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Bedrock Hydrogeologic Investigation

KENNECOTT MINERALS COMPANY
EAGLE PROJECT
ENVIRONMENTAL BASELINE STUDY
BEDROCK HYDROGEOLOGIC INVESTIGATION



Prepared for:
Kennecott Minerals Company and
Golder Associates Inc.



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**EAGLE PROJECT
BEDROCK HYDROGEOLOGIC INVESTIGATION**

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1.0 INTRODUCTION

1.1 Objectives

Kennecott Minerals Company (KMC) requested that Golder Associates Inc. (Golder) conduct a bedrock hydrogeologic investigation in September 2004 in the area of the Eagle Project (Project) in Michigan's Upper Peninsula. The project objectives were as follows:

- Characterize the hydraulic properties of the bedrock in the vicinity of six boreholes.
- Evaluate the degree of vertical hydraulic communication between the Quaternary aquifer and underlying bedrock groundwater system in the area of the six boreholes.
- Estimate mine inflows for an idealized tunnel.

Figures 1-1 and 1-2 show the boreholes that were used to evaluate the hydraulic properties of the bedrock. The boreholes were cored with the NQ2 system and extend to maximum true vertical depth of 323.10 m (1060.1 feet). Table 1.1 provides a summary of pertinent borehole information.

TABLE 1.1
BEDROCK BOREHOLES USED FOR THE BEDROCK
HYDROGEOLOGICAL INVESTIGATION

Borehole	Azimuth [°]	Inclination [°]	Casing Depth	Total Measured Depth	True Vertical Depth
04EA-47	180	-78	12.8 m (42 ft)	268.21 m (880.0 ft)	262.36 m (860.8 ft)
04EA-54	n/a	-90	12.8 m (42 ft)	323.10 m (1060.1 ft)	323.10 m (1060.1 ft)
04EA-73	180	-75	14.9 m (49 ft)	265.01 m (869.5 ft)	255.96 m (839.8 ft)
04EA-77	180	-70	21.3 m (70 ft)	255.99 m (839.9 ft)	240.57 m (789.3 ft)
04EA-83	180	-83	13.7 m (45 ft)	239.87 m (787.0 ft)	238.07 m (781.1 ft)
04EA-84	100	-60	13.7 m (45 ft)	302.07 m (991.1 ft)	261.60 m (858.3 ft)

In addition, Quaternary monitoring well QAL023 was used for monitoring water level changes during the hydraulic testing in the bedrock and is located 3.51 m (11.5 ft) from the collar of borehole 04EA-83.

The report is collaboration between North Jackson Company (North Jackson) and Golder. KMC provided geologic data and cross sections.

All depths are reported as measured depth along the borehole from ground surface unless otherwise noted.

1.2 Approach and Report Format

The approach to characterize the bedrock hydrogeology, described in a chronological order, is provided below.

- Selected six boreholes for measurements that penetrate the zones of interest, encounter representative lithologies and cover a range of orientations and inclinations to allow for consideration of anisotropy in the flow system. The bedrock geology is discussed in Chapter 2 (KMC and North Jackson).
- Performed geophysical logging and flow logging to identify localized zones of relatively moderate to high hydraulic conductivity and referred to as water conductive fractures (Chapter 3; Golder).
- Conducted hydraulic testing with packer equipment to quantify hydraulic parameters (Chapter 4; Golder).
- Performed monitoring (Chapter 5; Golder) and collected a water quality sample (Chapter 6; North Jackson and Golder) for an assessment of the vertical communication between the Quaternary aquifer and the bedrock groundwater system.
- Developed a conceptual model based on synthesis of all the data (Chapter 7; Golder).
- Predicted inflow into idealized portion of the mine (Chapter 8; Golder).

The conclusions and recommendations are presented in Chapter 9.

- **Appendix A** - Presents the procedures for hydraulic testing and water sampling.
- **Appendix B** - Includes plots for individual test data and analyses of this data.

- **Appendix C** - Contains the calibration records of the pressure gauges used for hydraulic testing, monitoring in Quaternary monitoring well QAL023 and for barometric pressure changes.
- **Appendix D** - Presents the field report for the well construction and geology for Quaternary monitoring well QAL023.
- **Appendix E** - Contains the laboratory results for the water quality sample collected at 257.54 to 260.29 m (845.0 to 854.0 ft) in borehole 04EA-84.

2.0 GEOLOGY

2.1 Quaternary Geology of the Project Area

Regional geologic maps for the Project Area show that the site is covered with a surficial deposit of unconsolidated, Quaternary glacial outwash and post-glacial Quaternary deposits. Details for the Quaternary Geology of the Project Area can be found in the Interim Hydrology Report Volumes I and II (North Jackson Company, 2004).

2.2 General Bedrock Geology – Yellow Dog Plains, Marquette County, Michigan

The Yellow Dog Plains in northern Marquette County is composed of Precambrian rocks covered by glacial Quaternary and post-glacial Quaternary sediments. The bedrock beneath the plains is mostly metasedimentary rocks of the Michigamme Formation, part of the Marquette Range Supergroup of Proterozoic age rocks (roughly 2 billion years old). These metasedimentary rocks are contained in an east-west trending structural trough known informally as the Baraga Basin (Klasner, et al., 1979). This trough is flanked on the north, south, and east by gneiss and greenstone Archean basement rocks, older than 2.5 billion years. Because of the extensive Quaternary deposit cover on the plains, very little exposure of the Michigamme Formation exists in this area. The Archean basement rocks have numerous outcrop exposures surrounding the Baraga Basin.

The Michigamme Formation beneath the Yellow Dog Plains consists of fine-grained clastic rocks, largely black slate and argillite as shown by core drilling (Klasner, et al., 1979). These rocks were deformed and metamorphosed to the greenschist facies about 1.9 billion years ago, during the Penokean orogenic event.

Emplaced into the Michigamme Formation are east to west-trending diabase dikes of early Keweenaw age, intruded about 1.1 billion years ago. The Yellow Dog Peridotite is present in the central Yellow Dog Plains, and is known from two outcrops located in T50N, R29W, Section 11 and 12, along one of these dike trends. The Eagle nickel mineralization prospect is located within the Peridotite near the outcrop located in Section 11. The Peridotite is generally undeformed and only moderately serpentized (Klasner, et al., 1979). The higher grade mineralization either post dates or is syn-deformation. The deformation event is best characterized as a WNW-ESE trending dextral shear couple with evidence of dilation. The event may have been responsible for the location of, and

controls the shape of, the intrusive units including the massive and semi-massive sulfide mineralization. Major structures could exist on the edges or contacts of the earlier intrusions, including gabbros, pyroxenites, and peridotites containing disseminated sulfides.

Figures 2-1 (East-West) and 2-2 (North-South) show cross sections that include the boreholes used in this investigation for geophysical logging, flow logging and hydraulic testing.

3.0 BOREHOLE GEOPHYSICAL AND FLOW LOGGING

Geophysical and flow logging was carried out in six exploration boreholes. The borehole designations were 04EA-47, 04EA-54, 04EA-73, 04EA-77, 04EA-83, and 04EA-84 (see Figures 1.1 and 1.2). All of these except for 04EA-54 were angled varying from -60 to -83° from horizontal. Borehole 04EA-54 was drilled at -90 or vertical (see Table 1.1).

The borehole geophysical logging was completed to identify localized zones of moderate to high hydraulic conductivity, attributed to water conductive fractures that intersect the borehole. The results of the logging, in addition to providing direct data for depth of water conductive fractures, were used to guide selection of test intervals for hydraulic tests (discussed in Chapter 4) and sampling intervals (discussed in Chapter 6).

The geophysical logging consisted of the following:

- Caliper to measure overall borehole diameter and locate coarse fracture zones;
- Fluid temperature and resistivity logs (FT/R) to help identify flow anomalies where fluid may be entering or exiting the borehole; and
- Heat Pulse Flow Meter (HPFM) logs under pumped and non-pumped conditions to measure the vertical flow volume in the well bore.

The logging was performed in 75.7-mm (2.98-inch) NQ2 diameter boreholes.

3.1 Methodology

All logs were collected using the MGX-II Logging system and tools manufactured by Mount Sopris Instruments Ltd.

3.1.1 Fluid Temperature and Fluid Resistivity (FT/R)

Geothermal gradients in the near surface are usually dominated by conduction and are generally linear due to the relative constancy of the thermal conductivity of the earth materials. Deviations from the linear thermal gradient are attributed to convective heat flow. Most commonly, this convective heat flow is within the borehole fluid and is caused by formation fluid entering or leaving

the borehole at some permeable interval. Abrupt changes in the temperature log (degrees Celsius, °C) are evidence of fluid transfer between the formation and the borehole and subtle changes in the thermal gradient may be attributed to fluid flow within the borehole.

Fluid resistivity (Ohm-metres) in the borehole is controlled primarily by salinity and salinity changes down the borehole can be attributed to fluid flow. Often fluid exchange between the formation and the borehole affects both the temperature and the fluid resistivity such that the response is evident in both logs.

The probe contains a seven-electrode, mirrored Wenner-type array for measuring borehole fluid resistivity and a temperature sensor based on a fast response semiconductor whose output voltage changes linearly with temperature. The two sensors are deployed in an opening at the bottom of the probe so that borehole fluid passes the sensors as the probe is lowered down the borehole. The thermal gradient profile as it affects the borehole fluid can be measured with this tool. The temperature is measured with a highly accurate thermistor calibrated by immersing the probe in water baths of known temperature.

3.1.2 Heat Pulse Flow Meter (HPFM)

The heat-pulse flow meter tool (HPFM tool) measures flow upwards or downwards in the borehole and consist of a heater grid and two thermistors located a fixed distance above and below the heating grid. Vertical flow in the borehole is diverted through the heating grid by a ring of soft rubber petals and the probe is centralized with two plastic, three-arm rings attached to the top and bottom of the probe.

A reading of upward/downward flow rate is taken as follows. A switch connected to the logging system is closed, which triggers a heat-pulse cycle to start. As the grid heats up, a lens of warm water forms at the heating grid. If fluid movement is occurring in the borehole, then the lens of heated water will move either upwards or downwards. The temperature difference between the two thermistors is monitored as a function of time elapsed since the heating grid was triggered. A differential temperature deflection to the left (negative) indicates downward flow, and a differential temperature deflection to the right (positive) indicates upward flow. The rate of flow is calculated as a function of the elapsed time between the start of the grid heating cycle and the time of the peak differential temperature response. The probe used for this work was calibrated to record in units of

US gallons per minute (gpm). Because diverter petals are employed and the distance between the heating grid and the thermistors are relatively small (approximately 30.5 mm (1.2 inch)), the flow rate measured is, according to the manufacturer, independent of the diameter of the borehole. At each test depth, 3 or more readings were taken and recorded for later analysis.

As natural groundwater gradients were expected to be low, upward flow was induced by means of a small submersible Grundfos pump. Pumping rates were variable and depended on the borehole conditions.

Heat pulse flow meter data is used to infer where fluid could be entering or exiting the borehole and is often displayed with fluid resistivity/temperature and caliper data to determine permeable horizons in the subsurface.

3.1.3 Caliper

The caliper log is used to measure borehole diameter by means of a probe with three spring-loaded arms that interact with pot resistors in the probe. The voltage output is calibrated against rings of known diameter.

The log is useful for locating the base of casings, or fractures that cross-cut the borehole. Rough areas in the borehole walls could represent bedding planes, solution openings, fractures, and roughness caused by drilling.

3.2 Field Work

The borehole geophysical logging was carried out from 29 September to 6 October 2004. Table 1.1 provides a list of the boreholes logged as well as ancillary information such as dip, azimuth, casing depth, provided by KMC.

In each borehole, Fluid Temperature and Fluid Resistivity (FT/R) logs were run first to acquire data in the boreholes with minimal disturbance to the borehole fluid. Caliper logs were run next and then the HPFM tool testing was completed.

3.2.1 Depth Calibration and Logging Speed

For each tool run, the start depth, the logged depth and the final depths were recorded. The start depths were based on the sensor offset for each logging tool and referenced to the top of the casing. For two of the boreholes (04EA-73 and 04EA-54) the casing had to be lengthened to extend the casing above standing water at ground surface. The extension was incorporated into the tool offset to maintain a “top-of-casing” reference. Differences between the start and final depths were generally less than 0.49 m (1.6 ft) or an error of <0.2%. These differences are within specification and can be accounted for by cable stretch or where the tool hung in the borehole on the down runs. The maximum difference between the start and final depth was 0.94 m (3.1 ft), or an error of 0.4 %, for the caliper run in Borehole 04EA-83. For logs where the difference between the start and final depths was greater than 0.29 m (1.6 ft), log depths were adjusted so that the final depth was used as the reference depth.

The FT/R and caliper logs were acquired at a logging speed of 2.50 and 2.99 m per minute (8.2 and 9.8 ft per minute) respectively, with an error range of +/- 0.09 m per minute (0.3 ft per minute). HPFM tool measurements were taken at discrete depths.

3.2.2 Tool Calibrations

Tool calibrations were based on manufacture specifications or on-site calibrations. Both the FT/R and HPFM tools were calibrated based on manufacturer specifications. The appropriate values were entered into the tool description files and saved on the logging computer. These calibrations are checked every 1 to 2 years and do not change significantly over time. The caliper tool was calibrated on site by comparing tool response to rings of measured diameter. The calibrations were checked at the start and end of each logging run. However, it should be noted that the caliper tool was a three-arm tool and centralizers were used to maintain tool position in the boreholes. Even so, for the inclined boreholes, the tool will still tend to rest on the downside, and depending on the position of the arms, the readings may be affected. Also, during logging, the tool will rotate in the borehole and as the arms reseal with respect to the downside, offsets in the log will occur. These appear as 1.0 to 2.0 mm (0.04 to 0.08 inch) jumps in the recorded borehole diameter.

3.2.3 Static and Dynamic HPFM Testing

For the HPFM testing, static tests were completed on the down-run and dynamic tests were completed on the up-run. The term static and dynamic are used to identify non-pumping and pumping conditions.

The static tests were completed at 25 to 100 m (82 to 328 ft) intervals in the boreholes based on accumulated knowledge of how the boreholes could be expected to perform as the logging progressed. Repeat measurements were recorded at each interval shown on the Figures 3.1 through 3.6.

Dynamic tests were run with the HPFM tool down the borehole and a 50.8 mm (2 inch) submersible Grundfos pump placed in the top of the borehole. Pump depths were determined based on how the boreholes responded – typically 15 to 20 m (50 to 65 ft) below the top of casing. Pumping rates were also determined based on how the boreholes responded. For Boreholes 04EA-77 and 04EA-73, it was not possible to balance the pumping rate against the drawdown. For these holes, dynamic testing was completed by cycling the pump to maintain the water level in the borehole close to the pump inlet. For boreholes 04EA-47, 04EA-54 and 04EA-84, the pump rates were maintained at approximately 3.8, 1.9 and 3.8 L/min (1, 0.5 and 1 gpm), respectively.

3.3 Results

The results from the logging are summarized on Figures 3-1 through 3-6 for Boreholes 04EA-47, 04EA-54, 04EA-73, 04EA-77, 04EA-83 and 04EA-84 respectively. On each figure, a schematic of the borehole construction is presented together with depth (along the borehole, meters and feet), caliper, fluid temperature, fluid resistivity (and fluid conductivity) and HPFM tool results. Results from the packer tests (hydraulic conductivity, K) are also presented graphically with the interval and posted K (cm/s) for four of the boreholes. Picks for interpreted water conductive fractures or zones are indicated by arrow heads at the right side of the log columns. The water conductive fractures selected based on the HPFM tool under non-pumping conditions are considered less reliable and discussed in section 3.3.4.

3.3.1 Caliper

Caliper log data show overall borehole diameter variations from 71.1 to 78.7 mm (2.8 to 3.1 inch) with an average of approximately 76.2 mm (3.0 inch). The boreholes were drilled with an NQ2 bit with a borehole diameter of 75.7 mm (2.98 inch). The discrepancy between the logged borehole diameter and the actual diameter is noted in the section above and likely arises from running the three-arm caliper tool in the inclined boreholes. The step-wise changes in the caliper log response is attributed to the tool rotating in the borehole and this likely occurs where there is roughness on the borehole wall due to structure or drill bit scour.

Apart from the caliper anomalies associated with the bottoms of casings, few anomalies were detected and are summarized as follows:

- 04EA-47 – no clear anomalies apart from diameter steps
- 04EA-54 – * 48.77 m (160 ft)
- 04EA-73 –118.87, 121.91 and 143.25 m (390, 400 and 470 ft)
- 04EA-77 –73.15 m (240 ft), *182.87 to 195.06 m (600 to 640 ft)
- 04EA-83 – no clear anomalies apart from diameter steps
- 04EA-84 – 167.63 m (550 ft)

The anomalies with an asterisk are consistent with indication for water conductive fractures identified with the HPFM tool at similar depths (see Figures 3.2 and 3.4).

3.3.2 Fluid Temperature

Fluid temperatures in each of the boreholes were bounded between 8° and 16° Celsius (C). Daytime temperatures were above 12° C and the casing acted as a source of heat for each borehole. This is indicated by the drop in temperature from > 12° C to less than 10° C within the casing depth. Shallow groundwater temperature is slightly above 8° C (8.2° C to 8.6° C) as indicated on the FT logs for Boreholes 04EA-47, 04EA-54, 04EA-73 and 04EA-77. The recorded shallow groundwater temperatures for Boreholes 04EA-83 and 04EA-84 were approximately 9° C and 10° C respectively.

These are higher than for the other boreholes and this is thought to be because the boreholes were recently drilled and the drilling process had raised the temperature of the surrounding rock and equilibrium had not been re-established at the time of logging.

Below the casing, temperature in the boreholes increased more-or-less smoothly to approximately 12° C at depths greater than 249.92 m (820 ft). The smoothly varying nature of the temperature logs suggests that there is only minor fluid transfer between the formation and boreholes under static conditions. Minor temperature fluctuations were interpreted together with caliper anomalies and HPFM tool data to indicate potential flow zones.

3.3.3 Fluid Resistivity

The fluid resistivity logs are highly variable between the boreholes – overall fluid resistivity varied from <1 Ohm-meter to approximately 75 Ohm-meters. It is noted that all of the logged boreholes contained drilling mud. Also, the flushing history of the boreholes was unknown. On-site personnel indicated that only Boreholes 04EA-83 and 04EA-84 had been flushed with an excess of 3800 L (1000 gallons). In addition, on-site personnel indicated that salts were associated with some of the sulfide-rich zones intersected in the boreholes and that it was likely that salt was dissolving into the borehole fluid from the formation. These factors reduce interpretation of these logs to a qualitative estimate of borehole/formation fluid transfer zones in combination with results from the other logs.

3.3.4 Heat Pulse Flow Meter

Results from the heat pulse flow meter (HPFM tool) testing are presented under both static (natural) and dynamic (pumped) conditions. For all of the boreholes, no flow or very minor flow was recorded under static conditions. Generally, the anomalies identified by the HPFM tool under non-pumping conditions are considered less reliable as the vertical gradient over the length of the borehole is not expected to be significant and a vertical gradient is needed for the measurements.

In two of the boreholes (04EA-73 and 04EA-77), it was not possible to establish a constant flow rate and the borehole fluid levels could only be drawn down to the pump inlet. Logs for these two boreholes show flow in the borehole under dynamic condition and the scales at the top were adjusted to reflect the maximum flow rates recorded.

For boreholes 04EA-47, 04EA-54 and 04EA-84, the pumping rates were maintained at approximately 3.8, 1.9 and 3.8 L/min (1, 0.5 and 1 gpm), respectively. Logs for these three boreholes show flow in the boreholes under dynamic conditions and the scales at the top of the log plots for these boreholes show normalized flow – recorded flow divided by the pumping rate.

For one of the boreholes (04EA-83) it was not possible to complete the HPFM under dynamic conditions. At the time of logging, there was no storage for the pumped borehole fluid and discharging to the ground surface was not an option for environmental reasons.

4.0 HYDRAULIC TESTING WITH PACKER EQUIPMENT

4.1 Introduction

Hydraulic testing was performed to obtain quantitative estimates of the hydraulic properties of the bedrock groundwater system. Packer equipment was used to isolate select zones of the borehole. In addition, a groundwater sample was collected in a localized zone of relatively moderate hydraulic conductivity. The water sampling and results are discussed in Chapter 6.

