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Water Test Reports

January 13, 2009

Mr. George King
Project Manager
2330 North FM 3083 Rd. East
Conroe, Texas 77303-1864

Subject: Aquifer Test Review

Dear Mr. King:

As you requested on December 23, 2008, our opinion is given below of the October 2008 test of Sandoval County (County) deep-saline wells 5 and 6 regarding the data quality, an independent interpretation of the data, a projection of well and wellfield performance, and comments on two earlier hydrogeologic reports (Intera[1], Shomaker[2]). The technical analysis is presented in the attached technical memorandum.

Summary

The data collected during the 31-day test serves to define aquifer and well performance at production well #6 and can be extended reliably for a period of many years. Well #6 can be pumped to yield 1000 gallons per minute (gpm) (1600 acre feet per year (AFY)) likely for decades. At observation Well #5, the data on response to flow at well #6 was obscured by background fluctuations, thus regional aquifer storage, transmissivity, and boundary effects from that site remain uncertain.

A reexamination of the data leads to the characteristic aquifer properties of transmissivity at 350 feet^2/day (ft^2/d), storage coefficient at 1×10^{-4}, with no apparent boundaries in the area of investigation. Using those aquifer properties alongside a published U.S. Geological Survey model description of the regional San Andres

[1] Intera Incorporated, December 9, 2008, Draft Sandoval County Rio Puerco Basin Water Development Project Aquifer Test and Analysis Report.
[2] Shomaker & Associates, Inc., December 17, 2008, Letter to Mr. Chris Stageman NMISC: Re: Sandoval County deep wells.

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limestone aquifer, we find the wellfield (28 sites from earlier Notices of Intent) can be planned to produce 2000 to 2700 AFY depending on whether 750 feet to 1200 feet pumping water levels (PWL) can be maintained for 10 to 100 years. The low improvement of wellfield yield versus single-well yield (2700 acre feet (AF)/1600 AF) is due to severe mutual interference among wells on one-mile centers. Wells should be spaced much farther apart than in the Notice of Intent, or fewer wells need to be drilled.

The earlier hydrologic report by Intera, Inc. derived a fully-serviceable set of aquifer parameters (their Analysis B). Intera put forward a related volumetric calculation for "production potential" or "reservoir capacity", which is understood to represent the volumetric water resource in a 2000-square mile area after a 3000 foot water-level decline. The other hydrologic report, by Shomaker & Associates, Inc. cautions that the volume of the aquifer is not "the amount that can be practically pumped" and the corresponding availability to County wells "seems doubtful". We concur. Shomaker further raises the New Mexico Interstate Stream Commission (ISC) issue of impacts on the aquifer discharge.

Balleau Groundwater, Inc. (BGW) recommends that modeling, and controlled production and observation, proceed together with oversight by a team of experts from interested agencies and parties to efficiently manage the recovery of the available deep-saline resource.

Data

We find the well #6 data quality to be good. The observation well #5 response is uncertain due to unsteady pre-test data trends. Stable conditions at observation well #5 were not established before the test began at well #6. We have attempted to adjust for the unstable observation well #5, but its utility for making conclusions about long-term trends during and beyond the test period is undercut. Thus, the well #6 data provides the primary basis for projections. Storage coefficient is roughly 1×10^{-4} from the observation well # 5 response but boundary trends are lost in the background noise.

We conclude from an independent look at the data that the 31-day test and recovery at well #6 establish a reliable aquifer transmissivity of 350 ft^2/d for projections of the single-well yield for many years.

Wellfield Calculation

Applying field-tested properties from Intera's analysis B to a wellfield of 28 wells spaced as planned, the yield would be 2,300 AFY at the end of 10 years with 750 feet drawdown. One hundred years of production would exceed 2,000 AFY. If PWL could be taken to 1200 feet of drawdown, yields would be somewhat less than proportionally increased to 2,500 AFY at 100 years due to non-linear head losses. The BGW wellfield calculation is described in the attached technical memorandum.

Intera Report

Our reading of the Intera report warrants the following comments for discussion. The overall impression is of a high-level technical effort addressing advanced issues such as flow-dimensionality. A few technical questions remain. Intera's access to the Sandia National Laboratories licensed program "nSights" is advantageous and might be further applied to some remaining questions.

Their Executive Summary provides Intera's main points. The purpose was to a) "determine the aquifer characteristics" and b) "establish the long-term production potential". The report gives two sets of aquifer characteristics (A & B) alongside two values (A & B) for "reservoir capacity". The reported volume of reservoir capacity is calculated from an area (2000 square miles), a depth (3000 feet), and either of two ratios of water content per unit head change (692 acre feet (AF) or 150 AF of water per million AF of aquifer head change), e.g., 2000 square mile x 640 acre/square mile x 3000 feet of head decline = 3840 million AF as a volume of head change. At 692 AF per million, that factor yields 2,660,000 AF as a volume of water from drawing down the 2000 square mile area by the 3000 feet amount. The smaller factor produces 576,000 AF.

The demand of 43,200 AFY is divided into those volumes to get a service lifetime. Intera concludes that the range of volume estimates (a factor of 4.6 in the estimates) reflects "the uncertainty associated with applying the result of a single test to ... an entire aquifer system". Additional exploration to reduce uncertainty is recommended by Intera.

Our view of the Executive Summary is that the numbers given for potential production and service lifetime are only partially linked to the 31-day test. Area, depth and demand are unrelated to the test. The "depth" term is treated variously as a geologic section or as a pressure drawdown. Regarding water released from storage, it should be considered a pressure drawdown exclusively. The report should clarify the authors' views on that point to remove a point of confusion to this reader. The two storage factors come from Intera's alternative interpretations of the test data, but BGW does not endorse the view that the uncertainty of the potential production is reflected in the reported range of volume estimates. The reasons for allowing a wider range are detailed below.

