish resource from a confined, fractured, bedrock aquifer. The hydrogeologic model developed for this report and the results of the Well 6 aquifer test indicate that brackish water is present in the SAG formations and that the potential reservoir capacity is dependant primarily on the storativity factor (derived from the test), the assumed area, and the assumed potential drawdown.

The presence of the 140-foot-plus thick Agua Zarca Member of the Chinle Formation that overlies the Moenkopi may provide a substantial additional ground water resource. The Agua Zarca is a recognized reservoir rock in the region (Hawkins et al., 1977), but was not completed as open in Well 6 due to drilling difficulties. Approximately 80 feet of Agua Zarca is open in Well 5, but this is not expected to contribute significantly to the test flow because of the relatively small diameter of Well 5 (as compared to an actual full completion across this unit in a production well). Future exploration or production wells should better reflect the presence of this potential aquifer. This is especially true in areas where fracturing is likely, such as near the Moquino Fault or the Puerco fault zone. If the Agua Zarca holds a quantity of water similar to that identified in the SAG, the total potential aquifer volume could increase proportionally.

4.2 Recommendations for Future Exploration

Future exploration efforts should be designed with consideration of the current geologic and hydrogeologic information presented in this report, as well as on land development needs as they will surely evolve. For example, drilling wells which tap the fault block west of the Moquino Fault improves the chances of finding the SAG and adjacent aquifers within a depth range that is similar to that in Wells 6 and 5. In contrast, drilling where the target formations are on the east side of this, or related "down-to-the-east" faults, could result in encountering the target aquifers at much greater depth, resulting in greater drilling and completion costs.

Experience with this project also suggests that ground water production may be enhanced by fault-related fracturing in the sandstone and limestone formations, and development of solution cavities within the limestone. Thus, drilling near the Moquino Fault (but with production from the west side of the fault), or within the Puerco Fault zone (where fracturing could enhance permeability), are strategies which could increase the chances of finding appreciable ground water production.

As the project moves into the pilot desalination phase, additional wells should be installed according to the strategies discussed above and additional aquifer testing should be conducted on these wells to better characterize the long term potential of the resource. Incorporating these data and additional well test data into a regional ground water flow model would enable a more defensible aquifer potential analysis, as it would allow for the following:

- evaluation of the aquifer potential within the context of a regional water balance

- incorporation of key geologic features, such as the Moquino Fault to better analyze the effect of these features on regional flow,
- optimization of pumping scenarios to ensure adequate aquifer yields are maintained, and
- analysis of the extent of drawdown under various scenarios

5.0 References

Agarwal, R.G. 1980. A New Method to Account for Producing Time Effect When Drawdown Type Curves are Used to Analyze Pressure Buildup and Other Test Data. SPE Paper 9289, Soc. of Petroleum Engineers, Richardson, Texas.

Balleau Groundwater, Inc., 2007. Technical Memorandum, Rio West Well Expl-6 Half-Day Flow Test Data and Interpretation.

Dillinger, J. K., 1990. Geologic Map of the Grants 30 x 60 degree quadrangle, West Central New Mexico, U.S. Geological Survey, Coal Investigations, Map C-118-A.

Fetter, C.W., 2001. Applied Hydrogeology, Fourth Edition. Prentice Hall, Upper Saddle River New Jersey, 07458, 598 p.

Freeze, R.A. and J.A Cherry, 1979. Groundwater. Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632, 604 p.

Gringarten, A. C., H. J. Ramey Jr., and R. Raghavan, 1974. Unsteady-State Pressure Distributions Created by a Well with a Single Infinite-Conductivity Vertical Fracture. SPEJ, 347-360, Trans. AIME 257.

Hantush, M.S., 1956. Analysis of Data from Pumping Tests in Leaky Aquifers. Transactions, American Geophysical Union 37:702-14.

Hawkins, J.M., R.W. Snyder, and S.B. Pahwa, 1977. *Journal of Petroleum Technology*. Volume 29.