The procedures for hydraulic testing and water sampling are provided in Appendix A. Appendix B contains plots of the individual test data and analyses. Calibration certificates for the pressure transducers used during hydraulic testing are provided in Appendix C. The sections below describe the borehole history, testing methodology, testing equipment, analysis approach, and results.

4.2 Borehole History

It is important to review the activities in the borehole prior to the performance of the hydraulic tests (borehole history). The boreholes were drilled with only water and polymers. Unlike bentonite based mud, these polymers do not form a significant filter cake or low permeability zone at the borehole wall. In addition, prior to testing, pumping was performed in all wells during flow logging which will remove any residual fluid in the near wellbore pore spaces. Finally, all the testing involved removing fluid from the wellbore which again will remove any residual fluid in the near wellbore pore spaces. Based on the information above, the test results are not expected to be significantly influenced by the borehole history. Also, the analysis approach emphasized late time data that represents relatively far field properties in relation to the properties at the wellbore face that may be influenced by drilling.

4.3 Methodology

Hydraulic testing was performed in four boreholes (see Figures 1-1 and 1-2). The intervals were selected as follows:

- Performed single packer test over majority of open hole for an estimate of transmissivity and bulk hydraulic conductivity;

- Performed single packer test over approximately the lower two-thirds of the open hole for an estimate of transmissivity and bulk hydraulic conductivity;
- Performed single packer test over approximately the lower one-third of the open hole for an estimate of transmissivity and bulk hydraulic conductivity; and
- If there was an indication during drilling or from the results of the flow logging, of a localized zones of relatively moderate to high hydraulic conductivity, a double packer test was performed over this interval to obtain more discrete data in comparison to the single packer tests.

After the packers were inflated, the hydraulic head was allowed to partially equilibrate for a minimum of 30 minutes prior to the main test phase. The main test phase was dependent on the relative magnitude of the transmissivity. Slug tests were performed in all but one interval due to relatively low interval transmissivity. A constant rate test was performed in one moderate transmissivity zone and a water sample was also collected at this location (borehole 04EA-84, 257.54 to 260.29 m (845.0 to 854.0 ft)).

4.4 Equipment for Packer Tests

The testing was performed with NQ wireline packer equipment in both single (Figure 4-1) and double packer (Figure 4-2) configurations. Each packer has a seal length of 0.46 m (1.5 ft) and a differential pressure rating of 2400 kPa (350 psi). No leaks were detected in the pressure tests conducted on the packers prior to and after the testing program. Also, the packer pressure was constant during the tests.

The pressure change during the tests was monitored with a Minitroll pressure transducer with a resolution of 1 kPa (0.15 psi).

4.5 Analysis Software

FlowDim (version 2.14) is a Golder in-house software that has been verified in assessment of potential nuclear repository investigations in Europe (NAGRA, 1997). All test types may be analyzed including constant rate, constant head and slug phases. Two step superposition is available—recovery following a constant rate period. In addition, the software includes the deconvolution approach to analysis of slug data (Enachescu and Chakrabarty, 1997). Flow models include homogeneous (HOM), composite (COM) and double porosity (DP). This package also includes the

derivative of pressure (i.e., rate of pressure change) with respect to the natural logarithm of time that has been shown to significantly improve the diagnostic and quantitative analysis of slug and constant rate pumping tests (Spane and Wurstner, 1993).

4.6 Analysis Approach

The analysis approach is summarized as follows:

- Select the most appropriate input parameters;
- View the semi-log derivative data in log log deconvolution plot (for slug tests) or log log plot (for constant rate tests) to select the most appropriate flow model that is consistent with the geology;
- Perform type curve matching to obtain an estimate for transmissivity (T); and
- Estimate hydraulic conductivity (K) by dividing the transmissivity by the assumed saturated thickness (assumed to be equal to the interval length).

4.7 Input Parameters for Analysis

Both slug and constant rate tests were performed. The measured response to a test is dependent on the hydraulic properties of the formation and the inner boundary condition.

The inner boundary condition for slug tests is wellbore storage and the sensitive parameter is the radius of the test tubing. For all tests, the water level was recovering within NQ core pipe (test tubing) with a radius of 30.15 mm (1.187 inch). A correction factor was needed as the volume change for a unit head change is larger for inclined boreholes, due to the longer measured length, versus vertical boreholes. The computation for the corrected test tubing radius is shown in Table 4.1.

TABLE 4.1
COMPUTATION FOR CORRECTED TEST TUBING RADIUS USED
IN THE ANALYSIS OF SLUG TESTS

Hole	Tubing Radius	Inclination	Distance for 1 m of Head Change	Volume for 1 m of Head Change	Corrected Test Tubing Radius
	[m]	[°]	[m]	[m ³]	[m]
47	3.02×10^{-02}	-78	1.0223	2.89×10^{-03}	3.03×10^{-02}
73	3.02×10^{-02}	-75	1.0353	2.93×10^{-03}	3.05×10^{-02}
83	3.02×10^{-02}	-83	1.0075	2.85×10^{-03}	3.01×10^{-02}
84	3.02×10^{-02}	-60	1.1547	3.26×10^{-03}	3.22×10^{-02}

The sensitive inner boundary condition for constant rate tests is the pumping rate. For the single constant rate test, the flow rate was measured with a calibrated container and a stop watch. The measured flow rate variation was less than + 5% which provided suitably controlled conditions for the analysis.

4.8 Flow Models Used in the Analysis

As described in section 4.5, the flow model selection was based on viewing the shapes and slopes of the semi-log derivative in log log coordinates and to be consistent with the available geological information. Three flow models were used in the analyses and are described below.

A homogeneous flow model (HOM) was chosen when the semi-log derivative data is dominated by a leveling off trend indicating radial flow. Transmissivity (T) was estimated from the pressure match. The skin (s) parameter is representative for the damaged zone and a type curve matched parameter while the storativity (S) was estimated from the time match and is applicable to all flow models (see Enachescu and Chakrabarty, 1997). Due to the high correlation of these parameters at early time, the estimated values for skin and storativity are considered to be poorly constrained.

A composite model was used to analyze formation responses that showed a change in transmissivity away from the well. The parameters derived from this model are as follows:

- Inner Zone Transmissivity (T): pressure match to the early time radial flow period;

- Discontinuity radius (brw): the discontinuity radius between inner and outer zones normalized to the borehole radius and a time match parameter; and
- Transmissivity ratio (rD1): ratio between inner and outer zone transmissivity with outer zone transmissivity estimated from the pressure match of the mid to late time radial flow period.

The outer zone transmissivity is representative of a larger scale of influence compared to the inner zone transmissivity. Therefore, the primary objective in the composite model was to evaluate the outer zone transmissivity.

A double porosity model was used to match formation responses where the semi-log derivative data showed a “hump”. This hump is characteristic for a storativity change between fracture dominated response, with relatively low storativity in the early time, and matrix or small scale fractures, with larger storativity in the late time. The parameters estimated from this model are as follows:

- Transmissivity (T): pressure match to radial flow period,
- Omega (OM): storativity ratio, sensitive to the size of the “hump”; and
- Lamda (LA): transmissivity ratio, sensitive to the timing of the “hump”.

Refer to Horne (1995) for additional details for this model.

4.9 Estimate for Hydraulic Conductivity and Inferred Values

Transmissivity is evaluated from the pressure match during radial flow conditions that is recognized by the leveling off of the semi-log pressure derivative data on the log plot. Hydraulic conductivity is then evaluated by dividing the transmissivity by the assumed saturated thickness. The approach in this investigation for the single packer tests was to set the saturated thickness equal to the length of borehole isolated by packers (interval length). As the measured transmissivity may be dominated by a few fracture zones with an effective saturated thickness considerably less than the interval length, the derived hydraulic conductivity should be considered an average value, rather than a value attributed to individual fractures, and hereafter referred to as bulk hydraulic conductivity.

Hydraulic conductivity values were also inferred from comparison of overlapping single packer tests to provide more discrete data for hydraulic conductivity profiles. The inferred values were derived by

subtracting the results of a shorter interval from a longer interval to estimate the properties for the interval that was not overlapped between the tests.

4.10 Analysis Results for Borehole 04EA-47

The results of the hydraulic tests performed in borehole 04EA-47 are summarized in Table 4.2 and a hydraulic conductivity profile is presented in Figure 4.3. The results show that the bulk hydraulic conductivity decreases with depth from 2.12×10^{-06} cm/s to 7.46×10^{-09} cm/s.

TABLE 4.2

ANALYSIS RESULTS FOR HYDRAULIC TESTS PERFORMED IN BOREHOLE 04EA-47

Test	Top	Bottom	Model	T [m ² /s]	K [m/s]	K [cm/s]	Method
1	14.02 m (46.0 ft)	268.21 m (880.0 ft)	DP	1.86×10^{-06}	7.32×10^{-09}	7.32×10^{-07}	type curve match
	14.02 m (46.0 ft)	100.88 m (331.0 ft)	N/A	1.84×10^{-06}	2.12×10^{-08}	2.12×10^{-06}	inferred
2	100.88 m (331.0 ft)	268.21 m (880.0 ft)	COM	6.17×10^{-08}	3.69×10^{-10}	3.69×10^{-08}	type curve match
	100.88 m (331.0 ft)	201.46 m (661.0 ft)	N/A	1.35×10^{-08}	1.34×10^{-10}	1.34×10^{-08}	inferred
3	201.46 m (661.0 ft)	268.21 m (880.0 ft)	HOM	4.98×10^{-09}	7.46×10^{-11}	7.46×10^{-09}	type curve match

4.11 Analysis Results for Borehole 04EA-73

The results of the hydraulic tests performed in borehole 04EA-73 are summarized in Table 4.3 and a hydraulic conductivity profile is presented in Figure 4.4. The results show that the bulk hydraulic conductivity decreases with depth from 1.79×10^{-06} cm/s to 1.46×10^{-08} cm/s.

TABLE 4.3**ANALYSIS RESULTS FOR HYDRAULIC TESTS PERFORMED IN BOREHOLE 04EA-73**

Test	Top	Bottom	Model	T [m ² /s]	K [m/s]	K [cm/s]	Method
1	15.24 m (51.0 ft)	266.38 m (874.0 ft)	HOM	1.30×10^{-06}	5.18×10^{-09}	5.18×10^{-07}	type curve match
	15.24 m (51.0 ft)	79.55 m (261.0 ft)	N/A	1.15×10^{-06}	1.79×10^{-08}	1.79×10^{-06}	inferred
2	79.55 m (261.0 ft)	266.38 m (874.0 ft)	DP	1.52×10^{-07}	8.14×10^{-10}	8.14×10^{-08}	type curve match
	79.55 m (261.0 ft)	149.65 (491.0 ft)	N/A	1.35×10^{-07}	1.92×10^{-09}	1.92×10^{-07}	inferred
3	149.65 (491.0 ft)	266.38 m (874.0 ft)	COM	1.71×10^{-08}	1.46×10^{-10}	1.46×10^{-08}	type curve match

4.12 Analysis Results for Borehole 04EA-83

The test results of the single packer hydraulic tests performed in borehole 04EA-83 are summarized in Table 4.4 and a hydraulic conductivity profile is presented in Figure 4.5. Consistent with the boreholes above, the highest bulk hydraulic conductivity of 5.12×10^{-06} cm/s was estimated for the upper portion of the borehole with lower values of 5.42×10^{-09} and 6.48×10^{-08} cm/s estimated for approximately the middle section and lower third of the borehole, respectively.

TABLE 4.4**ANALYSIS RESULTS FOR HYDRAULIC TESTS PERFORMED IN BOREHOLE 04EA-83**

Test	Top	Bottom	Model	T [m ² /s]	K [m/s]	K [cm/s]	Method
1	15.54 m (51.0 ft)	239.87 m (787.0 ft)	COM	3.33×10^{-06}	1.49×10^{-08}	1.49×10^{-06}	type curve match
	15.54 m (51.0 ft)	79.55 m (261.0 ft)	N/A	3.28×10^{-06}	5.12×10^{-08}	5.12×10^{-06}	inferred
2	79.55 m (261.0 ft)	239.87 m (787.0 ft)	COM	5.32×10^{-08}	3.32×10^{-10}	3.32×10^{-08}	type curve match
	79.55 m (261.0 ft)	164.89 m (541.0 ft)	N/A	4.62×10^{-09}	5.42×10^{-11}	5.42×10^{-09}	inferred
3	164.89 m (541.0 ft)	239.87 m (787.0 ft)	HOM	4.86×10^{-08}	6.48×10^{-10}	6.48×10^{-08}	type curve match
4	41.45 m (136.0 ft)	44.19 m (145.0 ft)	COM	3.40×10^{-09}	1.24×10^{-09}	1.24×10^{-07}	type curve match

In addition to the single packer tests, a double packer test (see Figure 4-3) was performed between 41.45 and 44.19 m (136.0 and 145.0 ft). This interval was selected based on partial loss of circulation in this depth range that could indicate a localized zone of relatively high hydraulic conductivity. The objective, in addition to estimating hydraulic properties, was to collect a representative water sample. However, the estimated hydraulic conductivity of 1.24×10^{-07} cm/s was too low to obtain a representative sample within a reasonable time period.

4.13 Analysis Results for Borehole 04EA-84

The analysis results from borehole 04EA-84 (Table 4.5) shows very similar results for the initial four tests with test intervals ranging between 2.74 m (9.0 ft) and 286.80 m (941.0 ft). Each of the intervals encompasses a significant flow anomaly identified with the HPFM tool (see Figure 3.6) at a depth of approximately 257.54 to 260.29 m (845.0 to 854.0 ft). This information indicates that the flow anomaly is the dominant water conductive feature in the borehole with an estimated hydraulic conductivity of 5.15×10^{-05} cm/s. In comparison, the inferred bulk hydraulic conductivity for the upper portion of the borehole is 1.05×10^{-06} cm/s and analysis of double packer test performed between 110.03 to 112.77 m (361.0 and 370.0 ft) shows a hydraulic conductivity of 2.90×10^{-07} cm/s (Figure 4.6).

TABLE 4.5

ANALYSIS RESULTS FOR HYDRAULIC TESTS PERFORMED IN BOREHOLE 04EA-84

Test	Top	Bottom	Model	T [m ² /s]	K [m/s]	K [cm/s]	Method
1	15.24 m (50.0 ft)	302.04 m (991.0 ft)	DP	2.80×10^{-06}	9.76×10^{-09}	9.76×10^{-07}	type curve match
	15.24 m (50.0 ft)	100.88 m (331.0 ft)	N/A	9.00×10^{-07}	1.05×10^{-08}	1.05×10^{-06}	inferred
2	100.88 m (331.0 ft)	302.04 m (991.0 ft)	DP	1.90×10^{-06}	9.45×10^{-09}	9.45×10^{-07}	type curve match
3	213.65 m (701.0 ft)	302.04 m (991.0 ft)	DP	4.08×10^{-06}	4.62×10^{-08}	4.62×10^{-06}	type curve match
4	257.54 m (845.0 ft)	260.29 m (854.0 ft)	HOM	3.14×10^{-06}	5.15×10^{-07}	5.15×10^{-05}	type curve match
5	109.72 m (361.0 ft)	112.8 m (370.0 ft)	COM	8.59×10^{-08}	3.13×10^{-09}	3.13×10^{-07}	type curve match

4.14 Analysis Results for Quaternary Monitoring Well QAL023

For completeness, a slug test was performed in Quaternary monitoring well QAL023. A hydraulic conductivity of 4.07×10^{-05} cm/s was estimated from the analysis by assuming a screen length equal to the saturated thickness.

5.0 MEASURED RESPONSE IN SHALLOW QUATERNARY MONITORING WELL QAL023 DURING HYDRAULIC TESTING IN THE BEDROCK

5.1 Introduction

Prior to the field investigation, Quaternary monitoring well QAL023 was installed within the Quaternary aquifer, proximal to the boreholes used for geophysical logging, flow logging, and packer testing (see Figures 1.1 and 1.2). This borehole was completed adjacent to a sandy unit (Appendix D) at a depth between 7.92 and 9.45 m (26.0 and 31.0 ft). The unconsolidated material below the screen consisted of silty clay with the top of the bedrock estimated at approximately 11.28 m (37.0 ft).

The objective of this well was monitoring water levels in the Quaternary aquifer during the hydraulic testing performed in the underlying bedrock. Evaluation of the monitoring data during testing would be used in conjunction with other information to assess the degree of vertical communication between the Quaternary aquifer and underlying groundwater system within the bedrock.

5.2 Equipment

Water level changes in Quaternary monitoring well QAL023 were continuously monitored with a pressure gauge installed at a depth of 6.98 m (22.9 ft) between 19:20 on 6 September 04 and 15:30 on 15 September 04. In comparison, the packer testing was performed between 11:38 on 7 September 04 and 15:20 on 15 September 04. The pressure gauge had a range of 210 kPa (30 psi), resolution of 0.05 % full scale and was programmed to record pressure in psi at 1 minute increments.

In addition, a 17 kPa (2.5 psi) pressure gauge with a resolution of 0.025% of full scale was used to measure barometric pressure changes between 10:00 on 8 September 04 and 17:00 on 15 September 04. The pressure gauge was programmed to record pressure in psi at 60 minute increments.

The time clock for each pressure gauge was synchronized to the clock time of the site lap top computer. Calibration certificates for all gauges are provided in Appendix C.

5.3 Methodology

The approach to investigate a potential response in the Quaternary monitoring well to hydraulic testing within the bedrock was to present the data on single plot to provide a direct comparison. To optimize the resolution to detect a response the plots were constructed as follows:

- The time was converted to normalized elapsed time with 0 elapsed time equal to 19:25:34 on 6 September 04 for all pressure gauges.
- The pressure change was displayed for each gauge with the initial reading subtracted from all subsequent readings. Hence, a negative pressure indicates a decrease in pressure in comparison to the initial pressure reading, while a positive number indicates an increase in pressure in comparison to the initial reading.
- The readings from the pressure gauge installed in the Quaternary monitoring well QAL023 and the barometric pressure gauge were plotted on the primary y-axis while the test data, which typically showed a much larger pressure change, were plotted on the secondary y-axis.

5.4 Quaternary Well QAL023 Water Level Response During Testing in Borehole 04EA-47

The collar of borehole 04EA-47 is 28.32 m (92.9 ft) from the collar of Quaternary monitoring well QAL023. Figure 5.1 shows the changes in hydraulic head measurements in Quaternary monitoring well QAL023, as measured with the pressure gauge, in comparison to the hydraulic head changes recorded with a pressure gauge during bedrock packer testing in borehole 04EA-47. There is no apparent reaction in the Quaternary aquifer at monitoring well QAL023 to the slug tests performed within the bedrock.

5.5 Quaternary Well QAL023 Water Level Response During Testing in Borehole 04EA-73

The collar of borehole 04EA-73 is 116.93 m (383.5 ft) from the collar of Quaternary monitoring well QAL023. Figure 5.2 shows the changes in hydraulic head measurements in Quaternary monitoring well QAL023, as measured with a pressure gauge, in comparison to the hydraulic head changes recorded with a pressure gauge during bedrock packer testing in borehole 04EA-73. There is no apparent reaction in the Quaternary aquifer at monitoring well QAL023 to the slug tests performed within the bedrock.

5.6 Quaternary Well QAL023 Water Level Response During Testing in Borehole 04EA-83

The collar of borehole 04EA-83 is 3.51 m (11.5 ft) from the collar of Quaternary monitoring well QAL023. Figure 5.3 shows the changes in hydraulic head measurements in Quaternary monitoring well QAL023, as measured with a pressure gauge, in comparison to the hydraulic head changes recorded with a pressure gauge during bedrock packer testing in borehole 04EA-83. There is no apparent reaction in the Quaternary aquifer at monitoring well QAL023 to the slug tests performed within the bedrock.

5.7 Quaternary Well QAL023 Water Level Response During Testing in Borehole 04EA-84

The collar of borehole 04EA-84 is 8.58 m (28.2 ft) from the collar of Quaternary monitoring well QAL023. Figures 5.4A and 5.4B shows the changes in hydraulic head measurements in Quaternary monitoring well QAL023, as measured with a pressure gauge, in comparison to the hydraulic head changes recorded with a pressure gauge during bedrock packer testing in borehole 04EA-84. There is no apparent reaction in the Quaternary aquifer at QAL023 to the performance of tests within the bedrock with one exception. A drawdown of 0.7 kPa (0.1 psi) was recorded in the QAL023 pressure gauge compared to a maximum drawdown of 59 kPa (8.5 psi) recorded in test interval 257.54 to 260.29 m (845.0 to 854.0 ft) during pumping for water quality sample.