Report Section 1 describes Intera's hydrogeologic model in the sense of areal extent and structure. We see no geologic reason to prefer Mt. Taylor as a "major structural break" 15 miles distant, rather than the Rio Puerco Fault zone, three to five miles distant. Mapped faults even closer may prove to be effective barrier boundaries consistent with the 31-day test data.

Report Section 2 describes the setup for the test. The recovery period lasted 60 days, but only 30 days were analyzed. BGW received 42 days of recovery data, including a strong decline in pressure at observation well #5 after 30 days of recovery. In discussion with Intera, the late perturbation of recovery at observation well #5 is unexplained. The full 60 days of recovery is critical to the interpretation of the test and should be presented and explained. We note that a casing or valve leak of one or two gpm could explain the anomalies at observation well #5, as could brine convection, gas evolution, internal circulation as frac zones clog or unclog, etc. In any case, the observation well data mask the test response with uncontrolled background changes.

The "independent hydrogeologic consultant" on analysis A should be identified and made available for interview and follow-up on the derivation of storage terms.

The pre-test flow of 72 hours is reported to have been logged, graphed and examined by Intera. Data should be recovered and integrated in the final report.

The rate change on October 18 is reportedly due to pressure having "essentially stabilized", but the flow-rate data show that was caused by declining rates. True stabilization requires that both rates and drawdown be steady, so this apparent condition at 18 days should not be misread as stable conditions in the aquifer.

The report cites "pressure stabilization" and "pressure recovery" after shut-down, but the data show that recovery after 42 days was neither stable nor fully recovered. The observed residual drawdown is significant.

BGW recognizes that data anomalies and control issues are so common as to be expected in real-time field work of this type. We believe further examination of the data during the anomalous response periods may have explanatory value. Observation well #5 was unsteady at the time of 31-day start-up, and it would have been good for test purposes to delay start-up until observation well #5 was stable and in control. The observation well #5 response was the best opportunity to get storage coefficient, regional transmissivity, and boundary-trend shifts, which now remain poorly defined.

Report Section 3.0 is on the test analysis. We note in contrast to flow period 1, that well #6 did not "stabilize" in flow period 2 when rates remained more-nearly steady.

Two analytical methods were applied by Intera. Analysis A applied a program, nSights, with strong capabilities for flow dimension, derivative plots, rate variation, and well efficiencies, all pertinent to this test. The program used 28 days of pumping data. We note that the earliest log cycle of data has a slope of 1.0, rather than 0.5, indicating an initial closed container, rather than a pipe-like fracture. The analysis assumed a pipe-like fracture to a distance of 3280 feet from well #6, then solved for flow dimension, plus transmissivity and storativity at larger radius.

The program was fitted to five data sets, some including 14 days of recovery. The pipe-like fracture to 3280 feet was in each analysis. The Intera Table 3 values appear to report only the near-well #6 fracture, where transmissivity and storativity are large representing the properties of pipe-like flow. We question how the nSights program calculates the storage term reported in Table 3. Is the water volume taken from accumulated pressure decline or from an aquifer space?

Intera Figure 15 shows the distance-drawdown plot resulting from the nSight analysis. The well #5 data problem is not dealt with in Figures 14 or 15. Pressure is flat to a distance of one kilometer, then is steep to a distance of ten kilometers. The flat zone in Figure 15 of the report corresponds to transmissivity of hundreds of thousands of ft^2/d (0.7 $meters^2/second$) (m^2/sec) as reported in Table 3, and the steep zone corresponds to about 200 ft^2/d ($2 \times 10^{-4} m^2/sec$). We note that Figure 15 shows an r_0 intercept nearer eight kilometers than 15. An eight-kilometer radius implies storativity $= 2 \times 10^{-5}$ by Cooper-Jacob[3] straight-line calculation. The zone of low transmissivity beyond 3280 feet is most pertinent to the projection of future aquifer performance, but is not tabulated in the report, or otherwise discussed.

The Intera report derives (outside the nSights program) effective storage coefficient for use in the "potential production" volume calculation by using the radius of influence in the far-flow field from report Figure 15. Intera calculates effective storage by an indirect method to be 6.92×10^{-4} as a product of the ratio of simulated formation volume ($1.06 \times 10^{8} m^3$) per formation volume at 15 kilometers distance ($2.61 \times 10^{10} m$) times simulated storativity (0.173).

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[3] Cooper, H.H. Jr., and Jacob, C.E., 1946, A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-field History: American Geophysical Union, Volume 27, pp. 526-534.

The Intera method of adjusting the simulator output raises two questions. Is the simulator output reporting a physically-based and dimensionally correct storativity? And if so, is the adjustment procedure equally correct? A discussion with the nSight's expert is needed. We cannot resolve the question about simulation output without talking to the program authors or seeing the source code. We are concerned also that the focus on aquifer volume is misdirected because storage coefficient is a ratio of water volume to pressure-change volume, not to aquifer volume. We do not follow the rationale. Does the nSights program report the pressure change or the aquifer volume as the basis for storage coefficient?

If we accept the 15 kilometer radius on Intera Figure 15 as r_0, then we calculate 5.5×10^{-6} storage coefficient for 33,000 m^3 (27 AF) of water volume produced in the 31-day test. The conventional Cooper-Jacob approach to quantifying storage coefficient at either eight kilometers or 15 kilometers gives a significantly smaller result than reported by adjusting the model simulation by aquifer volumes. Intera's conclusions on "potential production" hinge on this 6.92×10^{-4} value, which needs further examination regarding the nSight model workings.

Analysis B involves matching a customized type-curve for fracture-flow transitioning to radial flow in a leaky aquifer. We concur with that concept of the system, but note that a "decrease in the derivative plot after approximately 2.0 days" need not indicate fluid influx because such a decrease is a pattern of regular 2-D radial flow. We find no clear evidence of 3-D leakage in the data trends of our attached technical memorandum.

Intera reports "an acceptable visual match between the type-curve and the observations", but does not display the graph, which should be made available in the final report for others to inspect.