INTERA, 2008. Sandoval County Rio Puerco Basin Water Development Project Aquifer Test and Groundwater Sampling Field Work Plan.

Kernodle, John Michael, 1996. Hydrogeology and Steady-State Simulation of Ground-Water Flow In the San Juan Basin, New Mexico, Colorado, Arizona, and Utah. U.S. Geological Survey Water-Resources Investigations Report 95-4187. Regional Aquifer-System Analysis. Albuquerque, New Mexico.

Kruseman, G.P., and N.A. de Ritter, 1991. Analysis and Evaluation of Pumping Test Data, 2nd ed., Publication 47, International Institute for Land Reclamation and Improvement, P.O. Box 45, 6700 AA Wageningen, The Netherlands, 337 p.

Leake, S.A., J.P. Hoffmann, and J.E. Dickinson. 2005. Numerical Ground-Water Change Model of the C Aquifer and Effects of Ground-Water Withdrawals on Stream Depletion in Selected Reaches of Clear Creek, Chevelon Creek, and the Little Colorado River, Northeastern Arizona. U.S. Geological Survey Scientific Investigations Report 2005-5277.

Pollock, C.J., K.G. Stewart, P.J. Hibbard, L. Wallace, and R.A. Giral, 2004. Thrust Wedge Tectonics and Strike-Slip Faulting in the Sierra Nacimiento, New Mexico, New Mexico Bureau of Geology and Mineral Resources, Bulletin 160.

McLemore, V.T, 1998. Bluewater Lake State Park: New Mexico Geology, 20:2, pp. 44-46.

Sawyer, D. A., and S.A. Minor, 2006. Geologic Setting of the La Bajada Constriction and Cochiti Pueblo Area, New Mexico. U.S. Geological Survey Professional Paper 1720-A. <http://pubs.usgs.gov/pp/1720/downloads/pdf/p1720A.pdf>.

Sengebush, R.M., 2008. Structural and Stratigraphic Controls of Deep Brackish Water Exploration, Sandoval County, New Mexico, New Mexico Geological Society Spring Conference, 2008.

Summers, K. W., and F.E. Kottlowsk, 1969, reprinted 1996. The San Andres Limestone, A Reservoir for Oil and Water in New Mexico. New Mexico Geological Society, Special Publication No. 3.

Tedford, R. H, and S. Barghoorn, 1999. Santa Fe Group (Neogene), Ceja Del Rio Puerco, Northwestern Albuquerque Basin, Sandoval County, New Mexico, New Mexico Geological Society Guidebook, 50th Field Conference, Albuquerque Geology.

Theis, C. V., 1935. The Lowering of the Piezometer Surface and the Rate and Discharge of a Well Using Ground-Water Storage. Transactions, American Geophysical Union 16:519-24.

U.S. Geological Survey (USGS), 2005. The Water Supply of El Morro National Monument. USGS Water-Supply Paper 1766.

Van Hart, D., 2007. Geologic Report, Rio West Saline-Water Project, Wells EXP#5 and EXP#6, Sandoval County, New Mexico. Unpublished report.

Walker, D.D., and R.M. Roberts, 2003. Flow Dimensions Corresponding to Hydrogeologic Conditions, *Water Resources Research*, 39:12.

Williams, P.L., and J.C. Cole, 2007. Geologic Map of the Albuquerque 30’ x 60’ Quadrangle, North-Central New Mexico. USGS Scientific Investigations Map 2946.

Woodward, L.A., W.H. Kaufman, J.B. Anderson. 1972, Nacimiento Fault and Related Structures, Northern New Mexico, *Geologic Society of America Bulletin*, 83:8, pp. 2383-2396.

Appendix A

Well Test Data

(Provided Electronically)

Appendix B

Test Operations

(Provided Electronically)

Appendix C

Aquifer Test Work Plan

(Provided Electronically)

Appendix D

Field Note Books and Test Operations Field Forms

(Provided Electronically)

Appendix E
Photo Log of Test Operations