The interval 257.54 to 260.29 m (845.0 to 854.0 ft) was selected to encompass a localized zone of relatively moderate hydraulic conductivity (compared to global ranges for fractured rock) identified with the fluid conductivity tool and the HPFM tool under pumping conditions (see Figure 3.6). This localized moderate hydraulic conductivity zone is attributed to flow in water conductive fractures that are connected to the borehole at this location. No other anomalies were identified with the fluid conductivity tool and the hydraulic properties of the remainder of the borehole are inferred to be relatively low. All the packer tests in this borehole included the zone 257.54 to 260.29 m (845.0 to 854.0 ft) and the measured response would be expected to be dominated by flow from this zone. This is confirmed by the packer test transmissivity results that show similar values (see Table 4.5) for intervals varying between 2.74 and 286.80 m (9.0 and 941.0 ft).

Therefore, as each test is considered to be dominated by the flow in the zone 257.54 to 260.29 m (845.0 to 854.0 ft), the Quaternary well response that took place only during the shortest interval test can be explained as packer bypass. Packer bypass is hydraulic connection between the test interval

and the borehole above the packers due to localized fracturing that extends above or below the relatively small test interval. The hydraulic connection to the borehole would then result in drawdown in the annulus (zone above the packer) and a response in the Quaternary aquifer is then expected as there is no seal between the Quaternary aquifer and the casing.

6.0 WATER QUALITY SAMPLE FROM BOREHOLE 04EA-84

6.1 Introduction

The objective for water quality samples was to collect two samples at a relatively shallow and at a relatively deep depth from localized zones of relatively moderate to high hydraulic conductivity. A double packer tool was to be used with a 2.74 m (9.0 ft) spacing between packers for water sample collection from discrete water conductive features.

One sample was collected between 257.54 to 260.29 m (845.0 and 854.0 ft) in borehole 04EA-84, that was selected to encompass a flow anomaly identified with the fluid conductivity and the HPFM tools (see Figure 3.6). Several attempts were made to collect a second water sample from relatively shallow depths but in all cases the hydraulic conductivity was considered too low to collect a representative sample within a reasonable time period.

6.2 Sample Collection

A water sample was collected at approximately 15:30 on 8 September 04 from the interval 257.54 to 260.29 m (845.0 to 854.0 ft) in borehole 04EA-84 using a submersible pump. All sampling equipment was decontaminated with deionized water and the PVC discharge tubing was new at the start of the pumping. Prior to sample collection, the fluid in the NQ core pipe (735.4 L, 194.30 gallons) plus 3.6 test interval volumes (44.1 L, 11.65 gallons) were pumped from the interval. The field parameters measured during the purging period are shown in Table 6.1. All instruments were calibrated to known standards at the start of purging.

6.3 Discussion of Water Quality Results

Field parameters measured during purging are shown in Table 6.1 and laboratory results, along with water quality results from previous investigations (provided by North Jackson), are summarized in Table 6.2 and provided in Appendix E.

TABLE 6.1

**FIELD PARAMETERS MEASURED DURING PURGING FOR WATER SAMPLE
COLLECTED BETWEEN 257.54 TO 260.29 M (845.0 AND 854.0 FT)
IN BOREHOLE 04EA-84**

Date	Time	Volume Purged (L)	pH	Conductivity (uS/cm)	Temperature (°C)	Turbidity (NTU)	Flowrate (L/min)
08:10:04	1010	Started pumping	N/A	N/A	N/A	N/A	N/A
	1013	208 ¹⁾	6.67	223	12.2	>1000	3.8
	1051	307	8.62	223	13.6	>1000	3.8
	1110	378	Turned pump off to allow recovery			N/A	N/A
	1135	378	Turned pump on			N/A	N/A
	1137	386	9.35	227	12.9	>1000	3.8
	1210	409	9.31	232	13.2	>1000	2.5
	1227	443	8.65	309	13.2	>1000	1.7
	1240	465	8.53	489	13.4	>1000	1.7
	1255	499	8.18	753	13.4	>1000	2.2
	1310	530	8.04	981	15.3	>1000	2.1
	1325	556	8.06	1153	14.4	>1000	1.7
	1340	583	8.04	1089	13.5	>1000	1.9
	1355	617	8.21	1212	13.8	>1000	2.3
	1415	662	7.59	1392	14.4	>1000	2.3
	1430	681	8.01	1485	14.7	>1000	1.3
	1445	711	8.07	1319	14.7	>1000	1.9
	1500	742	8.58	1218	13.8	>1000	1.9
	1510	761	8.68	1428	13.4	>1000	1.9
	1515	770	8.70	1500	13.0	>1000	1.9
	1520	780	8.72	1507	12.7	>1000	1.9

1) includes volume removed during testing prior to purging

TABLE 6.2

**WATER QUALITY RESULTS FOR SAMPLES COLLECTED IN PREVIOUS STUDIES
COMPARED TO SAMPLES COLLECTED IN THIS STUDY**

Parameter	Units	Pump Test Samples (Previous Studies, Provided by North Jackson)				This Study
		04EA-054A	04EA-054B	04EA-054D	04EA-054E	04EA-084
Field Parameters		Bedrock	Bedrock	Bedrock	Bedrock	Bedrock
Temperature	°C	14.6	16.2	12.4	10.8	12.72
Specific Conductance	µmhos/cm @ 25°C	138	194	133	238	1507
pH	SU	9.41	9.71	9.73	10.15	8.72
D.O.	ppm	NM	NM	NM	NM	NM
Ferrous Iron	mg/L	NM	NM	NM	NM	NM
Metals/Inorganics						
Aluminum, Dissolved	µg/L	<100	<100	<100	<100	<100
Lithium, Dissolved	µg/L	<10	14	23	14	49
Antimony, Dissolved	µg/L	<5.0	<5.0	<5.0	<5.0	<5.0
Arsenic, Dissolved	µg/L	<2.0	<2.0	<2.0	<2.0	6.8
Barium, Dissolved	µg/L	27	60	<20	<20	<20
Iron, Dissolved	µg/L	22	<20	130	61	190
Beryllium, Dissolved	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Boron, Dissolved	µg/L	1340	1370	2720	3910	1590
Cadmium, Dissolved	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
Chromium, Dissolved	µg/L	<5.0	<5.0	<5.0	<5.0	<5.0
Cobalt, Dissolved	µg/L	<10	<10	<10	<10	<10
Copper, Dissolved	µg/L	<5.0	<5.0	<5.0	<5.0	<5.0
Lead, Dissolved	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Manganese, Dissolved	µg/L	<20	<20	<20	<20	220
Molybdenum, Dissolved	µg/L	<10	<10	11	<10	53
Nickel, Dissolved	µg/L	<25	29	<25	<25	59
Selenium, Dissolved	µg/L	<1.0	<1.0	1.1	<1.0	7.3
Silver, Dissolved	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2
Zinc, Dissolved	µg/L	<10	<10	11	12	88
Mercury, Dissolved	ng/L	0.653	0.428	0.651	4.95	89.1*
Major Anions						
Alkalinity, Bicarbonate	mg/L	80	<2.0	72	<2.0	62
Alkalinity, Carbonate	mg/L	<2.0	2.2	<2.0	15	<2.0
Chloride	mg/L	18	26	64	42	676
Fluoride	mg/L	0.17	0.19	0.14	0.12	0.53
Sulfate	mg/L	5.6	6.3	28	12	<5.0
Major Cations (filtered)						
Calcium, Dissolved	mg/L	8.9	34	25	19	31
Potassium, Dissolved	mg/L	2	8.1	7.1	4.3	12
Magnesium, Dissolved	mg/L	3.6	2.5	4.1	3.8	22
Sodium, Dissolved	mg/L	24	27	41	40	360
General Chemistry						
Hardness, (calculated) as CaCO ₃	mg/L	37	95	79	63	980
Residue, Dissolved @ 180°C	mg/L	124	128	272	210	1590
Tritium	TU	1.32	2.23	7.86	7.02	9.20

* The Hg concentration measured for this study was a total value.

Water quality samples from bedrock formations were collected in August 2004 from the specific capacity testing for the environmental baseline study and also in the bedrock hydrogeologic investigation in September 2004. These samples were analyzed for inorganic chemical constituents (major and minor ionic constituents, trace metals, general index parameters, and tritium). This is the same analytical parameter list being used for the Quaternary aquifer samples for the baseline environmental study.

The samples from the shallower horizons (upper 18.3 m (60 ft)) of borehole 04EA-054 (A and B samples) that were collected from the non-mineralized portion of the Yellow Dog Peridotite indicated fairly low total dissolved solids (TDS) concentrations (up to 128 mg/L) and can be classified as fresh water (TDS less than 1,000 mg/l). Samples collected from borehole 04EA-054 that also included semi-massive sulfide mineralization of the Peridotite (D and E samples, open to the upper 480 ft of bedrock) had higher TDS concentrations (up to 272 mg/L), but were still well within the classification of fresh water based on TDS concentration. The sample collected from borehole 04EA-084 within a massive to semi-massive sulfide has much higher TDS concentration (1,590 mg/L) and is classified as slightly brackish water (brackish water being defined as 1,000 - 10,000 mg/L, Freeze and Cherry, 1979).

For the water quality sample collected during this investigation, it should be noted that, although the conductivity measured during purging started to stabilize, the readings were still increasing when the water sample was collected (see Table 6.1). The increasing trend is likely due to an increase in the ratio between in-situ water and drill water with time or from the drawdown cone inducing flow from greater depths. In either case, as conductivity is related to TDS, the TDS would be expected to be greater as pumping or dewatering time is increased from a similar depth and from similar hydraulic conditions.

Major ion chemistry for groundwater samples collected from bedrock boreholes is presented in Figure 6.1. Water quality of most samples plot in the sodium-potassium-chloride ion-dominated region. In contrast, samples representative of Quaternary formation hydrostratigraphic units typically plot as strongly dominated by calcium-bicarbonate ions (samples QAL004A and QAL004D, Figure 6.1), similar to stream samples from the Salmon-Trout River system (North Jackson Company, 2004). From a major ion chemical evolution sequence observed typically, this pattern indicates increasing residence time of water within the bedrock formation relative to the overlying alluvium (Freeze and Cherry, 1979).

Minor constituents detected included iron in most samples plus fluoride. Trace metals detected in these groundwater samples consist of lithium, boron, barium, manganese, molybdenum, nickel, selenium, and zinc. The most notable trace constituent consistently detected in these samples is boron, with concentrations greater than 1 mg/L in all samples. In studies of Precambrian rock formations within the Lake Superior basin it has been documented that boron concentrations as high as 30 mg/L exist in highly saline brines (Tipping; Allen and Seyfried), often in association with metasedimentary rock formations originally deposited in marine environments, similar to the Baraga Basin on the Yellow Dog Plains.

Mercury was detected at concentrations less than 1 ng/L (total) in shallow horizons and up to 89.1 ng/L (total) in the deepest interval sampled in borehole 04EA-084.

Low level tritium analyses for these samples were also performed to provide relative age dating of these samples. Concentrations near 1 TU are typically considered indicative of sub-modern groundwater, indicating little connection to modern water sources and concentrations between 1-5 indicate mixed sub-modern and modern sources. Concentrations between 5-10 TU are indicative of modern water sources; therefore, on this scale of comparison, results from these samples indicate a relatively higher likelihood of modern water source with depth, which is contrary to the conceptual bedrock flow model, based on hydraulic testing described in this report. Also, due to a report of significant drill fluid (potable) loss to the formation while drilling below the “B” sample in borehole 04EA-054, it is considered likely that drill water mixing with the formation water in the samples from boreholes 04EA-54D and 04EA-054E may have also contributed to higher tritium concentrations. Likewise, the sample for 04EA-084 indicates a potential influence from drill fluids with the relatively high TU measured in comparison to 04EA-054A and 04EA-054B. As discussed in Section 5.7 there was potential connection between the borehole and the packer isolated sampling section. Data is not yet available for tritium from the Quaternary aquifers on the Yellow Dog Plains for comparison to these data or for an estimate on the degree of mixing of formation water and in situ water that may have occurred in these samples.

7.0 SYNTHESIS OF DATA FOR DEVELOPMENT OF BEDROCK CONCEPTUAL FLOW MODEL

The conceptual flow model presented here is considered in the early stages of development and should be checked against new data and refined on a regular basis. The main components of the conceptual model are divided into static and dynamic components.

In this report, the weathering zone is used as a generic rock mechanic description for the enhanced fracturing that typically occurs in the upper portion of the bedrock due to surface-related fractures. Surface-related fractures includes fractures developed during unloading, release of stored stress and strain, creation of free surfaces or unsupported boundaries, and weathering in general (Nelson, 2001).

7.1 Static Conceptual Model

The static hydrogeologic bedrock conceptual model has been simplified to three main components. Analysis results for hydraulic tests show relatively moderate hydraulic conductivity for the upper portion of the boreholes, attributed to enhanced fracturing due to weathering. Below the weathered zone, the hydraulic testing results show that the bulk of the rock mass has a relatively low hydraulic conductivity, proximal to what could be expected for the matrix of the formation. In two boreholes, localized zones of relatively moderate hydraulic conductivity (water conductive fractures) were identified with flow logging tools, attributed to flow in fractures, and quantified with hydraulic tests in one borehole. The relative infrequency of these water conductive fractures below the weathered zone suggests a relatively sparse distribution in the rock mass.

Weathered Zone: Top of Bedrock to Approximately 90 m (300 Ft) – True Vertical Depth

The conceptual model for the weathered zone is a true vertical depth of approximately 90 m (300 ft) with a hydraulic conductivity of 2×10^{-06} cm/s (2×10^{-08} m/s). Hydraulic tests performed in the upper portion of four boreholes provide the basis for defining the weathered zone and are summarized in Table 7.1.

TABLE 7.1**HYDRAULIC TEST RESULTS FOR UPPER SECTIONS OF BOREHOLES**

Borehole	Inclination [°]	Top	Bottom	True Vertical Depth for Bottom of Interval	K [cm/s]
47	78	14.02 m (46.0 ft)	100.89 m (331.0 ft)	98.8 m (324 ft)	2.12×10^{-06}
73	75	15.54 m (51.0 ft)	79.55 m (261.0 ft)	76.8 m (252 ft)	1.79×10^{-06}
83	83	15.54 m (51.0 ft)	79.55 m (261.0 ft)	78.9 m (259 ft)	5.12×10^{-06}
84	60	15.24 m (50.0 ft)	100.89 m (331.0 ft)	87.5 m (287 ft)	1.05×10^{-06}
geometric mean K					2×10^{-06}

Bulk of the Unweathered Bedrock Below Approximately 90 m – True Vertical Depth

The conceptual model includes an unweathered bedrock zone below a true vertical depth of approximately 90 m (300 ft) with an average hydraulic conductivity of 5×10^{-08} cm/s. It should be noted that maximum true vertical depth of the boreholes used in the field investigation was 323.10 m (1060.1 feet). The hydraulic conductivity is relatively low and considered representative of the matrix. Basis for defining the weathered zone in the conceptual model is the hydraulic tests performed in the lower sections of boreholes 04EA-47, 04EA-73 and 04EA-83, and summarized in Table 7.2.

TABLE 7.2**HYDRAULIC TEST RESULTS FOR UPPER SECTIONS OF BOREHOLES**

Borehole	Inclination [°]	Top	Bottom	True Vertical Depth for Bottom of Interval	K [cm/s]
47	78	100.9 m (331 ft)	268.2 m (880 ft)	262.4 m (861 ft)	3.69×10^{-08}
73	75	79.6 m (261 ft)	266.4 m (874 ft)	266.4 m (844 ft)	8.14×10^{-08}
83	83	79.6 m (261 ft)	239.9 m (787 ft)	238.0 m (781 ft)	3.32×10^{-08}
geometric mean K					5×10^{-08}

The results for the test conducted in the lower section of borehole 04EA-84 were excluded as the interval included a localized zone of relatively moderate hydraulic conductivity between 257.54 to 260.29 m (845.0 and 854.0 ft) and attributed to flow in fractures, discussed in the next section.

Water Conductive Fractures Below 90 m (300 ft) - Vertical Depth, Sparsely Distributed Within Bulk of Rock Mass

The interpretation of geophysical logs, flow logs and hydraulic test data for the presence of water conductive fractures below approximately 90 m (300 ft) vertical depth are summarized in Table 7.3. Water conductive fracture is identified based on deviations from the background trend in the HPFM log under pumping conditions (see Figure 3.4 and Figure 3.6) that were confirmed by other logs or by hydraulic testing.

TABLE 7.3

SUMMARY OF WATER CONDUCTIVE FRACTURES INTERPRETED FROM GEOPHYSICAL LOGS, FLOW LOGS AND HYDRAULIC TESTS, BELOW 90 M (300 FT)

Borehole	Inclination [°]	Top	Bottom	Drilled Length	Equivalent Vertical Distance	Equivalent Horizontal Distance	Number of Interpreted Water Conductive Fractures
47	78	90 m (300 ft)	268.22 m (880 ft)	262.37 m (860.8 ft)	176.78 m (580.0 ft)	36.76 m (120.6 ft)	0
54	90	90 m (300 ft)	323.1 m (1060.1 ft)	323.12 m (1060.1 ft)	231.68 m (760.1 ft)	0.00 m (0.0 ft)	0
73	75	90 m (300 ft)	265.0 m (869.5 ft)	255.97 m (839.8 ft)	266.38 m (874.0 ft)	68.94 m (226.2 ft)	0
77	70	90 m (300 ft)	256.0 m (839.9 ft)	240.58 m (789.3 ft)	266.38 m (874.0 ft)	91.10 m (298.9 ft)	1
83	83	90 m (300 ft)	239.88 m (787.0 ft)	238.08 m (781.1 ft)	239.87 m (787.0 ft)	29.22 m (95.9 ft)	0
84	60	90 m (300 ft)	302.09 m (991.1 ft)	261.61 m (858.3 ft)	239.87 m (787.0 ft)	119.93 m (393.5 ft)	1
Totals:				1582 m (5189 ft)	1421 m (4662 ft)	345.93 m (1135 ft)	2

Two water conductive fractures were interpreted from the data below 90 m (300 ft) true vertical depth for a total drilled depth of 1582 m (5189 ft), equivalent to a vertical distance of 1421 m (4662 ft) and equivalent to a horizontal distance of 345.93 m (1135 ft). Hence, this data suggests that water conductive fractures below approximately 90 m (300 ft) true vertical depth are sparsely distributed in the rock mass. A transmissivity of $3.14 \times 10^{-06} \text{ m}^2/\text{s}$ (test interval of 2.74 m (9.0 ft)) was estimated for the water conductive fracture identified in borehole 04EA-84 and no testing was performed for the water conductive fracture identified in borehole 04EA-77. The water conductive fractures were encountered in the shallowest dipping boreholes which are more likely to intersect sub-vertical water

fractures compared to the steeply dipping boreholes. One water conductive fracture was encountered in the north-south (180° azimuth) trending borehole (04EA-77) and the second water conductive fracture was interpreted in an east-west (100° azimuth) trending borehole (04EA-84). Both water conductive zones were within a massive or semi-massive sulfide unit. The pertinent information for the interpreted water conductive fractures is summarized in Table 7.4

TABLE 7.4
PERTINENT INFORMATION FOR INTERPRETED WATER
CONDUCTIVE FRACTURES BELOW 90 M (300 FT)

Borehole	Azimuth [°]	Inclination [°]	Pertinent Information for Interpreted Water Conductive Fractures					
			#	Top	Bottom	Geologic Unit	Contact Angle	T [m ² /s]
47	180	-78	0	N/A	N/A	N/A	N/A	N/A
54	n/a	-90	0	N/A	N/A	N/A	N/A	N/A
73	180	-75	0	N/A	N/A	N/A	N/A	N/A
77	180	-70	1	188.97 m (620.0 ft)	195.06 m (640.0 ft)	massive and semi-massive sulfide	low angle	no measurement
83	180	-83	0	N/A	N/A	N/A	N/A	N/A
84	100	-60	1	257.5 m (845.0 ft)	260.29 m (854.0 ft)	sulfide	no information	3.14 X 10 ⁻⁰⁶

Notes:

1. The source for the geologic unit and contact angle is KMC.
2. The water conductive fractures are likely constrained by the estimated top and bottom.