The resulting analysis B aquifer characteristics are transmissivity of 300 ft^2/d, storativity of 1.5×10^{-4}, a shorter pipe-like fracture length of 500 m, and an estimate of leakance.

Although the analysis B results appear to differ by orders of magnitude from the analysis A table values, the table values appear to represent different parts of the flow system; the near well fracture (A) and the far-flow field outside the fracture (B). The two Intera analyses appear to be more compatible when same zones are compared, with transmissivity values of 200 (Figure 15) to 300 ft^2/d (p. 40) for the aquifer zone outside the fracture length. Storage (1.5×10^{-4}) by analysis B is in the plausible range.

The forward prediction given on Intera Figure 26 is reasonable. The sensitivity of the prediction to closer boundaries at the Rio Puerco Fault zone, and sensitivity to well interference in a wellfield and to well skin effect is of interest. These points belong in a final report. The attached technical memorandum indicates our picture.

Intera's conclusions and recommendations address "reservoir capacity" by using storage values from each of analyses A and B, a 2000 square mile area and 3000 feet of drawdown (depth) throughout the area. We believe the analysis A storage is ill-founded, but the B value is plausible. The "reservoir capacity" should not be read as usable water producible from wells.

We note that Intera reports the radius of influence of the 31-day test to be 15 kilometers (9.3 miles), or an area of 270 square miles. BGW estimates that radius from the analysis B parameters to be 2.2 miles or an area of 16 square miles. That indicates the area of investigation of the test. The aquifer-test information should not be extended to characterize 2000 square miles, which has not been field-tested for productive aquifer zones. We have no more information today on the untested area than before the drilling began.

BGW does not expect that well production from PWL at 3000 feet in depth can be practically related to the well performance seen to date in these wells at a few hundred feet of drawdown. We are familiar with deep wells where fractures close-up, precipitation seals up, and turbulent flow losses are exponential, causing drastic and costly declines in yield at large drawdown.

We advise that production for well #6 can be safely planned at a PWL of 500 feet below static, and should be tested at greater levels up to 1000 feet to see how performance holds or deteriorates. We see no practical prospect of a 3000 PWL for these wells with worthwhile economic yield. Thus, the Intera Table 4 value for "Total Aquifer Capacity" and "Years of Water Supply" should be read with these practical limitations of resource area and depth in mind. The full 31-day field test has provided no data to characterize the full area and drawdown in report Table 4.

The Aqua Zarca sandstone should not be counted as a proportional increase in aquifer volume. Additional screen in the Aqua Zarca might increase the yield of individual wells, but the stored resource derived from dropping head in the San Andres for 100 years likely would include the Aqua Zarca stored resource by leakage. This question is related to whether geologic volume is the control on water yield, or whether pressure change is the control. Percolation of the pressure response from the San

Andres zones throughout interrelated geologic space is likely to reach all the available resource zones.

Intera recommends the 31-day test data and future well test data be incorporated in a regional groundwater flow model. BGW endorses that recommendation as the best way to quantify the inter-relationships among area, layers and geologic structure, and to address issues already identified in the Shomaker letter report, discussed below.

Shomaker Report

The Shomaker letter reviewing the Intera report is generally on point and lends a worthwhile perspective to the hydrogeologic picture from the 31-day test and prospects for development. The County might wish to ask for reciprocity from the ISC to receive and comment on Shomaker's study of the Rio Puerco Valley.

Shomaker begins by making an essential distinction between the "total volume in storage" and the "amount that can be practically pumped". These are different questions with greatly different water rates and amounts associated. You may want to be explicit in querying which aspect of the potentially producible amount you are interested in.

In hydrology, water production is commonly taken to mean water made available for use, rather than water that may be stored or in transit or bound up in the hydrologic cycle, but unattainable for practical use. A fraction of water stored in aquifers is not drainable by conventional well operations due to steep gradients required, or slow connection through aquitards, fault compartments, etc. Performance tests with observation wells in a full spatial array are the only practical means to identify the producible rate and amount. Eventually, tests with more than one observation well are required.

Shomaker points out that the transmissivity and storativity from analysis A are higher than associated with the well performance and are "not plausible". We read between the lines of the Intera report to see that the high values are reported for local pipe-like fractures, whereas the analysis A treated other aspects of the flow system as in Figure 15, but did not tabulate those other aspects of transmissivity and storativity in Report Table 3.

Shomaker considers analysis B plausible, as does BGW.

Shomaker notes that storage coefficient may be as much as 1×10^{-3} if 1000 feet of sediment is screened and productive. Drilling data on mud loss and geophysics reflecting permeability in well #'s 5 and 6 suggested that as little as four feet of the sedimentary section may be highly productive. We agree that longer screen intervals should be constructed and tested, but there is no assurance that effective storage will be increased thereby.

Shomaker correctly cautions that other wells may not reach the relatively high fracture yields of well #6. In fact, observation well #5 is an example of a lower-yielding well due to absence of such fractures. Shomaker also emphasizes that well interference will reduce the projected yield of individual wells in a wellfield.

Shomaker says the Table 4 values "seem doubtful" from the proposed County wells due to inaccessible mounds of water distant from the wells. BGW considers the Table 4 values to be impractical for the same reason even if wells are expanded into the 2000 square mile area.

Shomaker also notes that the San Andres flow is part of a dynamic recharge/discharge system that may affect the availability of water wherever that discharge is now occurring. That effect can be estimated in a 3-D MODFLOW simulation including initial conditions of recharge and discharge. However, we anticipate that aquifers containing water recharged 29,000 years ago probably will not show major impacts on availability of water at their discharge points within a planning horizon of 100 years due to the distance to discharge points.

<u>Age of Water</u>

Intera reports the new information that well #6 water may be 29,000 years old since recharge. Groundwater age also reflects permeability (K) of the flow system. Recharge likely occurred at Mt. Taylor or farther west on the continental divide. Assuming a 40-mile distance to recharge (a midrange distance of Mt. Taylor and the Continental Divide) and a corresponding velocity of 0.02 ft/d to reach well #6, then K = 0.02 times porosity divided by gradient, or $0.02 \times 0.1/0.001 = 2$ ft/d in porous media, or 20 ft/d in open solution channels where porosity may approach 1.0. A transmissivity of 350 ft^2/d would be associated with a 175-foot thick porous formation or a 17.5 foot thick cavernous zone. These age-related parameters appear to be reasonably compatible with the 31-day response.

Our core conclusions are listed below:

BGW Conclusions from Data and from Review of Two Reports

1. The 31-day aquifer test of October 2008 can be analyzed to derive aquifer performance characteristics that represent expected yield from well #6. The test added essential new information on the local aquifer performance, although the utility of observation well #5 data is degraded by unsteady starting conditions.

2. Well #6 operating alone can be planned firmly to produce 1000 gallons per minute (1600 acre feet per year) for several years and probably for decades.

3. The Intera Draft Report presents a superior technical analysis of a complex multi-zone aquifer. Their analysis A appears to represent a close-in fracture system, whereas analysis B represents the distant flow field, which is more pertinent to wellfield projections. The test area of investigation covers a few tens of square miles.

4. The available hydraulic test and response data cannot be extended to make any certain statements about future wellfield production from an area as big as 2000 square miles, or from pumping water levels as deep as 3000 feet.

5. The Shomaker letter report makes several valid points to the effect that the geologic extent of the aquifers is not of high importance, but that the amount that can be pumped from the proposed wells becomes the important question, and that wellfield interference must be considered.

6. Balleau Groundwater, Inc. has calculated the impact of wellfield interference on yields from 28 wells performing as seen at the 31-day test. Depending on fault-block extent and practical pumping water level, the wellfield may be planned to produce 2,000 to 2,700 acre feet per year for 10 to 100 years. The 28 wells interfere severely and should be spaced at much greater distances or fewer well-sites than now planned.

7. Sufficient regional and local information is available to specify initial and projected conditions in a MODFLOW model to address scenarios of interest to the County, the neighbors, administrative agencies and New Mexico Interstate Stream Commission regarding "future availability of water wherever that discharge is now occurring" as described by Shomaker. Such a model program is recommended to be undertaken and periodically updated in cooperation

among Sandoval County and New Mexico Interstate Stream Commission experts to address collective issues.

Thank you for allowing BGW to comment on this technically innovative program, and to see the advanced scientific contributions of our colleagues at the Intera and Shomaker firms. The most important finding of the 31-day test is that well #6 can reliably produce 1000 gpm for an extended period, but that wells as close as one-mile spacing will severely interfere with one another. Please call if more discussion is needed.

Very truly yours,

BALLEAU GROUNDWATER, INC.

AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
CERTIFICATE NUMBER 2716
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WILLIAM PETER BALLEAU
CERTIFIED PROFESSIONAL GEOLOGIST

W. Peter Balleau
President

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Attachment: Technical Memorandum

MEMORANDUM

To File KING/SANDOVAL COUNTY January 13, 2009

From Casey W. Cook, P.E., and Steven E. Silver, GISP

Subject DEEP WELL 31-DAY TEST ANALYSIS AND WELLFIELD CALCULATION

Introduction

On December 23, 2008, Mr. George King, consultant to Sandoval County, requested that Balleau Groundwater, Inc. (BGW) review and provide independent analysis of a 31-day flow test at Sandoval County's deep-saline well Expl-6. Intera, Inc. tested the well in October 2008 and reported the test and analyses in Intera (2008). Test data were provided to BGW by Mr. Guy Bralley of Sandoval County on December 19, 2008 and by Mr. Rob Sengebush of Intera on December 23 and 24, 2008 and on January 7 and 9, 2009. This technical memorandum provides an opinion of data quality, our analysis of test data, and projections of single well and wellfield yield. Wellfield yield is calculated with a superposition groundwater model described later in this memorandum.

Test Data

Hydrographs of well pressure at depth for test well Expl-6 and observation well Expl-5 are shown in Figure 1. The plot shows absolute pressure converted to feet H_2O assuming a standard water density of 2.31 feet/psi. Pressure in both wells is measured by Geokon vibrating wire piezometers set 3200 (Expl-6) to 3370 (Expl-5) feet below ground. Intera data include a record of barometric pressure ranging 2.45 to 7.0, in undefined units. An inspection of the data suggests the barometric gage data are not usable. We understand that test well Expl-6 was flowed for three days in August to test instrumentation and provide water to weight a storage pit plastic liner. Subsequently, the well was flowed several times in August and September for various undocumented purposes. Background water levels at Well #6 appear reasonably stable prior to the start of the 31-day test.

The well Expl-5 piezometer was set on September 27. Following that date, the well exhibits an unexplained pressure decline of about 30 feet H_2O prior to test start. Observations of well-casing pressure and tubing pressure in Expl-5 are shown in Figure 2. We understand the tubing was filled with brine on August 26, 2008 to hold back formation pressure for installing instrumentation. However, the tubing became partially repressurized before instruments were set on September 27. From the test start on October 1 to mid-November, tubing pressure increases by 125 feet H_20. Brine circulating from the tubing into the well bore may explain the pre-pumping pressure decline observed at the deep piezometer and the tubing pressure increase. A significant pressure drop in the well casing also is observed on about November 27 after test shut-down. The pressure drop resembles a response to well flow, but discussion with Intera indicates that no water was observed flowing or leaking at the wellhead. We note that a casing leak of one or two gallons per minute (gpm) could explain the anomalies at observation Expl-5, as could brine convection, gas evolution, internal circulation as frac zones clog or unclog, etc. The unstable background pressure conditions at Well Expl-5 mean that the response to flowing Well Expl-6 cannot be isolated and analyzed with confidence in the details.