7.2 Dynamic Conceptual Flow Model

Hydraulic Communication Between Quaternary Aquifer and the Bedrock Groundwater System

The pressure gauge installed in Quaternary monitoring well QAL023 during testing in the bedrock showed no response to the packer testing in the bedrock wells with one exception which was attributed to packer bypass (see Chapter 5 for discussion). Therefore, the monitoring results indicate no direct hydraulic communication between the Quaternary aquifer and the bedrock groundwater system in vicinity of the boreholes.

The water sample collected within the bedrock between 257.54 to 260.29 m (845.0 and 854.0 ft) in boreholes 04EA-84 shows a TDS concentration that is much greater than expected for the water quality of the Quaternary aquifer (see Chapter 6 for details). This large difference in chemistry infers

that locally the Quaternary aquifers and the deep bedrock groundwater systems are in poor hydraulic communication.

Water Conductive Fractures

The details for the dynamic interaction between the rock matrix and fractures has been studied and referenced in the oil industry. Aguilera (1995) classifies fractured basement rocks, which he defines generally as igneous and metamorphic rocks, as Type 3 Reservoirs. The characteristic for Type 3 Reservoirs is a rapid decline in the pumping rate as fluid flows to the boreholes. This is because fractures have a low storage capacity and there is no recharge from matrix, which comprises the majority of the rock mass. The matrix in basement rocks has essentially no effective porosity (Aguilera, 1995) and very low hydraulic conductivity.

Therefore, water conductive fractures encountered in the unweathered bedrock will potentially have a high inflow rate when a large hydraulic gradient is first applied to them that will then decline with time. The rate of decline will be dependent on the storage capacity of the fractures with a more rapid decline expected for water conductive fractures with relatively small storage capacity. However, there are exceptions. For example, the rate would not be expected to decline rapidly if the water conductive fractures were in good hydraulic communication with a source of recharge such as the weathered zone, which has a much higher storativity and hydraulic conductivity and would essential behave as a constant pressure boundary.

Bulk of the Unweathered Bedrock

In the following chapter, the inflow will be estimated for an idealized tunnel within the unweathered bedrock. The flow to a tunnel is expected to have a transient flow condition at early time following tunnel excavation and steady state condition at late time. Steady state conditions would be expected once the pressure transients reach the weathered zone and following a transition period. For this conceptual model, the time to reach steady state conditions in the bulk of the unweathered bedrock would be dependent on the time for the pressure transient to reach the constant pressure boundary which can be approximated with re-arrangement of the equation below:

$$d = A \sqrt{\frac{T}{S}} t_s \quad \text{Streltsova (1988)}$$

The coefficient 'A' is a constant dependent on the definition for the radius of investigation. Typically, the 'A' constant is estimated to be 2, corresponding to a dimensionless drawdown of approximately 0.3. Assuming a transmissivity of $1.26 \times 10^{-07} \text{ m}^2/\text{s}$ (hydraulic conductivity of $4.64 \times 10^{-10} \text{ m/s}$ and thickness of 274.3 m (900 ft), a storativity of 1×10^{-04} , distance of 274.3 m (900 ft) for a tunnel located at 365.7 m (1200 ft), the estimated time for transients to reach the weathered zone is 173 days. There will be a transition period between the transient and steady state periods.

8.0 IMPLICATIONS FOR MINE INFLOW

The inflow into a mine is dependent on the following:

- Duration since start of mining;
- Geometry, volume and location of the mine openings;
- Hydraulic properties of the formation influenced by dewatering; and
- Boundary conditions.

Analytical equations were used in this study to estimate mine inflow into an idealized tunnel that is 152.4 m (500 ft) in length and 3.0 m (10 ft) in diameter for two locations. The first location was 45.7 m (150 ft) vertical depth and positioned to provide indication for inflow from the weathered bedrock. The second location was positioned at 365.7 m (1200 ft), which is the planned maximum depth of the mine, and positioned to provide inflow from the unweathered bedrock and water conductive fractures at depth. Also, a constant head inner boundary condition was assumed with the head difference equal to the distance between the elevation of the excavation and the elevation of the static water level. As time since excavation increases, the flow rate is expected to decrease as the radius of influence expands and results in lower hydraulic gradient.

It should be noted that hydraulic conductivity values (units of cm/s or m/s) are used when estimating inflow from the bulk of the rock mass while transmissivity values (units of m^2/s) are used to estimate inflow from water conductive fractures at depth. The flow from fractures at depth will be controlled by the transmissivity as, unlike the bulk of the rock mass, will not involve large reductions in saturated thickness with time.

8.1 Inflow Estimates within the Weathered Zone into Idealized Tunnel

Boundary conditions for inflow estimates within the weathered zone (see Figure 8.1) were assumed as follows:

- The contact between the weathered and unweathered bedrock was assumed to be a no-flow boundary, as the much lower hydraulic conductivity of the

unweathered bedrock is not expected to contribute significant flow compared to the weathered bedrock.

- The contact between the alluvium and the bedrock was assumed to be no-flow boundary in Simulation #1 and a recharge boundary in Simulation #2, to assess the sensitivity for the degree of hydraulic communication between the alluvium and the bedrock.
- The lateral boundary conditions were assumed to be infinite in lateral extent.

In relatively early time, flow to a tunnel is expected to be transient and the expected flow regime during the transient period is vertical radial flow. During vertical radial flow regime, the inflow is dependent on the horizontal and vertical hydraulic conductivity of the bedrock. Once the transients reach the base of the weathered zone and the top of the bedrock, which were both assumed to be no-flow boundaries, flow would be horizontal to the tunnel. The analytical software INTERPRET2, distributed by Baker Hughes, was used for the forward simulations to estimate flow to a horizontal well that is analogous to a horizontal tunnel. Input parameters are shown in Table 8.1. The simulator was used to estimate flowrates needed to obtain and maintain a drawdown of 45.7 m (150 ft) for a tunnel length of 152.4 m (500 ft). The simulations estimate inflow rates between 75.7 L/min (20 gpm) at 0.01 days after the start of dewatering, and 7.57 L/min (2 gpm) at 1000 days after the start of dewatering.

TABLE 8.1

**INPUT PARAMETERS FOR WEATHERED ZONE FORWARD SIMULATION OF
TRANSIENT PERIOD**

Input Parameter	Value	Basis
horizontal hydraulic conductivity	2×10^{-06} cm/s	see Table 7.2
vertical hydraulic conductivity	2×10^{-06} cm/s	see Table 7.2
storativity	1×10^{-04}	assumed
horizontal tunnel length	152.4 m (500 ft)	input
tunnel diameter	3.0 m (10 ft)	input
viscosity	1 [cp]	assumed
base of weathered zone (90 m (300 ft))	No Flow	assumed
top of bedrock (9 m (50 ft))	No Flow	assumed
lateral extent	Infinite	assumed
drawdown	45.7 m (150 ft)	input

As mentioned above, the contact between the bedrock and the alluvium was assumed to be a no-flow boundary for Simulation #1, which would be consistent with poor vertical communication between

the alluvium and the bedrock. To assess the sensitivity of the inflow estimates to the degree of hydraulic communication between the bedrock and the alluvium, a recharge boundary was assumed in Simulation #2, which would be consistent with good vertical hydraulic communication. Simulation #2 estimate inflow rates between 75.7 L/min (20 gpm) at 0.01 days after the start of dewatering, and 18.9 L/min (5 gpm) at 1000 days after start of dewatering.

In relatively late time, flow to a tunnel is expected to approach steady state conditions (Figure 8.2). The equation used to estimate inflow into a tunnel for steady state conditions is after Goodman et al. (1965) and shown below:

$$Q = K \cdot 2\pi (\Delta H) / \ln(R/r)$$

Where:

Q = average flowrate per m of tunnel (m^3/s per m of tunnel and converted to L/s)

K = hydraulic conductivity (2×10^{-06} cm/s, see Table 7.2)

R = distance to recharge boundary (91.4 m (300 ft), assumed to be twice the drawdown as the default used by Goodman (1965))

r = effective tunnel radius (1.5 m (5 ft), assumed radius of tunnel)

ΔH = drawdown (45.7 m (150 ft) based on assumption that static head equates to ground surface)

The estimated total inflow from the weathered bedrock for 152.4 m (500 ft) length of horizontal tunnel with a radius of 1.5 m (5 ft) is 15.14 L/min (4 gpm) and shows good agreement to the late time inflow estimates assuming transient conditions.

A summary of estimated inflows into an idealized tunnel located at 45.7 m (150 ft) vertical depth within the weathered zone is provided in Table 8.2.

TABLE 8.2**INFLOW ESTIMATES FOR IDEALIZED TUNNEL WITHIN THE WEATHERED ZONE**

Duration [days]	Transient Conditions		Steady State
	Simulation #1- Poor Vertical Communication between Bedrock and Alluvium	Simulation #2 - Good Vertical Communication between Bedrock and Alluvium	Estimated Inflow under Steady State Conditions
0.01	65.6 L/min (20 gpm)	65.6 L/min (20 gpm)	not computed
0.1	30.3 L/min (8 gpm)	30.3 L/min (8 gpm)	not applicable
1	18.9 L/min (5 gpm)	(6 gpm)	not applicable
10	11.4 L/min (3 gpm)	18.9 L/min (5 gpm)	not applicable
100	7.6 L/min (2 gpm)	18.9 L/min (5 gpm)	not applicable
1000	7.6 L/min (2 gpm)	18.9 L/min (5 gpm)	not applicable
Steady State	N/A		18.9 L/min (5 gpm)

8.2 Inflow Estimates within the Unweathered Zone into Idealized Tunnel

The conceptual model for the bedrock groundwater system below 90 m (300 ft) true vertical depth is comprised of two components; unweathered bedrock that is controlled primarily by matrix properties for the bulk of the rock mass; and water conductive fractures with moderate hydraulic conductivity with a relatively sparse distribution. The estimated inflow for a 152.4 m (500 ft) section of a horizontal tunnel at a depth of 365.7 m (1200 ft) is discussed below for the two components using analytical equations. The total inflow will be the inflow from the matrix plus the inflow from the water conductive fractures.

The inflow from water conductive fractures was estimated for transient conditions, while the inflow from the matrix was estimated for both transient and steady state conditions to provide a consistency check for the relatively late time. A recharge boundary is required for the steady state estimate and was assumed to be at the contact between the weathered and the unweathered bedrock. It is assumed that once the pressure transient reach the weathered zone, the much higher hydraulic conductivity of this unit will be analogous to recharge boundary and will stabilize the cone of depression. The lateral boundary conditions were assumed to be infinite in lateral extent in all computations.

Inflow Estimates from Water Conductive Fracture into Idealized Tunnel

The inflow from intersection of water conductive fractures will be dependent on the actual number of water conductive fractures that will be encountered during mining and their hydraulic properties. For this investigation, two water conductive fractures were interpreted below approximately 90 m (300 ft) true vertical depth in the six boreholes used for measurements. Assuming the two conductive fractures are not hydraulically connected, this is equivalent to a frequency of one water conductive fracture for 790.9 m (2595 ft) drilled length, one water conductive fracture for 710.5 m (2331 ft) of vertical length and one water conductive fracture for 173.1 m (568 ft) of horizontal length.

For an estimate for mine inflow from water conductive fractures, one water conductive fracture was assumed to be encountered within the 152.4 m (500 ft) tunnel length, which is similar to the frequency encountered in the boreholes on a horizontal length basis. The transmissivity for the water conductivity fracture(s) was assumed to be $3.14 \times 10^{-06} \text{ m}^2/\text{s}$, which is equal to the transmissivity derived for the water conductivity fracture encountered between 257.54 to 260.29 m (845.0 to 854.0 ft) in borehole 04EA-84. Flow was assumed to be horizontal and radial within the fracture to the tunnel and no boundaries are assumed to influence the test response. The Jacob Method (Cooper and Jacob, 1946) for flow in a confined aquifer was used to estimate inflow and the equation is shown below.

$$Q = T * 4\pi(\text{delta } H) / \ln(2.25 * T * t / r^2 * S)$$

Where:

Q = average flowrate (m^3/s and converted to L/s)

t = time (seconds)

T = transmissivity ($3.14 \times 10^{-06} \text{ m}^2/\text{s}$, from analysis of test 257.54 to 260.29 m (845.0 to 854.0 ft) in borehole 04EA-84)

S = storativity (1×10^{-04} , assumed)

r = radius (1.5 m (5 ft), assumed radius of tunnel)

delta H = drawdown (365.7 m (1200 ft) based on assumption that static head equates to ground surface)

The equation above estimates that the inflow will vary between 215.7 L/min (57 gpm) after 31 minutes of dewatering, and declines to 60.6 L (16 gpm) after 1000 days of dewatering. The lower time scale was selected based on the smallest time period the equation is considered to be valid. Todd

(1959) states this equation is valid when $u < 0.01$ which is approximately 31 minutes based on the rearrangement of the equation below:

$$u = r^2 S / 4 T t$$

Where:

t = time (since start of dewatering in seconds)

u = (0.01, lower validity of equation)

r = radius (1.5 m, assumed radius of tunnel)

T = transmissivity ($3.14 \times 10^{-06} \text{ m}^2/\text{s}$, from analysis of test 257.54 to 260.29 m (845.0 to 854.0 ft) in borehole 04EA-84)

S = storativity (1×10^{-04} , assumed)

It is important to highlight that the inflow estimates for water conductive fractures are based on two sensitive assumptions. First, one water conductive fracture is assumed per 152.4 m (500 ft) of tunnel length which is based on the frequency of interpreted water conductive fractures for six boreholes. Secondly, the magnitude of the transmissivity is based on one measurement, which is a reflection of the relative infrequency which these water conductive fractures were encountered in the boreholes, and transmissivity is typically assumed to have a log normal distribution.

Inflow Estimates from Bulk of the Unweathered Bedrock into Idealized Tunnel

In relatively early time, flow to a tunnel is expected to be transient and the expected flow regime during the transient period is vertical radial flow (see Figure 8.2). During vertical radial flow regime, the inflow is dependent on the horizontal and vertical hydraulic conductivity for the formation. The analytical software INTERPRET2, distributed by Baker Hughes, was used for the forward simulations to estimate flow to horizontal well that is analogous to a horizontal tunnel. Input parameters are shown in Table 8.3.

TABLE 8.3

**INPUT PARAMETERS FOR UNWEATHERED ZONE FORWARD SIMULATION
OF TRANSIENT PERIOD**

Input Parameter	Value	Basis
horizontal hydraulic conductivity	5×10^{-08} [cm/s]	see Table 7.2
vertical hydraulic conductivity	5×10^{-08} [cm/s]	see Table 7.2
storativity	1×10^{-04}	assumed
horizontal tunnel length	152.4 (500 ft)	input
tunnel diameter	3.0 m(10 ft)	input
viscosity	1 [cp]	assumed
boundaries	infinite in lateral extent	assumed
drawdown	365.7 m (1200 ft)	input

The simulator was used to estimate flowrates needed to obtain and maintain a drawdown of 365.7 m (1200 ft) for a tunnel length of 152.4 m (500 ft). The simulations estimate inflow rates are between 11.4 L/min (3 gpm) at 0.1 days after the start of dewatering and 2.3 L/min (< 1 gpm) at 1000 days after the start of dewatering.

In relatively late time, flow to a tunnel is expected to approach steady state conditions (Figure 8.2). The equation used to estimate inflow into a tunnel for steady state conditions is after Goodman et al. (1965) and shown below:

$$Q = K \cdot 2\pi (\Delta H) / \ln(R/r)$$

Where:

Q = average flowrate per m of tunnel (m^3/s per m of tunnel and converted to L/min)

K = hydraulic conductivity (4.64×10^{-8} cm/s, see Table 7.2)

R = distance to recharge boundary (274.3 m (900 ft), distance from tunnel to weathered zone)

r = effective tunnel radius (1.5 m (5 ft), assumed radius of tunnel)

ΔH = drawdown (365.7 m (1200 ft) based on assumption that static head equates to ground surface)

The estimated total inflow from the unweathered bedrock, with no water conductive fractures, for 152.4 m (500 ft) length of horizontal tunnel with a radius of 1.5 m (5 ft) is 2.3 L/min (<1 gpm) and shows good agreement to late time flow estimate for transient conditions.

Total Inflow Estimate into Idealized Tunnel

The total inflow estimates using analytical equations for idealized tunnel located at 365.7 m (1200 ft), assuming the tunnel intersects one water conductive fracture, is summarized in

TABLE 8.4
INFLOW ESTIMATES FROM MATRIX AND WATER CONDUCTIVE FRACTURED
WITHIN THE UNWEATHERED ZONE

Time [days]	Estimated Inflow from One Water Conductive Fracture	Flow from the Matrix of the Unweathered Bedrock		Total Estimated Inflow
		Estimated Inflow under Transient Conditions	Estimated Inflow under Steady State Conditions	
0.02 (31 min.)	215.7 L/min (57 gpm)	not computed	not computed	not computed
0.1	155.2 L/min (41 gpm)	11.4 L/min (3 gpm)	not applicable	167 L/min (44 gpm)
1	109.8 L/min (29 gpm)	3.8 L/min (1 gpm)	not applicable	114 L/min (30 gpm)
10	87.1 L/min (23 gpm)	2.6 L/min (0.7 gpm)	not applicable	90 L/min (24 gpm)
100	68.1 L/min (18 gpm)	2.3 L/min (0.6 gpm)	not applicable	70 L/min (19 gpm)
1000	60.6 L/min (16 gpm)	2.3 L/min (0.6 gpm)	not applicable	63 L/min (17 gpm)
Steady State	N/A	N/A	2.3 L/min (0.6 gpm)	N/A

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The primary objectives for the bedrock hydrogeological investigation were three fold:

- Characterize the hydraulic properties of the bedrock in the vicinity of six boreholes.
- Evaluate the degree of vertical hydraulic communication between the Quaternary aquifer and underlying bedrock groundwater system in the area of the six boreholes.
- Estimate mine inflows for an idealized portion of the mine.

To meet the objectives, the general approach was to use multiple methods for collection of static and dynamic data, each with different objectives and scales of influence. Also, the boreholes used for measurements were selected to penetrate the zones of interest and encounter a range of representative lithologies; and selected to cover a range of orientations and inclinations to evaluate possible anisotropy in the flow system. A summary of the methods, their specific objectives, and brief description of the results are summarized below.

Geophysical and flow logging were performed in six boreholes. The main objective of the logging was to identify the location and frequency of water conductive fractures (localized zones of relatively moderate to high hydraulic conductivity) that intersect the boreholes. Results of the logging are summarized as follows:

- The majority of the flow anomalies were measured in the upper approximately 90 m (300 ft) true vertical depth and are assumed to be due to flow in fractures in the weathering zone.
- Only two flow anomalies were interpreted below 90 m (300 ft) true vertical depth from evaluation of the HPFM log under pumping conditions and confirmed with either anomalies observed in other logs or hydraulic testing or both. This frequency suggests a relatively sparse distribution for water conductive fractures below 90 m (300 ft) true vertical depth.
- The water conductive fracture below 90 m (300 ft) true vertical depth interpreted in borehole 04EA-77 (north-south trending, inclination of -70) occurs over the

interval 163.80 to 169.09 m (620.0 to 640.0 ft) within a massive sulfide (low angle contacts) and semi-massive unit.

- The water conductive fracture below 90 m (300 ft) true vertical depth interpreted in borehole 04EA-84 (east-west trending, inclination of -60°) occurs over the interval 257.54 to 260.29 m (845.0 to 854.0 ft) within a massive sulfide unit. This zone was selected for hydraulic testing.

The objective of the hydraulic testing was to quantify the hydraulic properties of bedrock, evaluate the data for trends with depth, and quantify the water conductive fractures that are not related to weathering. The results of the hydraulic testing are summarized below.

- the geometric mean hydraulic conductivity for tests in the upper portion (varies between boreholes but approximately 90 m (300 ft) true vertical depth) of the four boreholes is 2×10^{-06} cm/s and relatively moderate;
- the geometric mean hydraulic conductivity for tests in the lower portion (below approximately 90 m (300 ft) true vertical depth) in three of the boreholes is 5×10^{-08} cm/s, considered representative for the matrix response; and
- one of the four boreholes, 04EA-84, contained a water conductive feature below 90 m (300 ft) true vertical depth, which is estimated to have a transmissivity of approximately 3×10^{-06} m²/s.