The data at well Expl-5 as collected include the response to flow at Expl-6 and to other uncontrolled pressure fluctuation as described above. Our attempts to correct the data by imposing flat, linear and logarithmic background trends failed to produce a useable data set. We conclude that no useful analysis of the magnitude of Expl-5 response to flow at Expl-6 can be isolated from the background noise in the observation well data. Explicit storage coefficient, transmissivity (T), and boundary trends are uncertain due to the uncontrolled conditions at observation well Expl-5. However, we find from the timing of response, regardless of magnitude, that the storage coefficient (S) is approximately 1×10^{-4}.

Well Expl-6 was tested at two rates, about 155 and 260 gpm. The rate changed 17 days into the test. Well response to the rate change indicates well efficiency of about 80 percent.

Figure 3 shows well Expl-6 drawdown (prior to the rate change) with a generalized radial flow (GRF) (Walker and Roberts, 2003) curve match to early data (t <2000 min) and Theis (1935) curve match to late data (t > 3000 min). The GRF concept utilizes a flow dimension to describe direction of flow in fractured rock, bounded aquifers, and other flow systems. The ideal Theis (1935) case deals with only two-dimensional radial flow. Ideally, flow dimension (n) of one represents parallel flow in a one-dimensional prism (e.g., fracture), n= 2 is two-dimensional (Theis) radial flow and n = 3 is spherical three-dimensional flow. Higher dimension can represent recharge from sources external to the flow system. The type curves indicate that well yield for the first day comes from a high-T (10,000 feet^2/day (ft^2/d)) linear fracture (flow dimension n = 1.1), which transitions after a couple of days to radial flow with T = 350 ft^2/d. We interpret a flattening trend after t = 15,000 minutes to be related to diminishing flow rate. A leakage response is not apparent in the test well data. A lumped parameter with effective well radius (r) of 75 feet and S = 0.0001 reflects a high-permeability fracture or cavern across which the well is screened.

Well Expl-6 recovery data are shown in Figure 4. No positive or negative boundary impacts the recovery trend to 71 days. The trend can be reliably projected back to the origin at t/t' = 1.0, representing the long-term future performance. A Theis recovery line with T= 350 ft^2/d matches the trend.

Specific-drawdown (s/Q, or drawdown at unit stress) at well Expl-6 is projected to ten years in Figure 5. The projection extends the last log cycle of test data forward as a log-time linear trend. The recovery trend in Figure 4 supports the extension. Boundaries at later times are not recognized, but if present would change the trend slope up (leakage) or down (barrier) and consequently change the projected s/Q. We expect, however, that any change would be minor.

The s/Q projection is useful for estimating single-well yield. We understand Sandoval County wishes to project yield with drawdown limits of 750 feet to 1200 feet. A reasonable future projection from the test data is two log cycles past the 4.5 cycles of test data, or about eight years. Specific drawdown at eight years is 0.75 ft/gpm. Projected yield is therefore 750 feet divided by 0.75 ft/gpm = 1000 gpm, or about 1600 acre feet per year (AFY) from well Expl-6 operating as a single point of withdrawal. For 1200 feet of drawdown, the yield would be 1600 gpm or 2600 AFY. The projection does not account for non-linear losses (inefficiencies) and screen degradation, which likely will limit yield below 1000 gpm. Expl-6 pump chamber casing size (10-inch) may limit standard pump size and yield, but a specialized high capacity, small diameter pump may be suitable for the projected yield. Interference from other planned wells also would reduce the single-well performance of Expl-6. A groundwater model, described below, is utilized to assess the effects of boundaries and of well interference on aquifer yield consistent with observed well performance. Diminishing return from an overly dense wellfield pattern is apparent where 28 wells produce only 1.4 times as much as the single well Expl-6.

Well-Field Yield

A groundwater model is utilized to assess the effects of boundaries and of well interference on aquifer yield of the 28 Sandoval County Notice of Intent (NOI) wells for 100 years. The model was developed with MODFLOW-2000 (Harbaugh and others, 2000) and uses the multi-node well package (Halford and Hanson, 2002) to calculate the effects of well interference and well inefficiencies on yield. For purposes of this calculation, the 26 undrilled NOI wells, and Expl-5 and Expl-6 are assumed to be completed in the San Andres-Glorieta (SAG) aquifer.

The model extends into the San Juan Basin in the west and is truncated at Santa Fe Group Aquifers in the east (McAda and Barroll, 2002). The 12,237 square-mile active model domain is shown on Figure 6. The model is inactive where SAG is absent in the Zuni Mountains, and on the Lucero and Nacimiento uplifts (Baldwin and Anderholm, 1992).

The SAG T zones used for the model are shown on Figure 7. Outside the area tested by Expl-6, these were adapted from the U.S. Geological Survey (USGS) model of the Acoma Embayment and Zuni Uplift (Frenzel, 1992). The T and S for the Rio Puerco fault zone (T=300 ft^2/d and S=0.00015) are adapted from the analysis B done by Intera. Cavernous or fracture permeability is not represented. Mapped faults in the Rio Puerco area are represented by zones of lower T (Figure 7).

Underlying aquifers in Permian and Pennsylvanian rock units and overlying aquifers in Triassic, Jurassic and Cretaceous rock units can potentially be a source of water to the SAG by leakage. These units are represented in the model with a total T of 67 ft^2/d and a vertical hydraulic permeability of $1x10^{-5}$ ft/d.

The model boundary conditions are set to display the difference in flow or head at boundaries, rather than to simulate the absolute magnitude. Instead they simulate a superimposed surface that accounts for the three-dimensional (3-D) hydrologic response to groundwater pumping as it propagates from deep wells in the SAG. This is the approach of the USGS authors (Leake and others, 2008) for the Colorado River studies and is analogous to Theis, but with better spatial details. The model represents surface discharge areas (springs and perennial streams) on the SAG outcrop using the MODFLOW river package. General head boundaries (GHB) on the eastern model boundary represent discharge into the Albuquerque Basin.

Because the boundary conditions are not elevation-based, the model solution does not estimate groundwater recharge and observed discharge flow components. We consider model calculations of capture from boundaries to be illustrative until a 3-D calibrated model of the area, or a more-detailed inventory of the discharging features is available.

Two model scenarios were run to analyze the potential yield of the 28 wells with PWL of 750 feet and with a PWL of 1200 feet. A well efficiency of 80 percent for the 750-foot PWL case is derived from the 31-day test data. Well inefficiencies are projected to be somewhat less (illustrative 60 percent) with a PWL of 1200 feet.

Figure 8 shows the yield of each of the 28 wells over the 100-year period with PWL set at 750 feet. The wellfield yield is about 2500 gpm (4000 AFY) for the first year, then tapers off to 1420 gpm at ten years and 1275 gpm (2,000 AFY) at 100 years. Figure 9 shows the yield of each of the 28 wells over the 100-year period with PWL set deeper at 1200 feet. At 1200 feet PWL, the well field yield is up to about 2500 gpm (4000 AFY) for the first year, then tapers off to 1688 gpm at ten years and 1545 gpm (2,500 AFY) at 100 years.

Projected yield at ten years is tabulated on Table 1 to show the variation among locations. Wells with the greatest yield tend to be on the periphery of the wellfield. Wellfield interference serves to cut the productivity of interior wells. It is recommended that future model scenarios address wellfield layouts with spacing considerably beyond one mile. Five or six wells may be able to produce almost the entire projected yield of 28 wells. The average well spacing as discretized currently into the model's half-mile grid cells is about two miles, which is too dense.

Drawdown at 100 years for the 750 foot PWL case is shown on Figure 10. Drawdown of 500 feet or more is projected to cover 27 square miles area around the wellfield. The ten-foot drawdown contour extends east to the Mt. Taylor region and covers an area of 3000 square miles. The bulk of wellfield production is from aquifer storage.

Conclusions

1. Sandoval County conducted a 31-day flow test of deep saline well Expl-6 with observations of pressure change at the test well and at well Expl-5 about 0.65 miles distant. Recovery observations are reported for 41 days following shutdown.

2. Test data at well Expl-5 are affected by uncontrolled pressure fluctuations not related to flow at well Expl-6 and are not suitable for detailed analysis. Aquifer storage and leakage parameters thus cannot be calculated reliably from existing data. Regional storage coefficient from the timing of Expl-5 response is approximately 1×10^{-4}.

3. Test data for well Expl-6 are serviceable for characterizing local and regional aquifer transmissivity. The late time recovery trend supports the projection for long-term yield. Response at the test well indicates linear flow for the first day with flow dimension of 1.1 in a highly-transmissive fracture, followed by radial flow at transmissivity = 350 ft^2/d. Leakage is not apparent in test data.

4. Late-time recovery at Expl-6 indicates regional aquifer transmissivity is 350 ft^2/d.

5. Projected yield at well Expl-6 for several years is 1000 gallons per minute or 1600 acre feet per year. Non-linear losses at that high flow rate may reduce the practical yield.

6. Wellfield interference serves to drastically cut the productivity of individual wells. Well spacing should be extended far beyond one mile.

7. The yield of the 28 Sandoval County Notice of Intent wells at 100-years may be as much as 2500 acre feet per year depending on pumping water level. Simulated individual well performance ranges from 25 gallons per minute to 160 gallons per minute because of mutual interference.

8. The source of water for wells is predominately groundwater storage with some fraction from capture. The area of ten-foot drawdown may extend to 3000 square miles at 100 years.

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Attachments: Table
Figures (10)