The degree of vertical communication between the Quaternary aquifer and the bedrock groundwater system was evaluated with both direct measurements and indirect evidence from comparison of water quality characteristics between the two systems. The results of the evaluation are summarized as follows:

- The monitoring results in Quaternary alluvium well QAL023 during the hydraulic testing indicates no direct hydraulic communication between the Quaternary aquifer and the bedrock groundwater system in the vicinity of the four boreholes used for hydraulic testing with one exception which was attributed to packer bypass (see Chapter 5 for discussion).
- The water sample collected within the bedrock between 257.54 to 260.29 m (845.0 and 854.0 ft) in boreholes 04EA-84 shows a TDS concentration that is much greater than expected for the water quality of the Quaternary aquifer (see Chapter 6 for details). This large difference in chemistry infers that locally the Quaternary aquifers and the deep bedrock groundwater systems are in poor hydraulic communication.

The water sample collected between 257.54 to 260.29 m (845.0 and 854.0 ft) in borehole 04EA-84 showed a TDS of 1590 mg/L and is classified as slightly brackish water (brackish water being defined as 1,000 - 10,000 mg/L, Freeze and Cherry, 1979). It should be noted that, although the conductivity measured during purging had started to stabilize, the readings were still increasing when the water sample was collected (see Table 6.1). The increasing trend may be due to either an increase in the ratio between insitu water and drill water with time or from the drawdown cone inducing flow from greater depths. In either case, as conductivity is related to TDS, the TDS would be expected to be greater as pumping or dewatering time is increased from a similar depth and from a similar hydraulic condition.

After completion of the field program, the data and interpretations were summarized on synthesis plots (Figures 3-1 to 3-6) along with available geological information. A conceptual model was then developed, which provided the basis for the methodology and inputs for estimation of mine inflows. It should be noted that the model is based primarily on measurements in six boreholes.

The inflow estimate is considered a preliminary indication for inflow into an idealized tunnel and is intended to provide the basis for future more comprehensive evaluations. Analytical equations were used in this study to estimate mine inflow into an idealized tunnel that is 152.4 m (500 ft) in length and 3.0 m (10 ft) in diameter for two locations. The first location was 45.7 m (150 ft) vertical depth and positioned to provide indication for inflow from the weathered bedrock. The second location was positioned at 365.7 m (1200 ft), which is the planned maximum depth of the mine, and positioned to provide inflow from the unweathered bedrock and water conductive fractures at depth.

The results of the mine flow estimates are summarized as follows:

Weathered Bedrock (15 to 90 m (50 to 300 ft) true vertical depth): The transient simulations estimate inflow rates from the weathered bedrock between 75.7 L/min (20 gpm) at 0.01 days after the start of dewatering and 18.9 L/min (5 gpm) at 1000 days after the start of dewatering. This estimate compares well with the steady state approximation of 15.1 L/min (4 gpm) which is representative for a relatively late time since the start of dewatering.

Unweathered Bedrock And Water Conductive Fractures (> 90 m (300 ft)): Inflow into the idealized tunnel is simplified to be the summation of flow from the matrix, that comprises the bulk of the rock mass, and flow from relatively sparsely distributed water conductive fractures. The idealized

tunnel was assumed to be intersected by one water conductive fracture which is consistent with the frequency of interpreted water conductive fractures for the equivalent horizontal drilled length for the boreholes used in the investigation. Inflow from the water conductive fracture is estimated to be 215.7 L/min (57 gpm) at 31 minutes after the start of dewatering and declines to 60.6 L/min (16 gpm) at 1000 days after the start of dewatering. The steady state inflow from the matrix of the unweathered bedrock, with no water conductive fractures, is estimated to be 2.3 L/min (0.6 gpm). Initial inflows from the bedrock matrix would not be significantly greater.

It is important to highlight that the inflow estimates for water conductive fractures below 90 m (300 ft) true vertical depth are based on two sensitive assumptions. First, one water conductive fracture is assumed per 152.4 m (500 ft) of tunnel length which is based on the frequency of interpreted water conductive fractures for six boreholes. Secondly, the magnitude of the transmissivity is based on one measurement, partly due to the infrequency which these water conductive fractures were encountered in the boreholes, and transmissivity is typically assumed to have a log normal distribution.

9.2 Recommendations

The recommended work flow for the project is summarized below:

- Update the conceptual flow model as additional geotechnical data and analyses become available.
- Develop numerical flow model based on conceptual flow model;
- Incorporate mine schedule into the numerical model and estimate mine inflows;
- Perform sensitivity simulations to assess uncertainty;
- If required, perform additional field program to constrain hydraulic parameters;
and
- Update numerical model and update estimates for mine inflow.

The additional field program, if required, would likely involve water sampling at depth, longer duration tests with monitoring zones to evaluate large scale properties and connectivity of the flow system. The water sampling could be performed in existing holes with a Moyno Pump system, which has proven successful in obtaining representative water samples from packer isolated intervals from

depths greater than 500 m (2000 ft) in NQ size holes. As numerous exploration boreholes have been drilled to date with an extensive data base of information that includes dynamic data for six of the boreholes, the recommended approach is to perform the additional field program in existing boreholes to the extent that is practical. The only exception would be if the additional geotechnical studies would suggest that the fractures intensity measured in the existing boreholes are not representative for the bulk of the rock mass due to the bias from the borehole inclination or azimuth.

Long term monitoring is also recommended to allow for updating of flow models and to have a direct measurement for the degree of hydraulic communication between the alluvium and bedrock groundwater systems. It is recommended that the monitoring network be installed in advance of mining to provide background data. The monitoring network system should be adapted to the specific dynamics of the project but preliminary recommendations are as follows:

- Permanent pressure gauges are recommended to be installed within the bedrock with up to three gauges per borehole that allow for monitoring of pore pressure prior to and during mining. The gauges must be hydraulically isolated from each other. All gauges should be synchronized to a common clock time. A total of up to two to three boreholes are recommended for permanent pressure gauge installation that are proximal to but outside the planned mine openings. One method, referred to as “piezometers in fully grouted boreholes” (Mikkelsen and Green, 2003), is a cost effective installation technique.
- Long-term monitoring is recommended with continuous recording pressure gauges installed in Quaternary monitoring wells prior to and during mining. All pressure gauges should be synchronized to a common clock time. Slug tests should be performed in the monitoring wells so if communication is observed between the Quaternary aquifer and the groundwater bedrock system, the flowrate required for the observed drawdown can be computed.

10.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

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FIGURES

APPENDIX A

WIRELINE PACKER TEST PROCEDURES FOR THE EAGLE PROJECT

MEMORANDUM

1000, 940 - 6 Ave. S.W.
Calgary, Alberta, Canada
T2P 3T1



Golder Associates Ltd.
Telephone No.: 403-299-5600
Fax No.: 403-299-5606

DATE: 20 September 04 P04-2154
TO: Mike Lemon and Marc Rougier
FROM: John Wozniewicz
RE: Wireline Packer Test Procedures for the Eagle Project Site, Version 1

INTRODUCTION

The aim of the wireline testing is to perform well controlled tests to allow for accurate derivation of transmissivity and static water level. Also, selected intervals will be chosen for water sampling.

PROJECT CONTROLS

The pertinent forms used for documentation are listed below:

- Logbook: document the pertinent details during testing; and
- Summary Sheet: document top and bottom of the interval, test type, etc.

Example forms will be forwarded. All pertinent information and problems should be noted on the logbook. These forms will be completed in electronic format while the testing is running and therefore a laptop computer will be required. Also, all electronic files will be emailed to jwozniewicz@golder.com and mrougier@golder.com on a daily basis to allow for feedback as the testing progresses. Set-up a directory system for electronic files – borehole name and test name and alluvium well.

The files will be labelled with borehole number after the description of the form type and engineer. For data files, the test interval should also be included in the file name. For example, the logbook would be designated as Logbook_BH3_Lemon.xls. The electronic files should be backed-up on a portable memory stick on a daily basis.

In addition, two excel files will be forwarded that should be used to compute packer inflation pressure and maximum surface pressure during injection tests so that the formation fracture pressure is not reached.



CLOCK TIME

It will be important to use a consistent clock time for programming gauges and documenting site activities. The best approach is use the clock time from a common laptop that is planned to be used for programming gauges to document all site activities.

DEPTH MEASUREMENTS

All depth measurements, both above and below the ground, need to be referenced to ground level and measured along the hole.

MONITORING IN ALLUVIUM WELL

The water level in the new alluvium well will be monitored with a 30 psi Minitroll gauge. The transducer shall be installed prior to the start of testing and retrieved from the borehole after testing is completed. Ideally, the transducer would be installed at least one day prior to the start of testing, and removed one day after testing was completed.

The procedure for installation, monitoring and removal of the Minitroll gauge is as follows:

- Program gauge to record pressure in kPa and time in elapsed hours (under preferences in the main menu);
- Synchronize the clock in the gauge to the common laptop time that will be used to document all site activities;
- Program the gauge to record every one minute (55 days of memory at this acquisition rate);
- Start the logging and download file to ensure gauge is recording;
- Measure water level in the alluvium well;
- Lower gauge 5 m below the water level;
- Tape the electrical line to the casing so gauge will not move;
- Download data to hard drive of computer every day and place all files in directory for alluvium well, name the file wellname_datefiledownloaded.xls (note – you do not have to restart a new file – just download the file);
- Just before retrieving the gauge, perform slug injection or slug withdrawal test.

Measure the water level from the top of the casing and measure the distance between the top of the casing and the ground surface.

In addition, one gauge with a low pressure range (10 psi or less) shall be placed at the wellhead to monitor for barometric pressure changes on an hourly basis. Again, the data logger needs to be synchronized to the common laptop.

TESTING IN EXISTING BOREHOLES

PACKER LOCATION

The wireline packer testing planned in two existing holes, following flow logging, will be performed as follows:

- (Test 1) A single packer is set just below the top of the bedrock;
- (Test 2) A single packer is moved down to test the lower 2/3 of the open hole section;
- (Test 3) A single packer is moved down to test the lower 1/3 of the open hole section; and
- (Optional – Test 4 and Test 5) A double packer (about 10 feet of spacer pipe) is used to isolate relatively high permeability zones identified in the flow logging.

The target packer depths in Test 2 and Test 3 may be moved down to exclude a significant water producing zone within 20 m of the target packer depth. However, the packer depths should not be moved down if greater than 20 m below the target test depth.

Test Interval Depth and Packer Inflation

The test interval will be a set distance below the bit for each test which should be measured as the distance from the base of the bit stop to the bottom of the packer element. Prior to each test, the NQ core rods and bit would need to be lowered to the set distance above the packer interval. Remember to reference all measurements to ground surface, measured along the hole.

The packer inflation pressure will be the sum of the following components:

- hydrostatic pressure: the **vertical** depth to the top of the packer divided by 2.31 to obtain psi;
- stretch pressure: the pressure that is needed to stretch the element to the borehole wall which is about 75 psi; and
- differential pressure: assume to be approximately 100 psi.

The maximum inflation pressure should be approximately 500 psi. A 500 psi gauge should be placed between the regulator on the nitrogen bottle and packer to provide higher resolution to control the packer inflation. Packer specifications are provided in attachment A.

Test Procedure

The test procedure for each test in the existing holes will be as follows:

1. Inflate packer and measure water level inside the NQ core rods;
2. Program Minitroll and lower to 30 feet below water level;
3. After 30 minutes, measure water level again and document;
4. lower Waterra tubing 25 feet below ground surface;
5. Connect Waterra tubing to nitrogen bottle and using 50 psi, (the tubing is rated to 90 psi) and displace fluid from the HQ casing;
6. Monitor recovery for 30 minutes;
7. Remove tubing and Minitroll (down load file to hard drive of the computer; the file name should be borehole number_top depth_bottom depth.xls)
8. Place rubbers in stuffing box and connect flow control equipment;
9. Start injection at a low rate and slowly increase rate until target pressure is reached;
10. Maximum surface pressure for all tests will be 50 psi or fracture pressure, whichever is lower;
11. Once pressure is proximal to target pressure, inject at 60 minutes and document surface pressure readings and injection rate on 5 minute increments (Note: longer duration tests are recommended for overnight; provide driller crew instructions on test documentation and control – i.e, measure rate and pressure on regular basis and turn pump off if maximum pressure is reached); and
12. Deflate packers and move packers to the next interval.

The static water level measurements prior to the start of the test will be measured from the top of the NQ casing and distance is needed from the top of the NQ casing to the surface, along hole. Also, document the distance the pressure gauge is above ground and again, along the hole.

The Waterra tubing will need to be taped to casing at surface so that the air pressure does not force the tubing out of the NQ core rods. Also, the tubing can be weighted-down to prevent from being ejected from the borehole.

TESTING IN NEW BOREHOLES

PACKER LOCATION

The coring will be interrupted every 50 m for wireline packer testing or upon encountering loss circulation zones for water sampling. The water sampling will be discussed in the next section. After coring 50 m, the procedure will be as follows:

- Interrupt the coring every 50 m;
- Remove 50 m of core rods;
- Perform testing;
- Remove wireline packer tools; and

- Resume coring and repeat the process.

Test Procedure

The majority tests are expected to be relatively low transmissivity due to relatively short interval. The procedure is the same as in the existing coreholes described above except if the recovery is incomplete within 5 minutes after air-lifting, there is no need to perform an injection test.

WATER SAMPLING

If loss circulation conditions are encountered, the following procedure will be followed:

- Interrupt the drilling immediately (Golder responsibility to inform the driller);
- Raise core rods 5 m;
- Lower wireline packers; and
- Produce fluid from interval with pump or air-lifting methods

The target is to collect one sample relatively shallow and one sample relatively deep between the two coreholes.

The minimum fluid that needs to be produced prior to sample collection is a volume that is 3 times the volume of the interval plus the volume of the NQ core rods, and after the field parameters stabilizes. If air-lifting method is used to produce fluid from the interval, two samples need to be collected. One sample needs to be collected at the surface and a second sample needs to be collected with a bailer. Alternatively, the sample could also be collected with a submersible pump. The submersible pumps should not be installed more than 50 feet below the water level.

During production, the rate should be measured on a regular basis. Also, the Minitroll can be attached to the discharge tubing just above the pump if the submersible pump is used.

An injection test should be performed after the sample is collected, as described in the sections above.

Suppliers

Contact number for suppliers are listed below.

- **Baski** (303-789-1200): fittings, inflation line
- **In-Situ Inc.** (1-800-446-7488): Minitroll
- **Wattera** (314-952-6860): tubing and 12V submersible pump
- **Far West** (800-438-3808): wireline packers and equipment
- **RST** (1-800-665-5599): wireline packers and equipment

If there is a need to re-order equipment in the field, contact Rick Booth to discuss or contact Mike Dobr or Darren Kennard in Golder Vancouver.

APPENDIX B

TEST DATA AND ANALYSIS PLOTS

BOREHOLE 04EA-47

Figure 04EA-47_1A: 46.0 to 880.0 ft; Slug Test

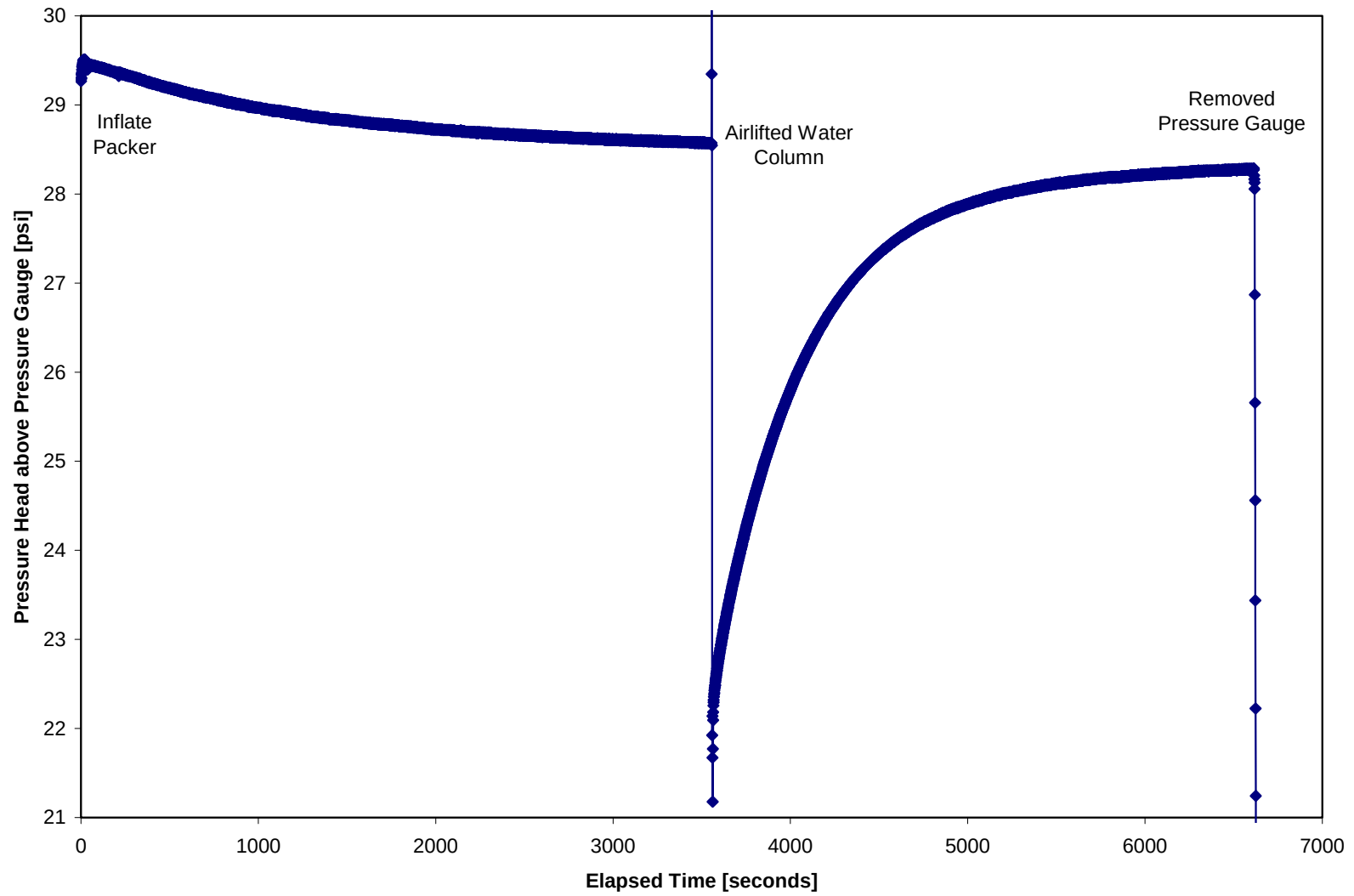


Figure 04EA-47_1B: 46.0 to 880.0 ft; Slug Test; Match on Log Log Deconvolution Plot

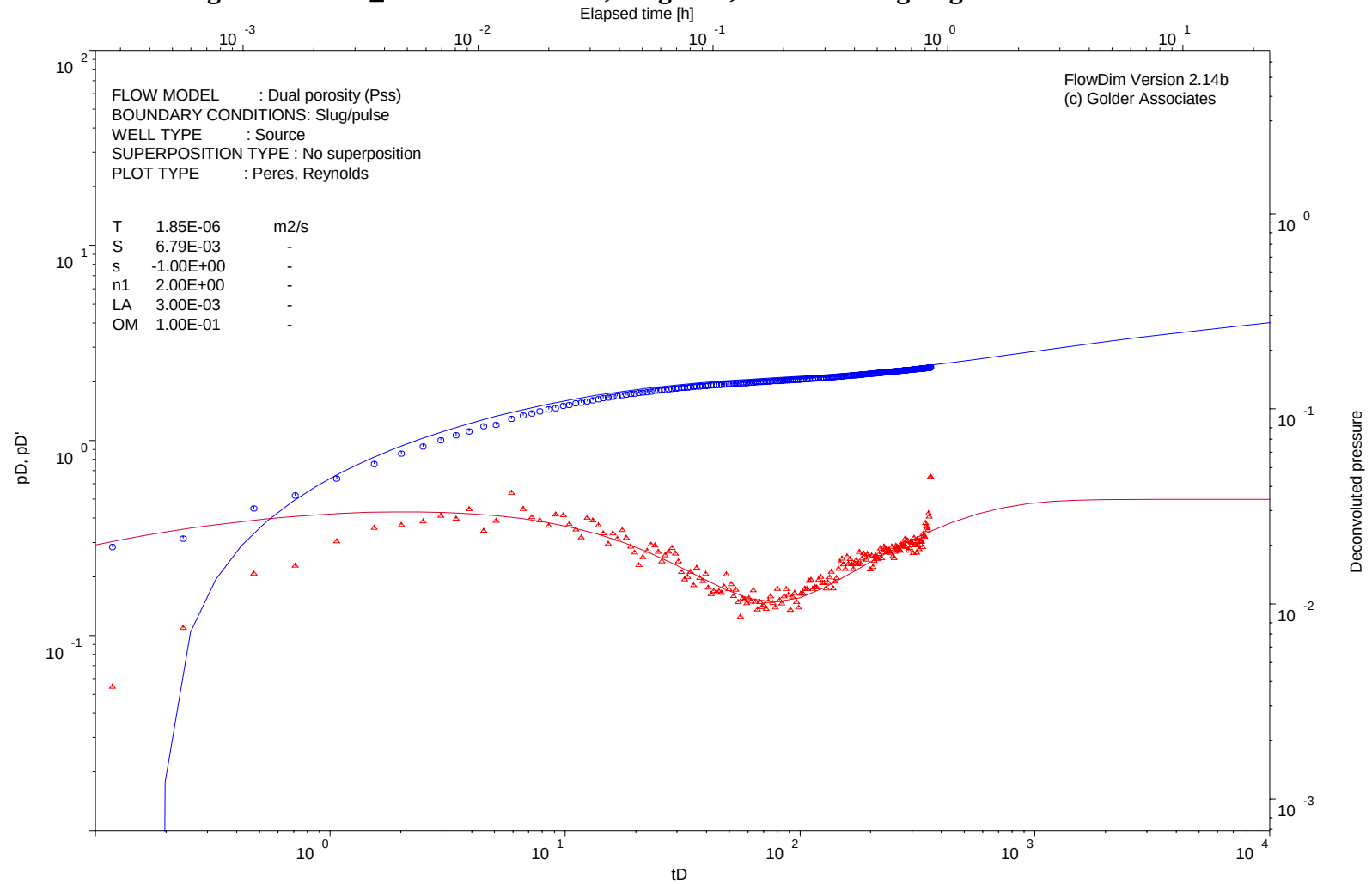


Figure 04EA-47_2A: 331.0 to 880.0 ft; Slug Test

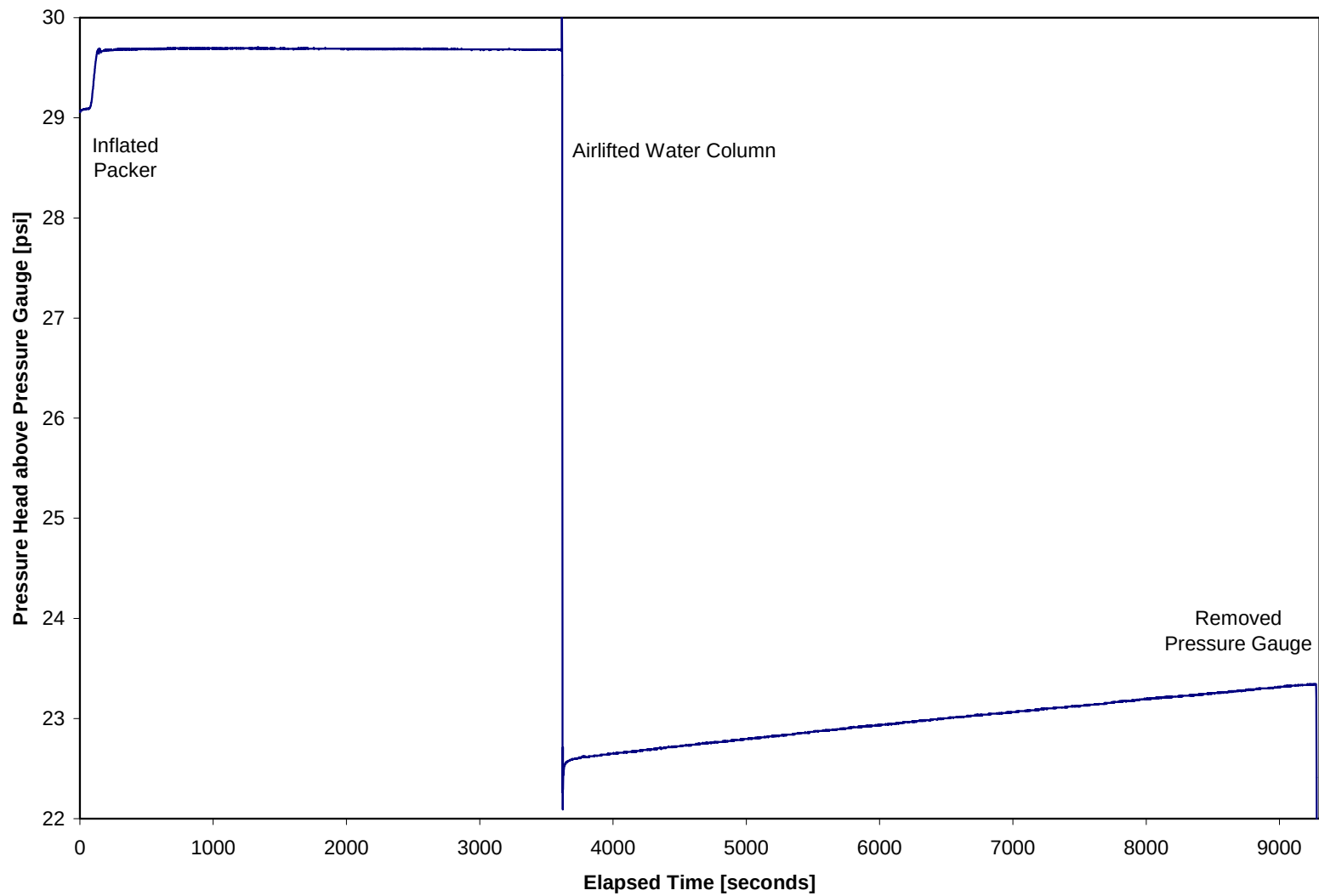


Figure 04EA-47_2B: 331.0 to 880.0 ft; Slug Test; Match on Log Log Deconvolution Plot

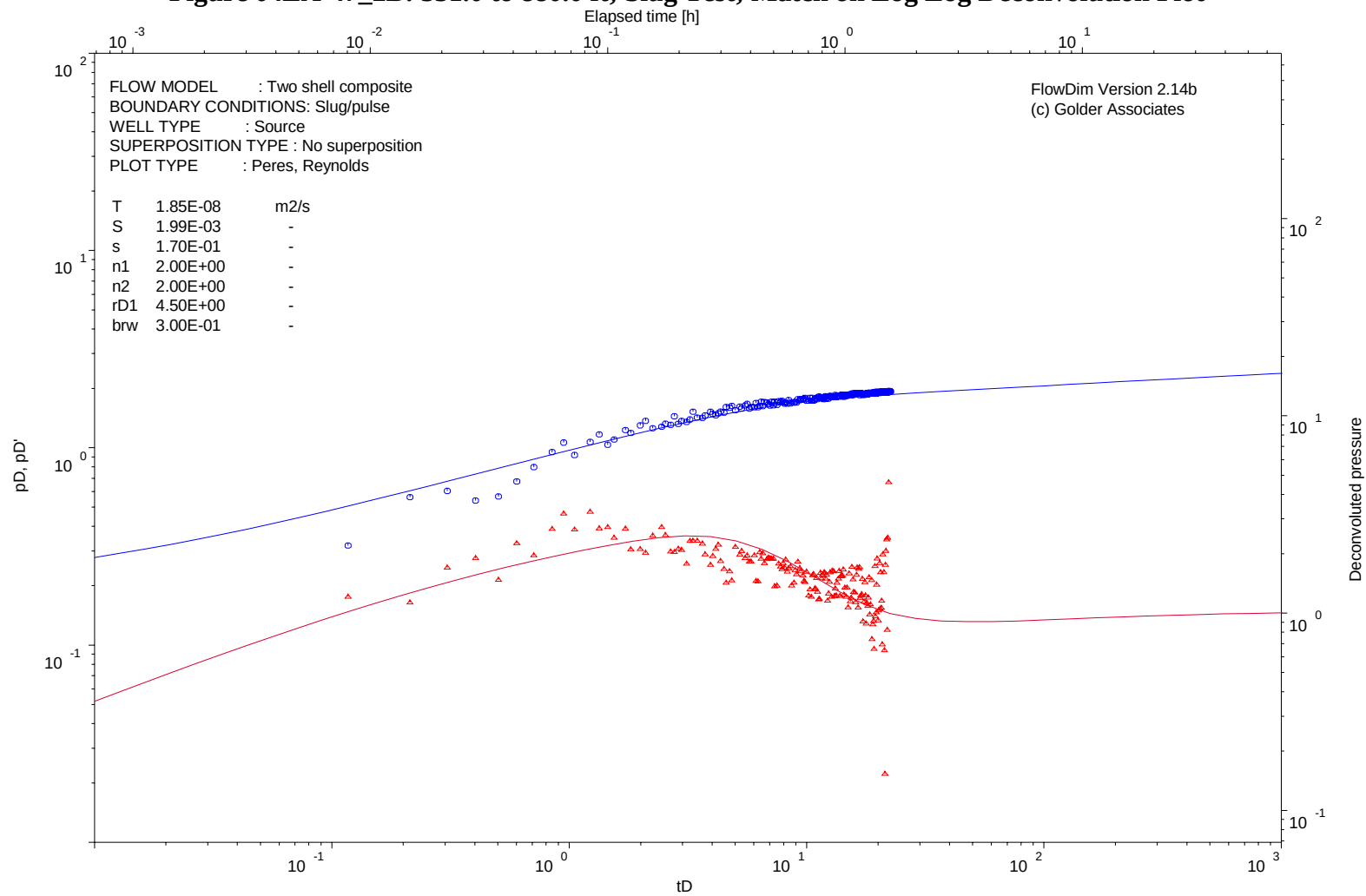


Figure 04EA-47_3A: 661.0 to 880.0 ft; Slug Test

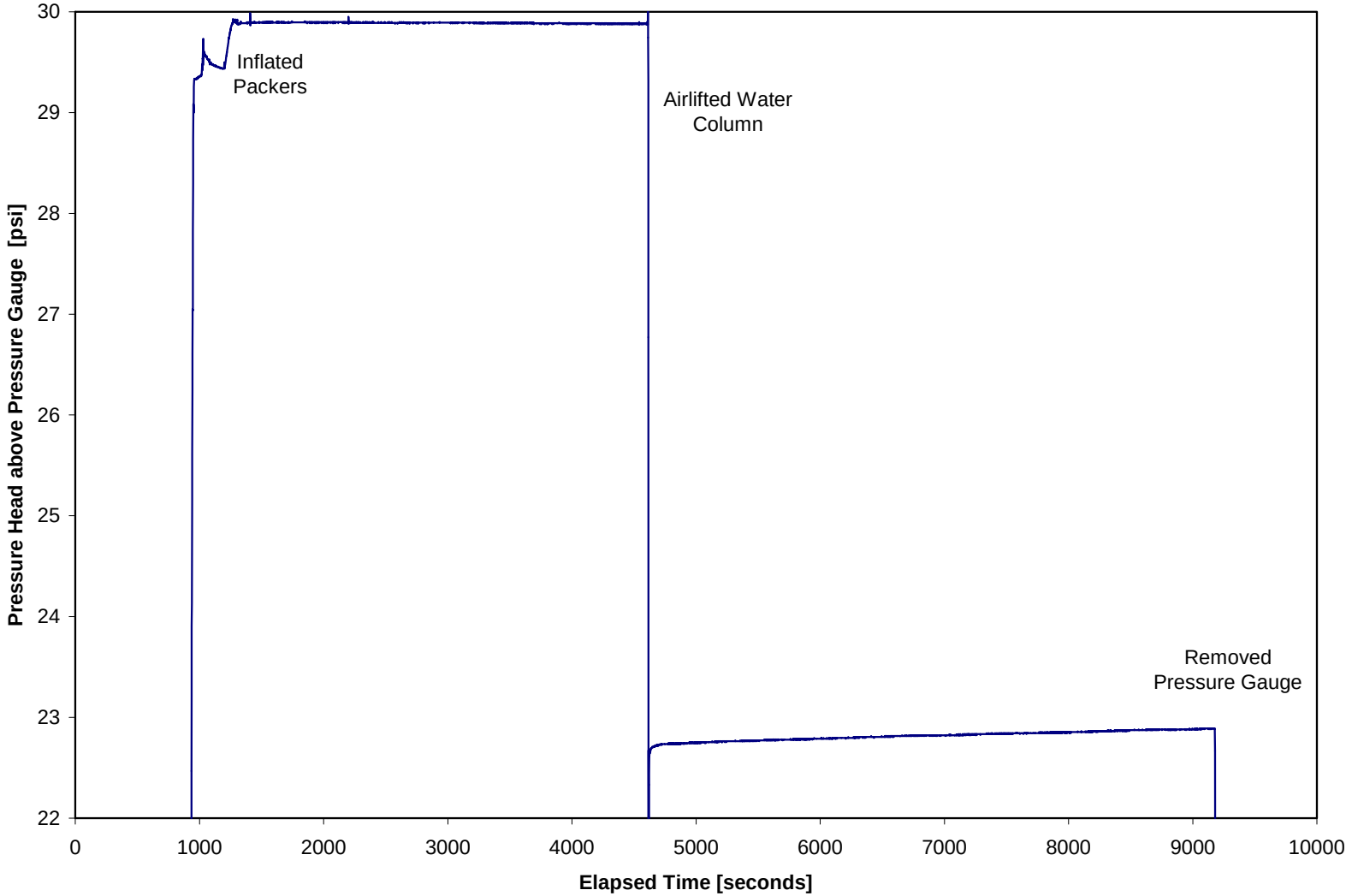
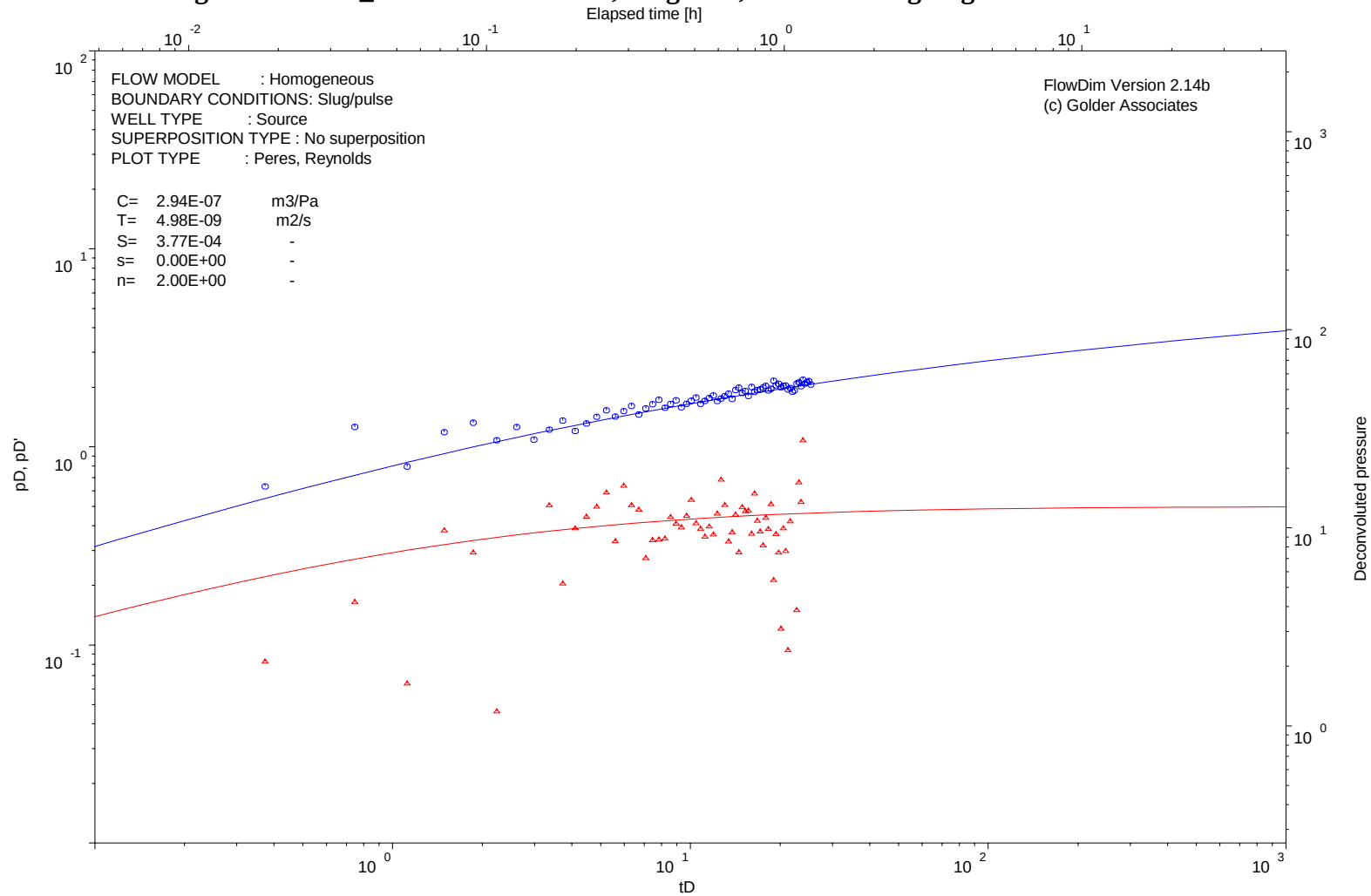


Figure 04EA-47_3B: 661.0 to 880.0 ft; Slug Test; Match on Log Log Deconvolution Plot



BOREHOLE 04EA-73

Figure 04EA-73_1A: 56.0 to 874.0 ft; Slug Test

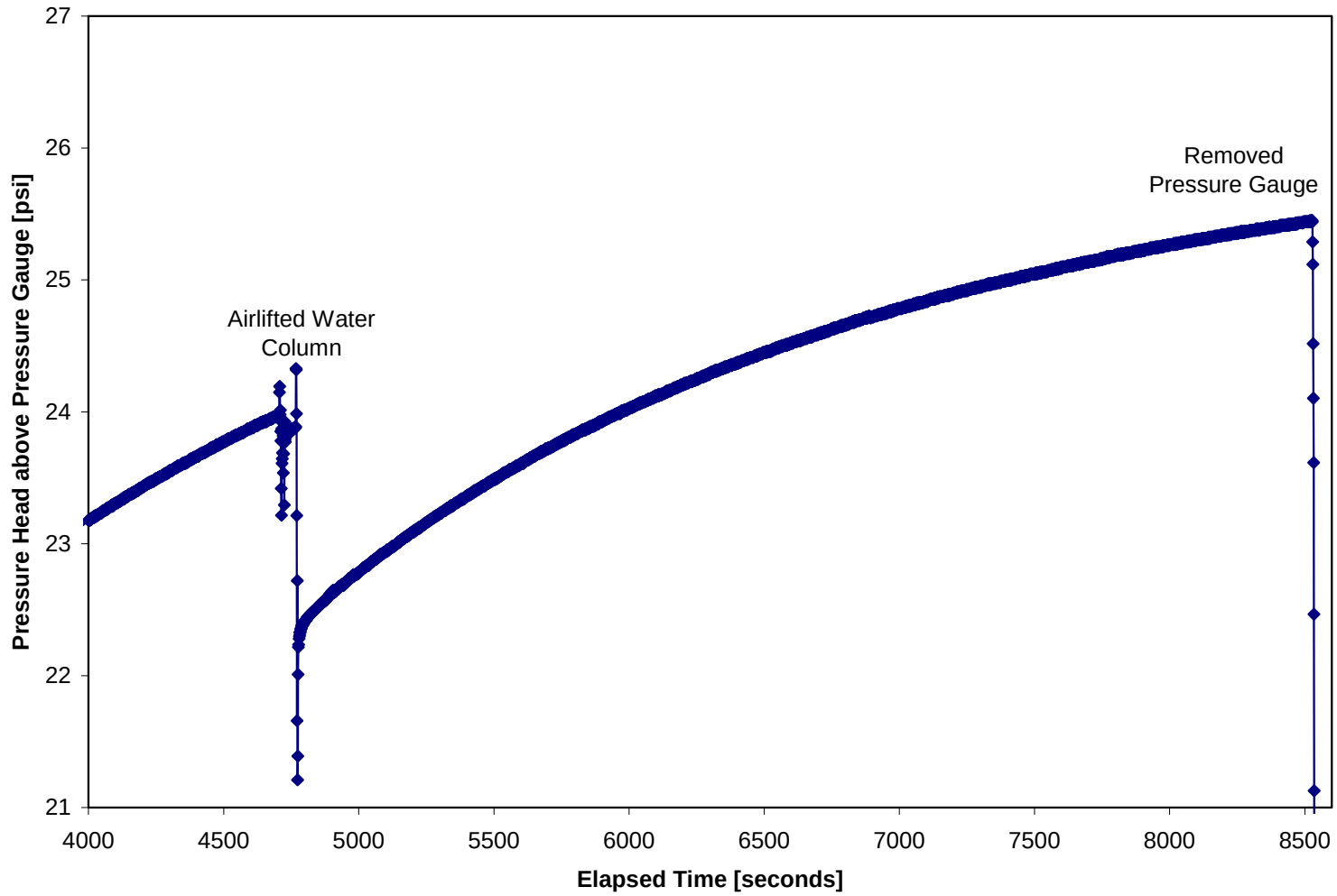


Figure 04EA-73_1B: 56.0 to 874.0 ft; Slug Test; Match on Log Log Deconvolution Plot