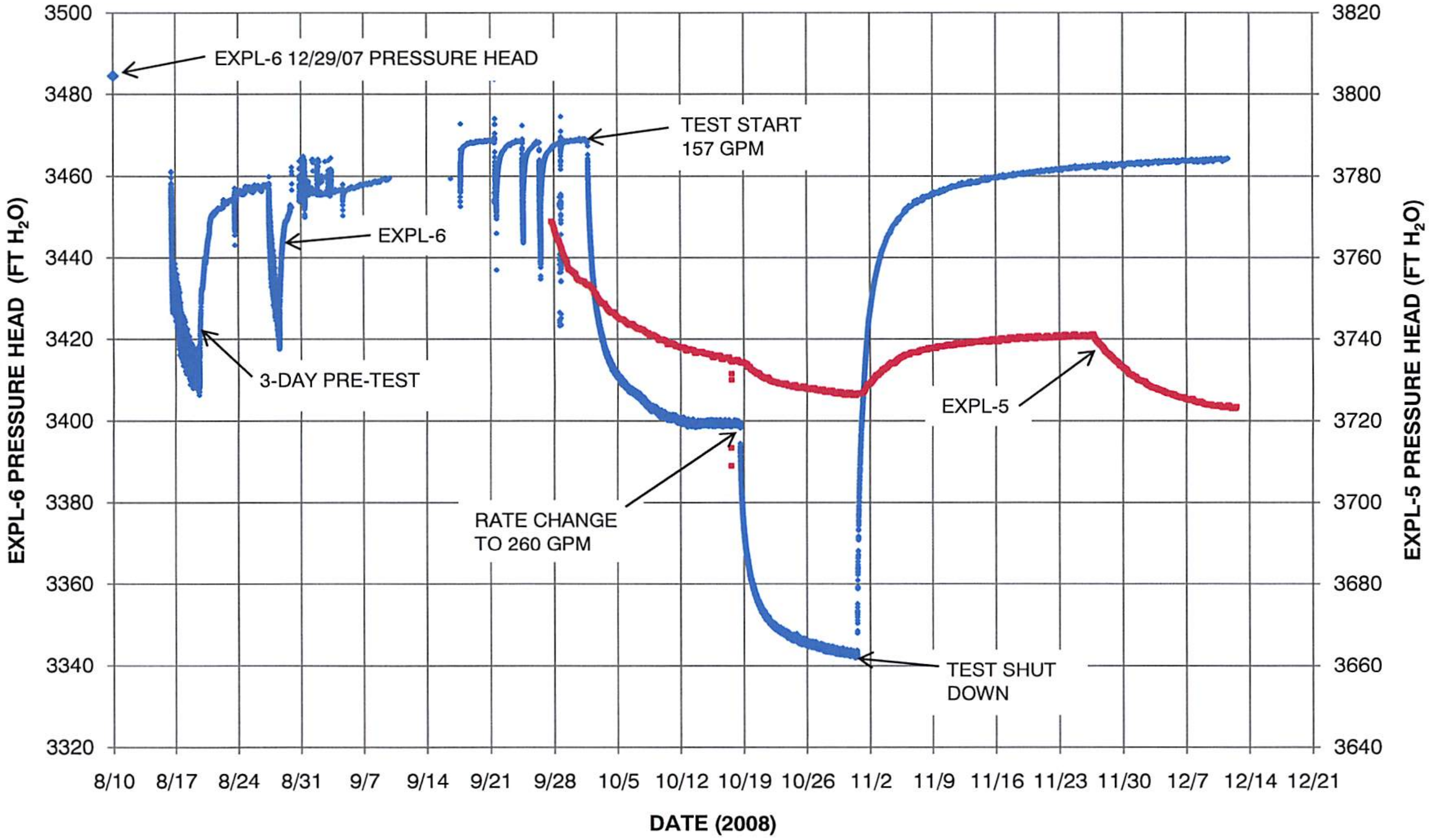
SANDOVAL COUNTY

TABLE 1. PROJECTED YIELD OF WELLS AT 10-YEARS

Well Site	Well Yield (GPM)	
	750 ft PWL	1200 ft PWL
Well No. 3-15	71	84
Well No. 3-17	69	82
EXP-1	65	77
Well No. 3-16	35	42
EXP-2	35	42
Well No. 3-18	37	44
EXP-3	49	58
Well No. 10-20	33	40
Well No. 11-21	28	33
EXP-6 (built)	28	33
Well No. 12-23	51	60
EXP-7	51	60
Well No. 12-24	80	96
EXP-4	52	62
Well No. 10-19	21	25
EXP-5 (built)	21	25
Well No. 11-22	43	51
Well No. 15-25	32	38
Well No. 15-26	25	30
EXP-10	36	43
EXP-8	58	69
Well No. 15-28	38	45
Well No. 15-27	33	39
EXP-9	33	39
EXP-11	80	95
EXP-12	71	83
EXP-13	111	132
EXP-14	136	161
SUM (GPM)	1421	1688
SUM (AFY)	2300	2700

Conclusion: Interior well locations yield a small fraction of peripheral well sites. The planned well locations are too dense.