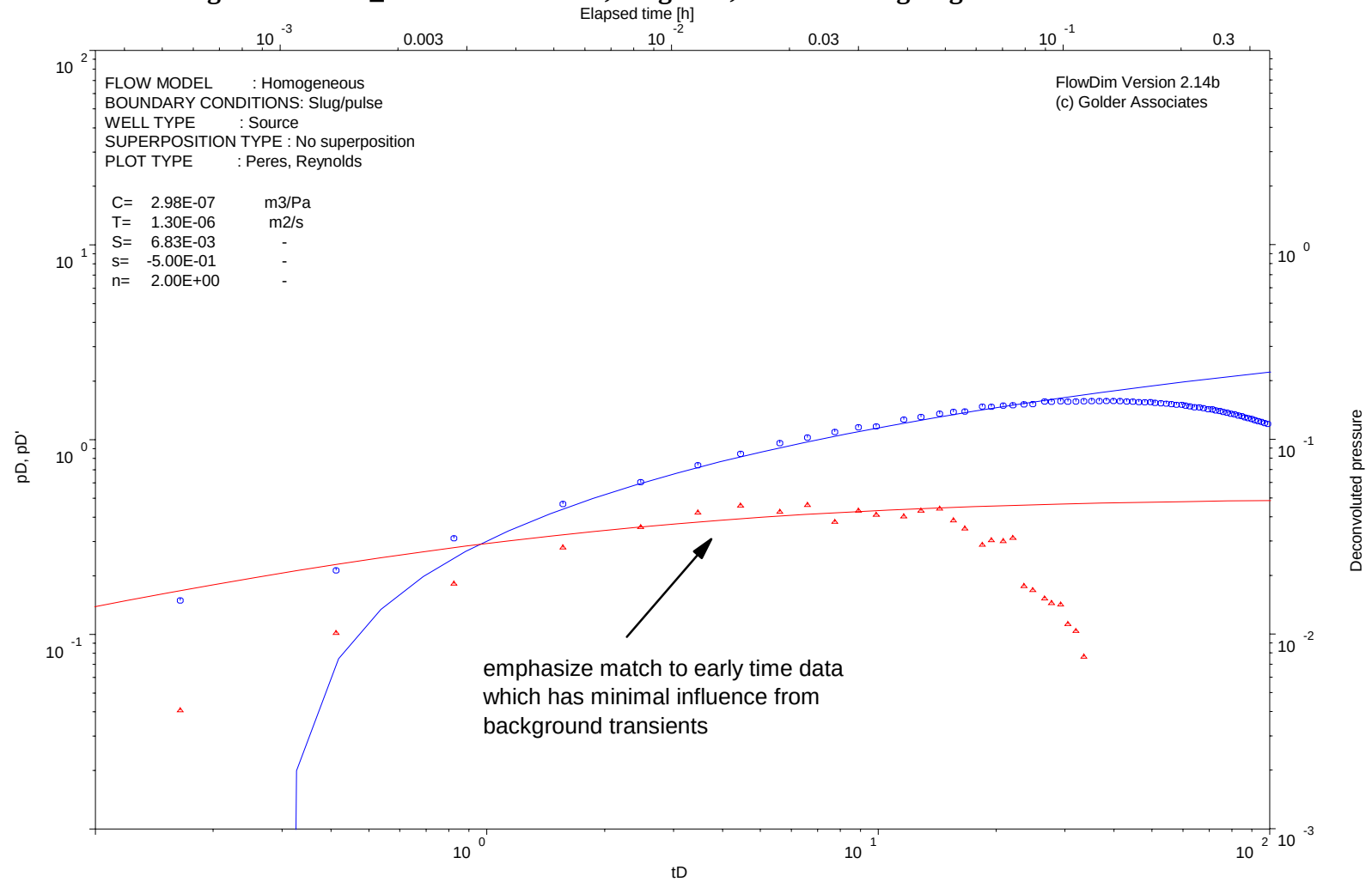


Figure 04EA-73_2A: 261.0 to 874.0 ft; Slug Test

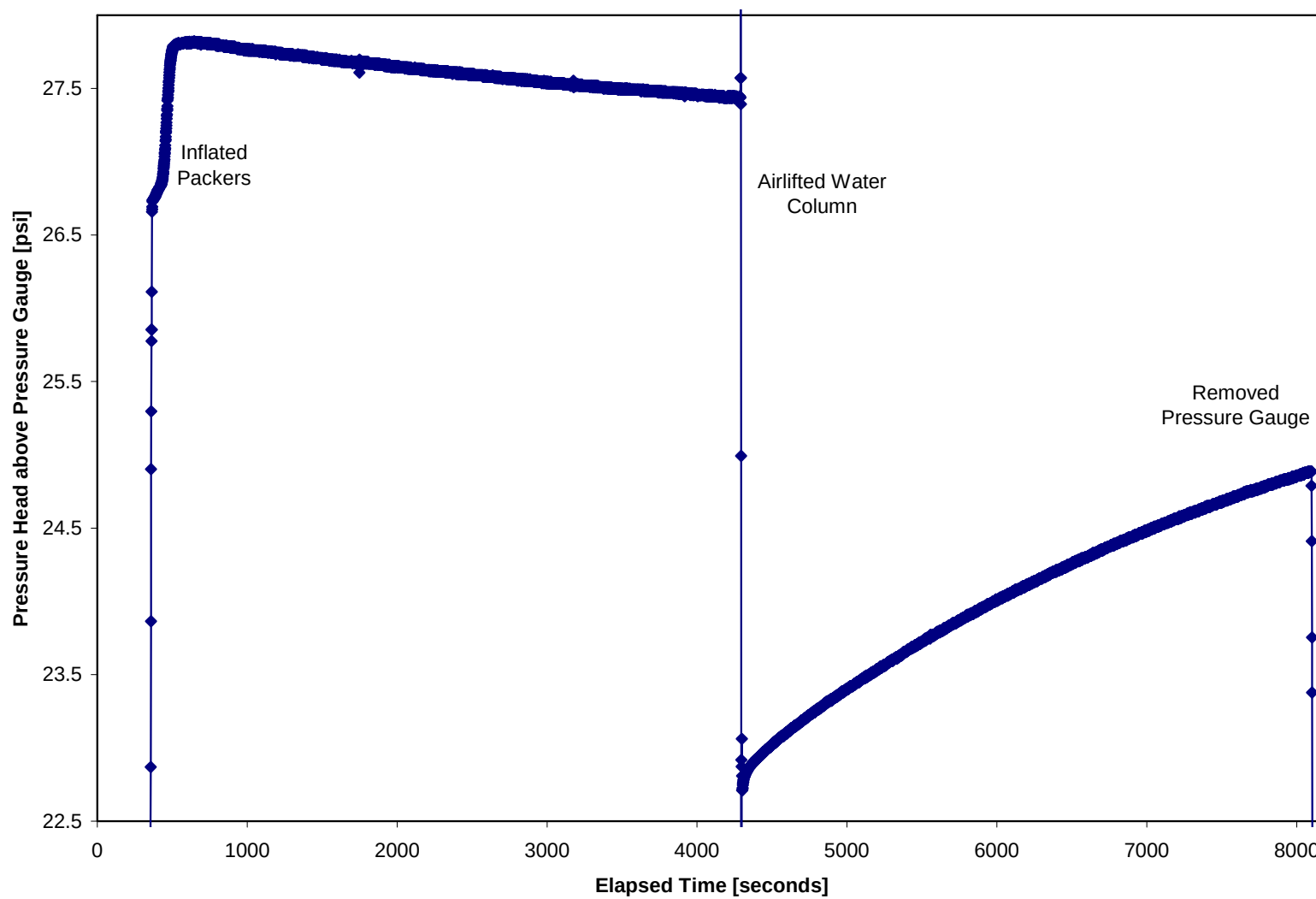


Figure 04EA-73_2B: 261.0 to 874.0 ft; Slug Test; Match on Log Log Deconvolution Plot

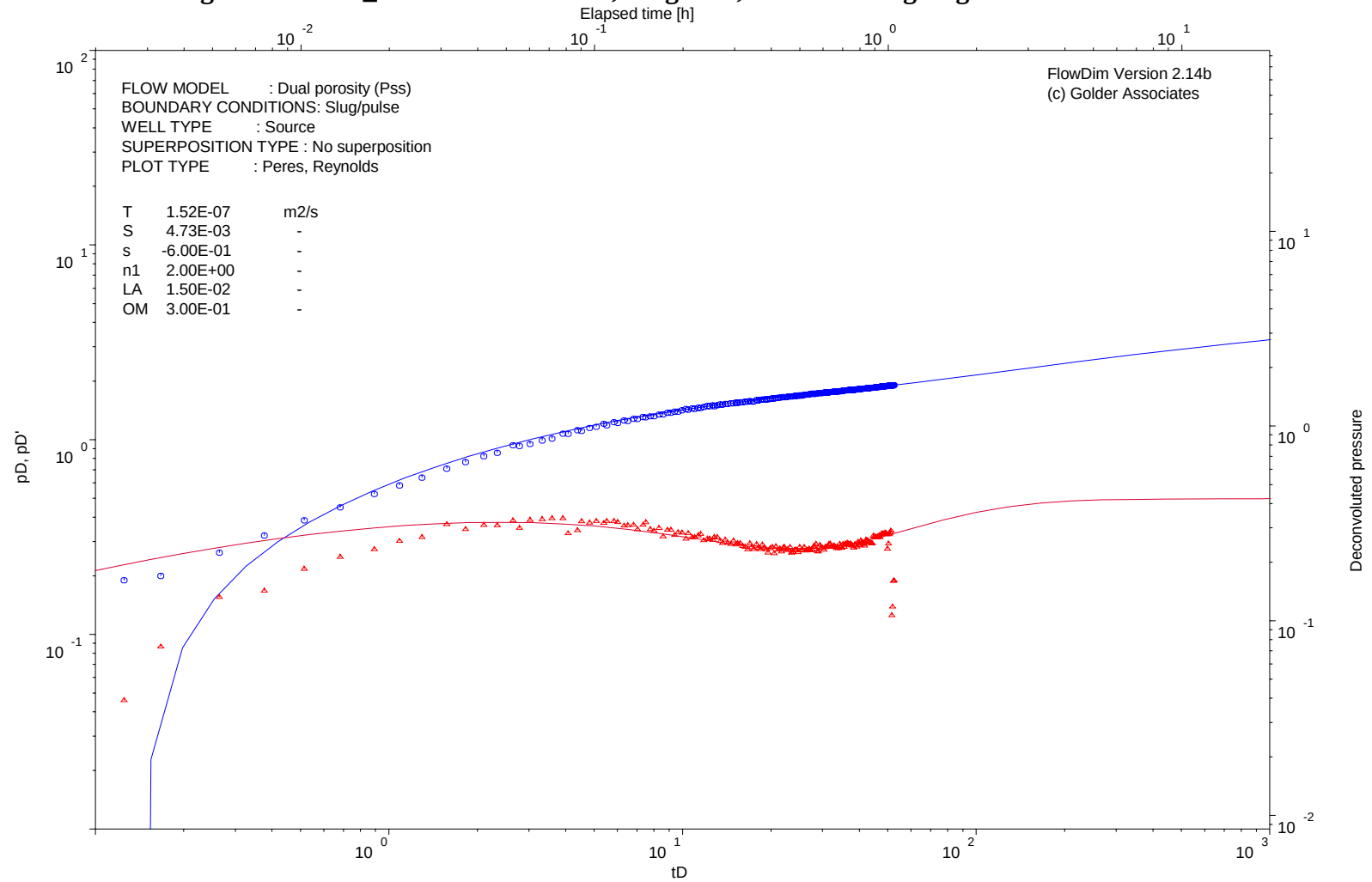


Figure 04EA-73_3A: 491.0 to 874.0 ft; Slug Test

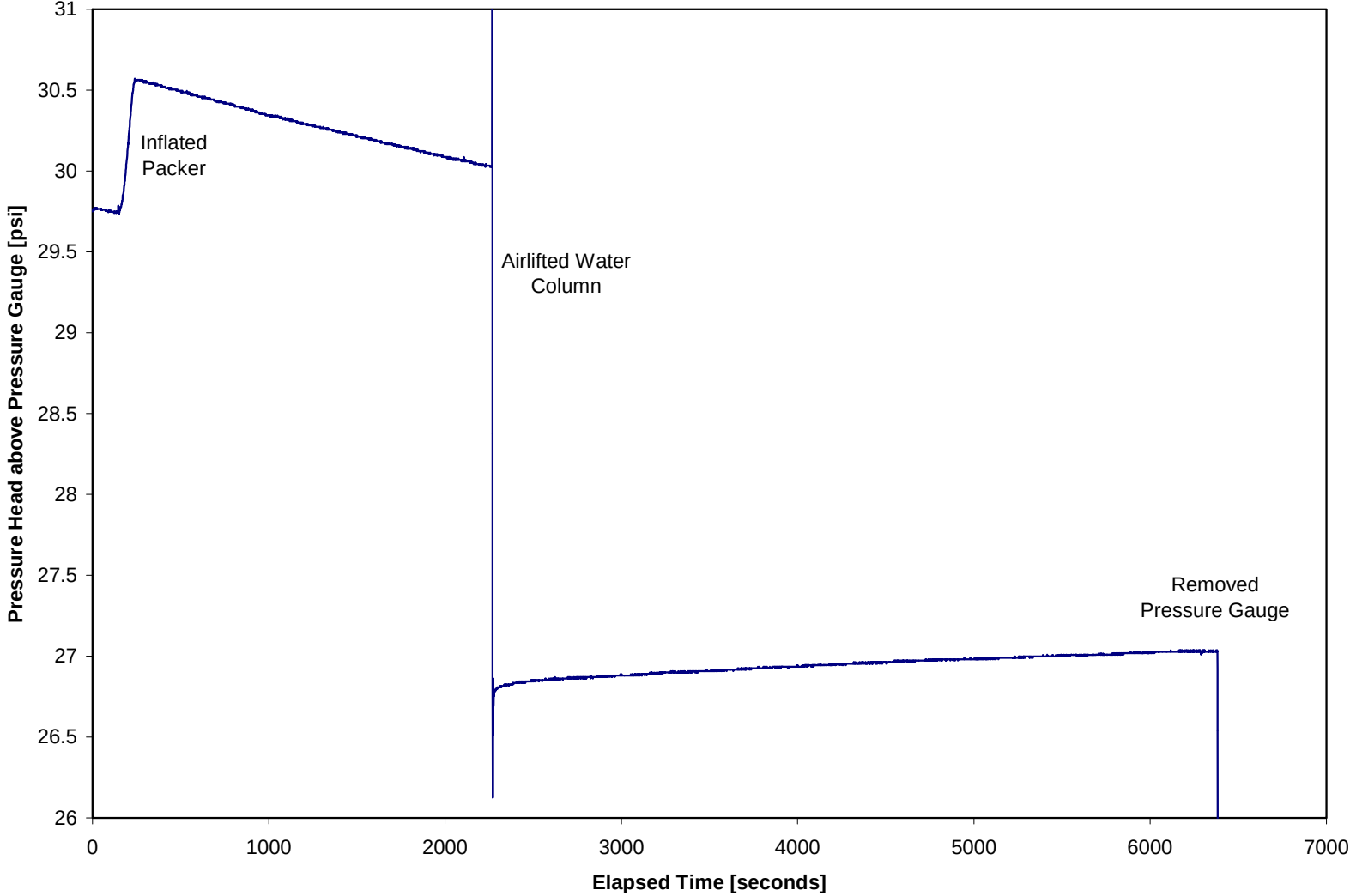
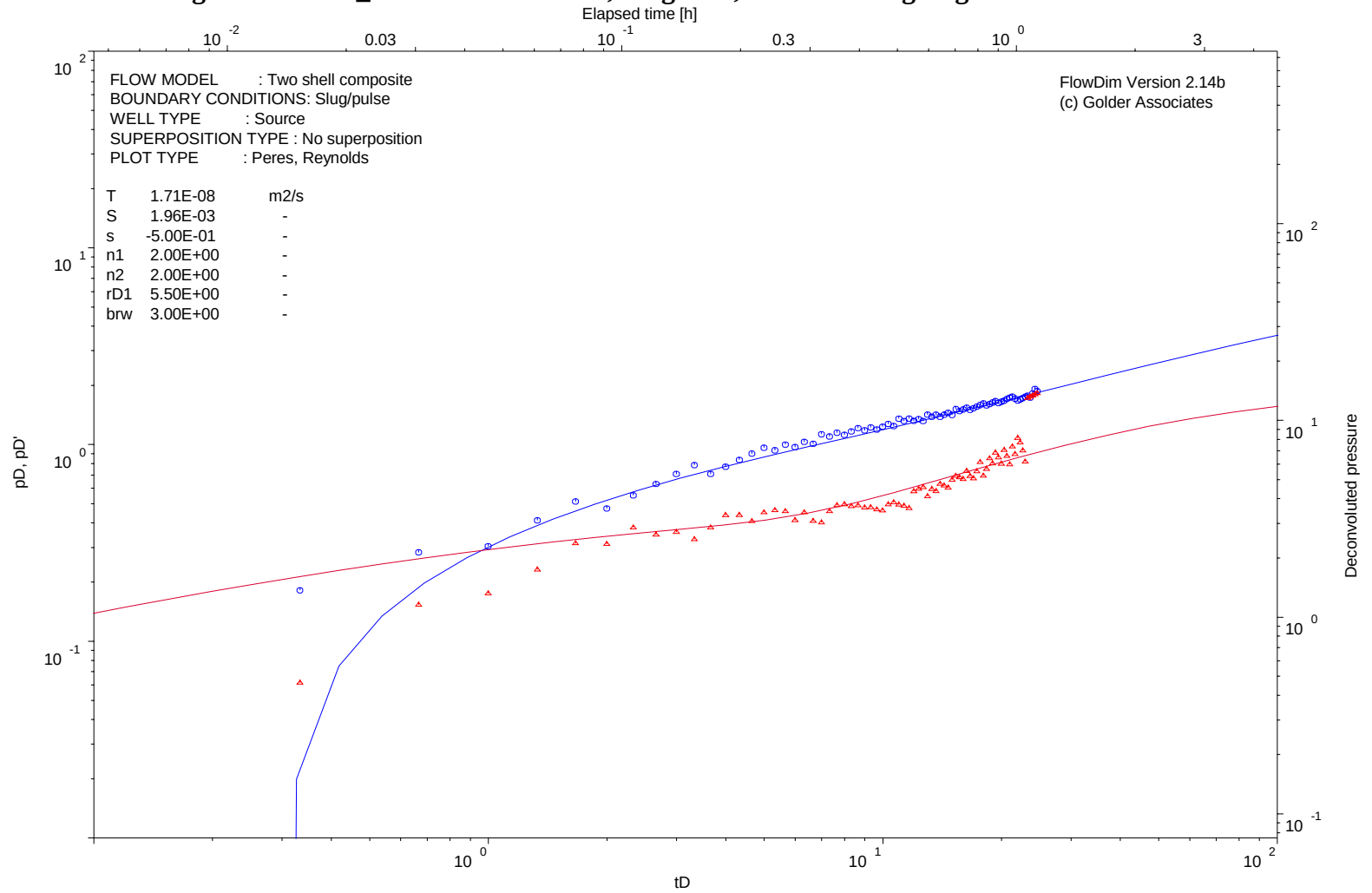