FIGURE 1
WELL EXPL-6 31-DAY TEST HYDROGRAPH



Expl6_31-day.xlsb
FIG1
CC
1/13/2009

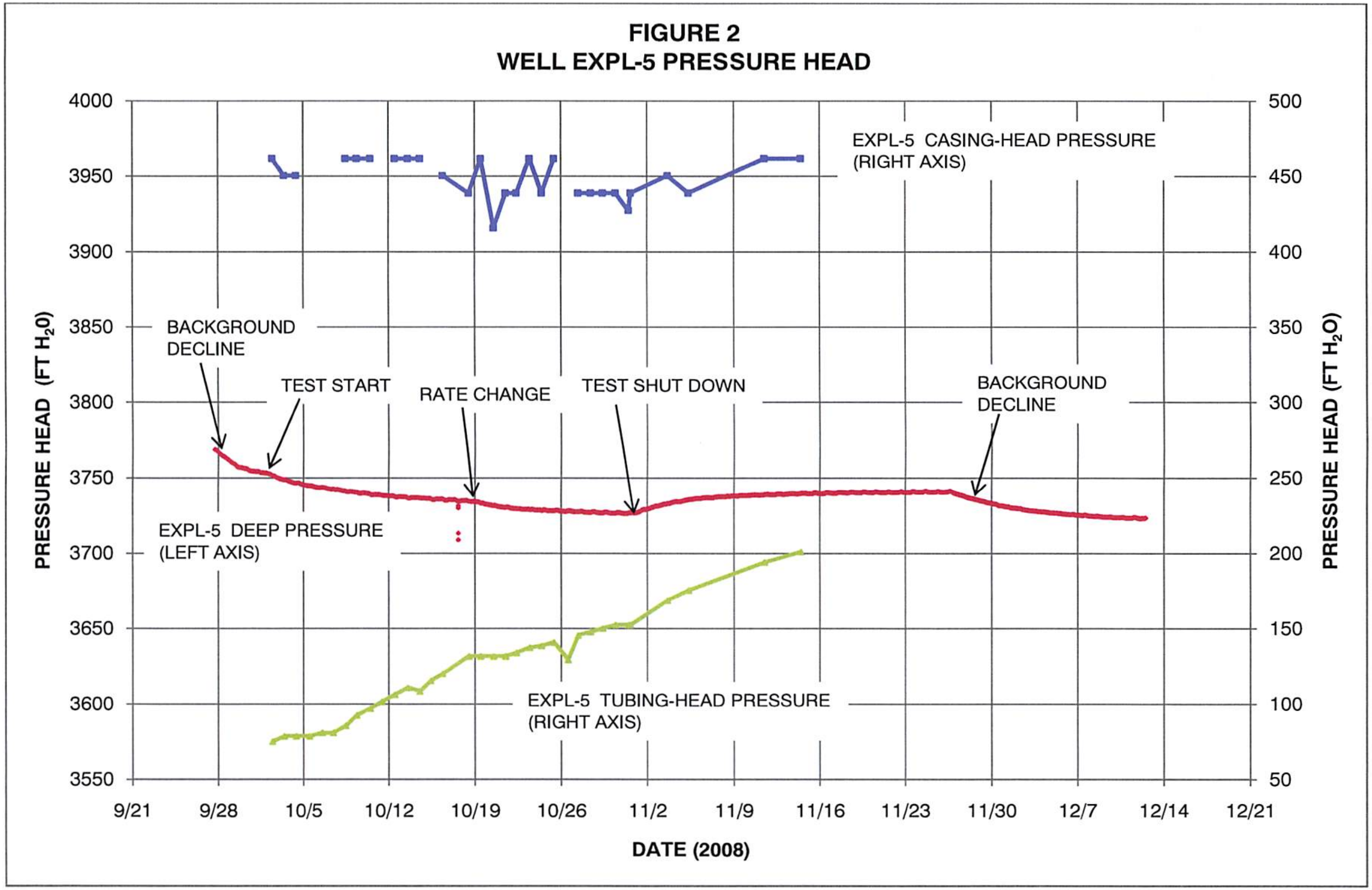
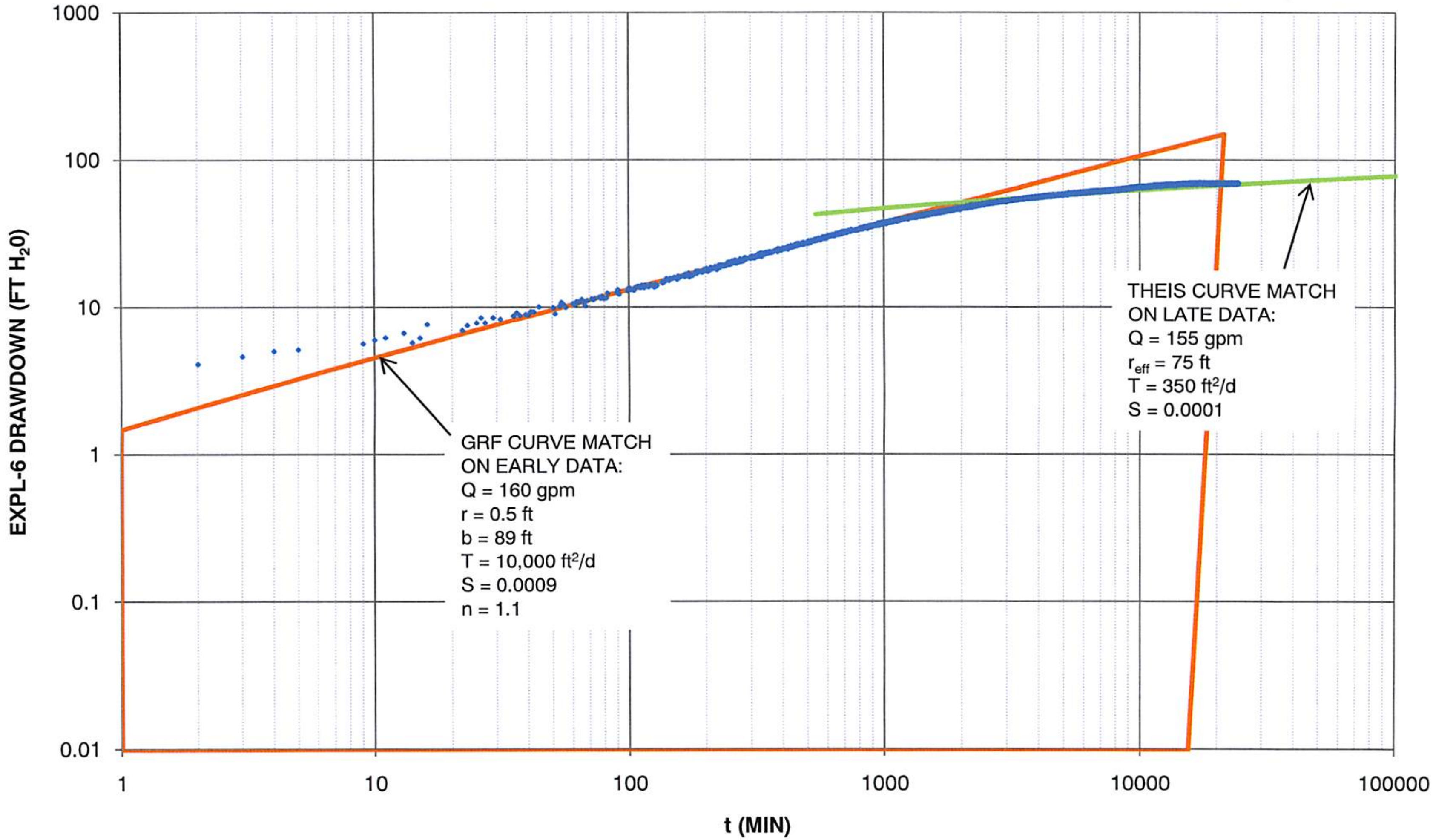


FIGURE 2
WELL EXPL-5 PRESSURE HEAD
4000
3950
3900
3850
3800
3750
3700
3650
3600
3550
500
450
400
350
300
250
200
150
100
50
PRESSURE HEAD (FT H2O)
PRESSURE HEAD (FT H2O)
EXPL-5 CASING-HEAD PRESSURE
(RIGHT AXIS)
BACKGROUND
DECLINE
TEST START
RATE CHANGE
TEST SHUT DOWN
BACKGROUND
DECLINE
EXPL-5 DEEP PRESSURE
(LEFT AXIS)
EXPL-5 TUBING-HEAD PRESSURE
(RIGHT AXIS)
9/21
9/28
10/5
10/12
10/19
10/26
11/2
11/9
11/16
11/23
11/30
12/7
12/14
12/21
DATE (2008)

FIGURE 3
WELL EXPL-6 DRAWDOWN WITH THEIS AND GRF CURVE MATCHES



Expl6_31-day.xlsb
FIG3
CC
1/2/2009