Figure 04EA-73_3B: 491.0 to 874.0 ft; Slug Test; Match on Log Log Deconvolution Plot



BOREHOLE 04EA-83

Figure 04EA-83_1A: 51.0 to 787.0 ft; Slug Test

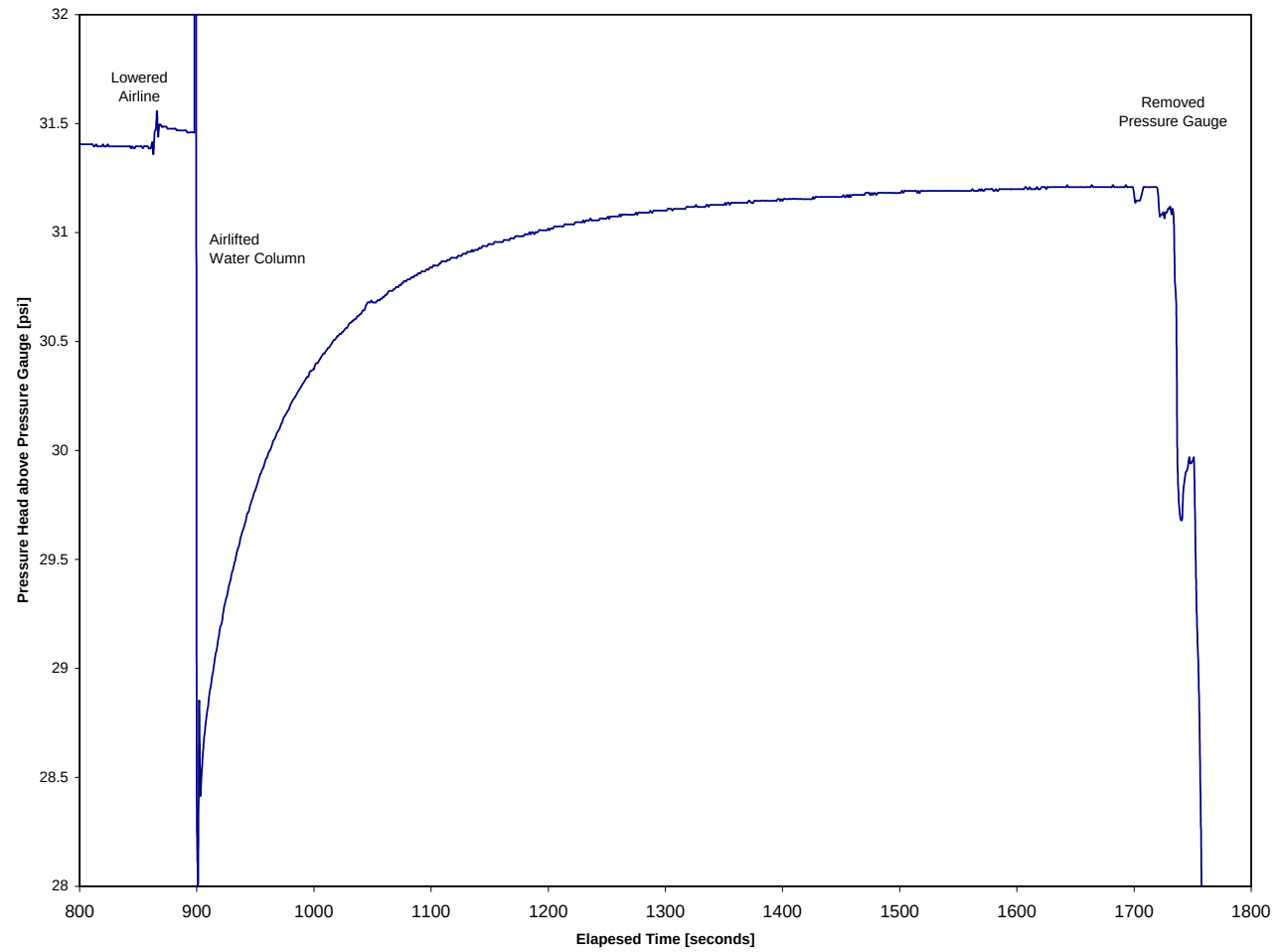


Figure 04EA-83_1B: 51.0 to 787.0 ft; Slug Test; Match on Log Log Deconvolution Plot

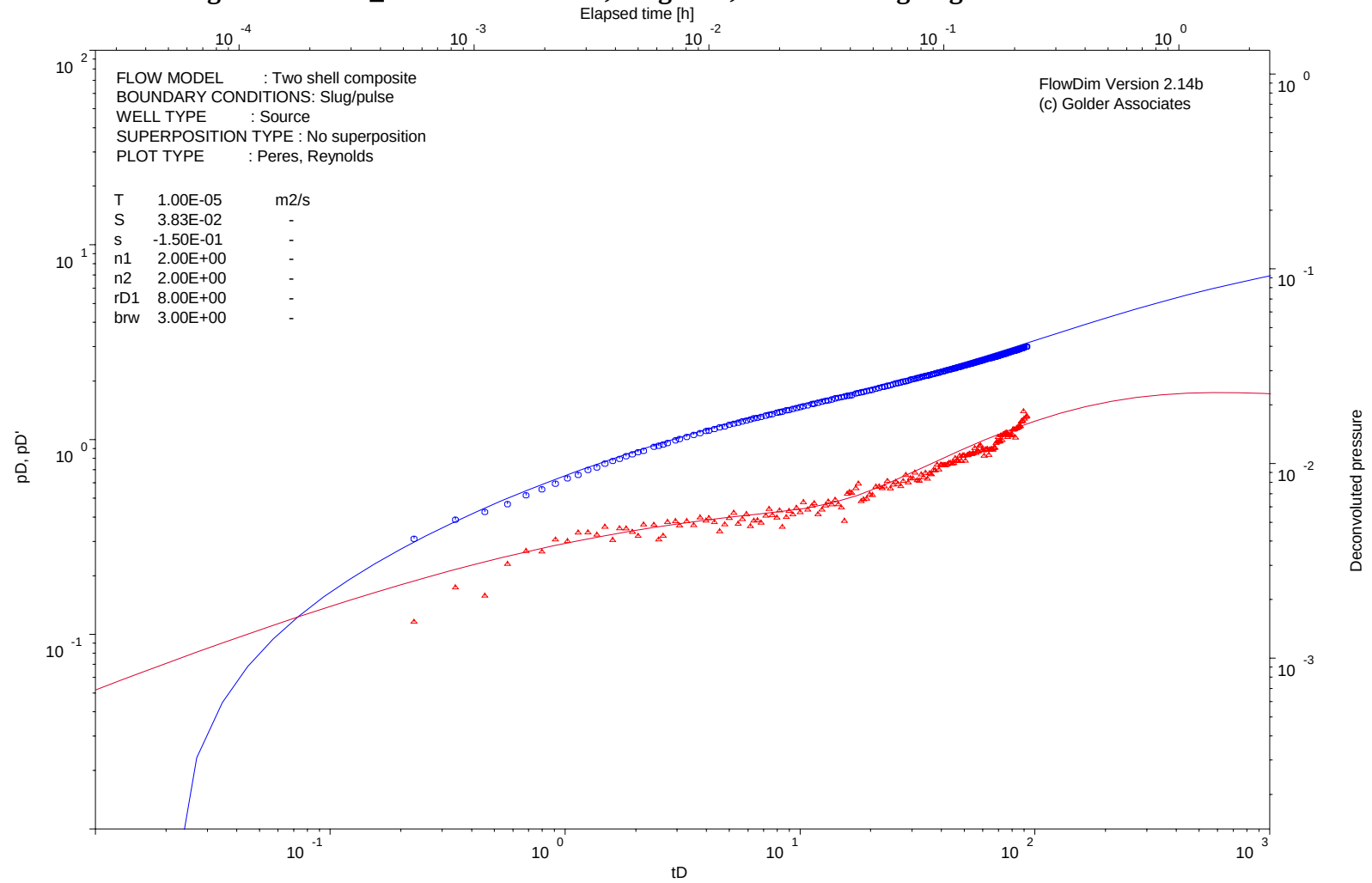


Figure 04EA-83_2A: 261.0 to 787.0 ft; Slug Test

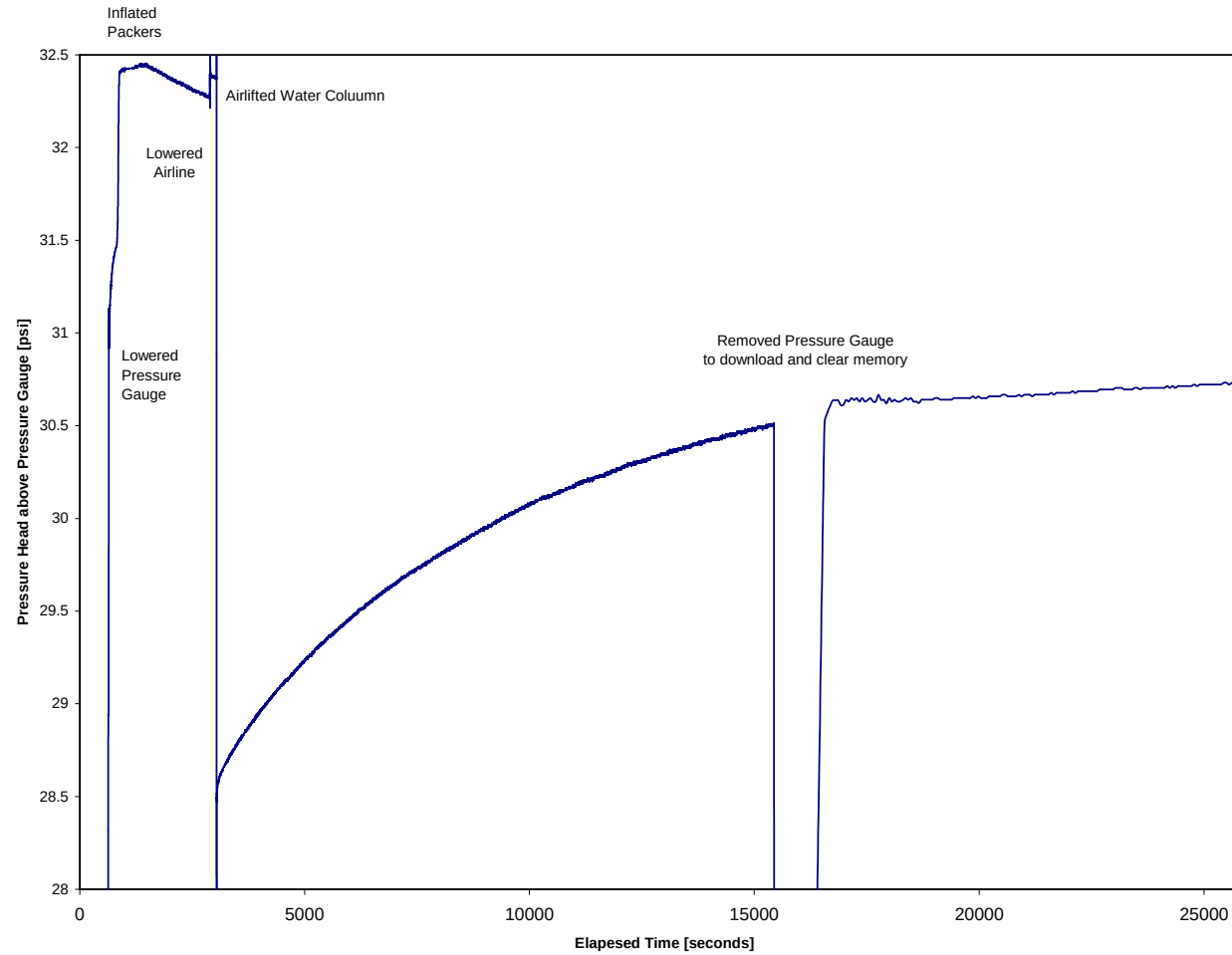


Figure 04EA-83_2B: 261.0 to 787.0 ft; Slug Test; Match on Log Log Deconvolution Plot

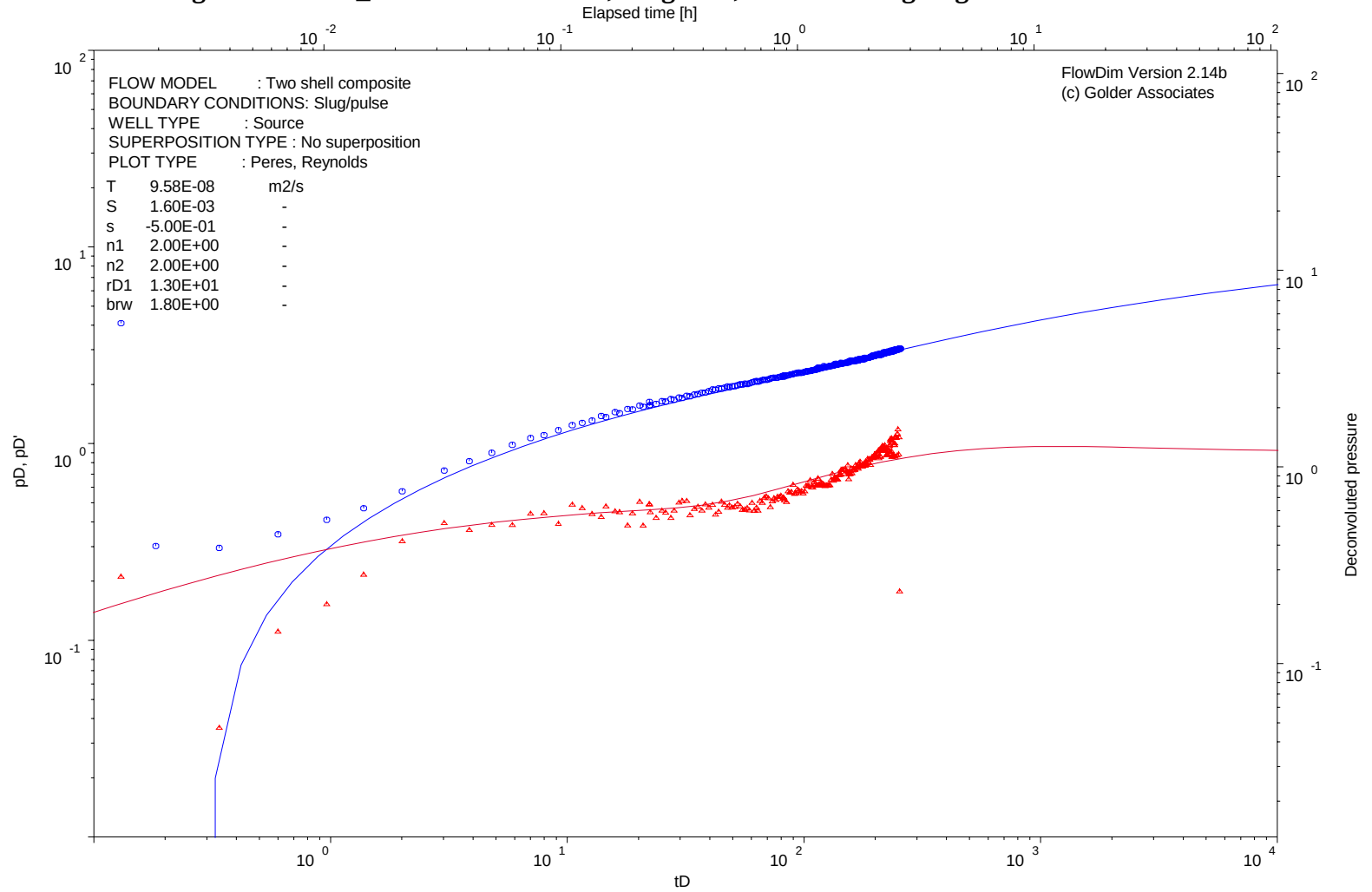


Figure 04EA-83_3A: 541.0 to 787.0 ft; Slug Test

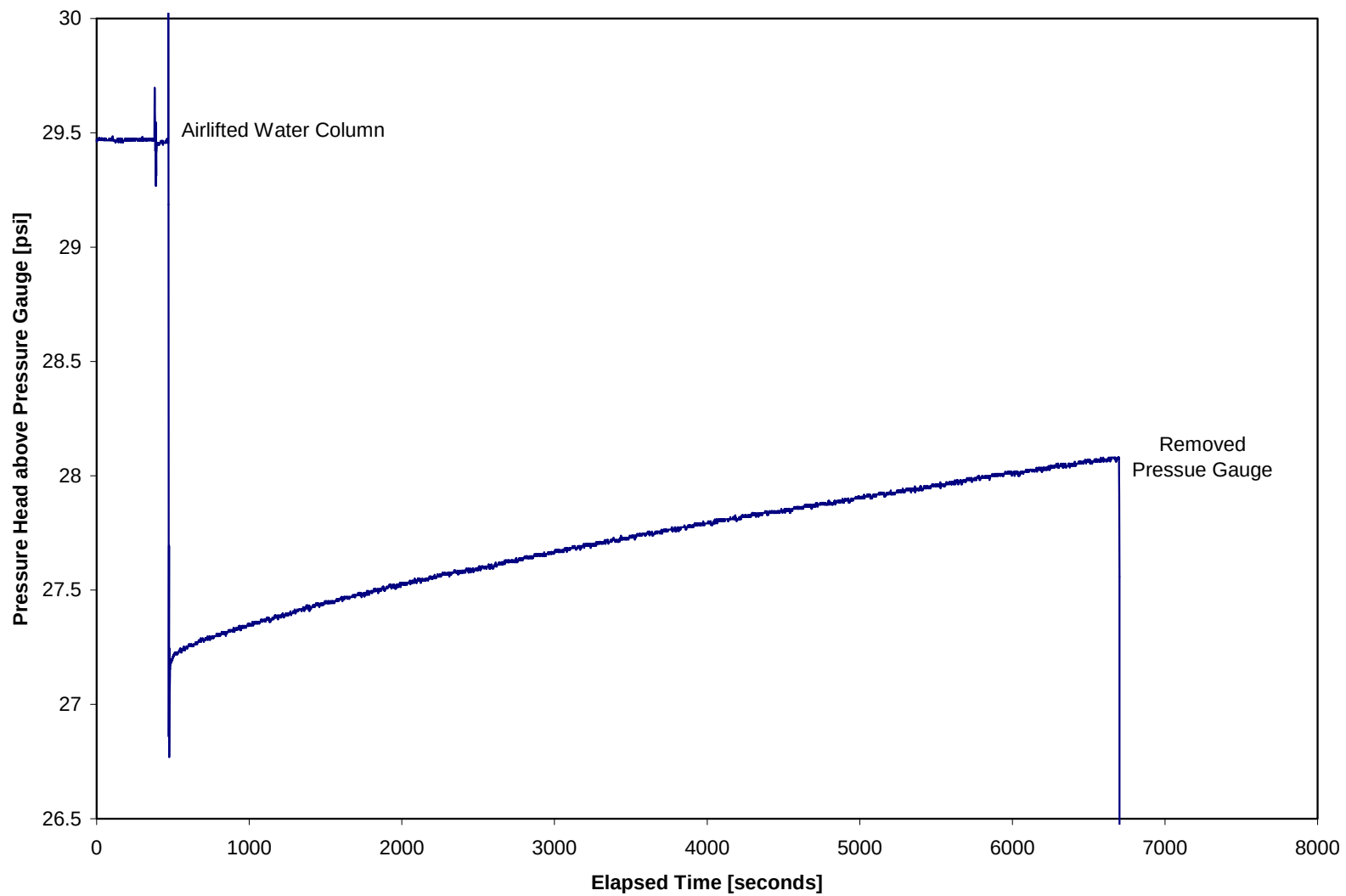


Figure 04EA-83_3B: 541.0 to 787.0 ft; Slug Test; Match on Log Log Deconvolution Plot

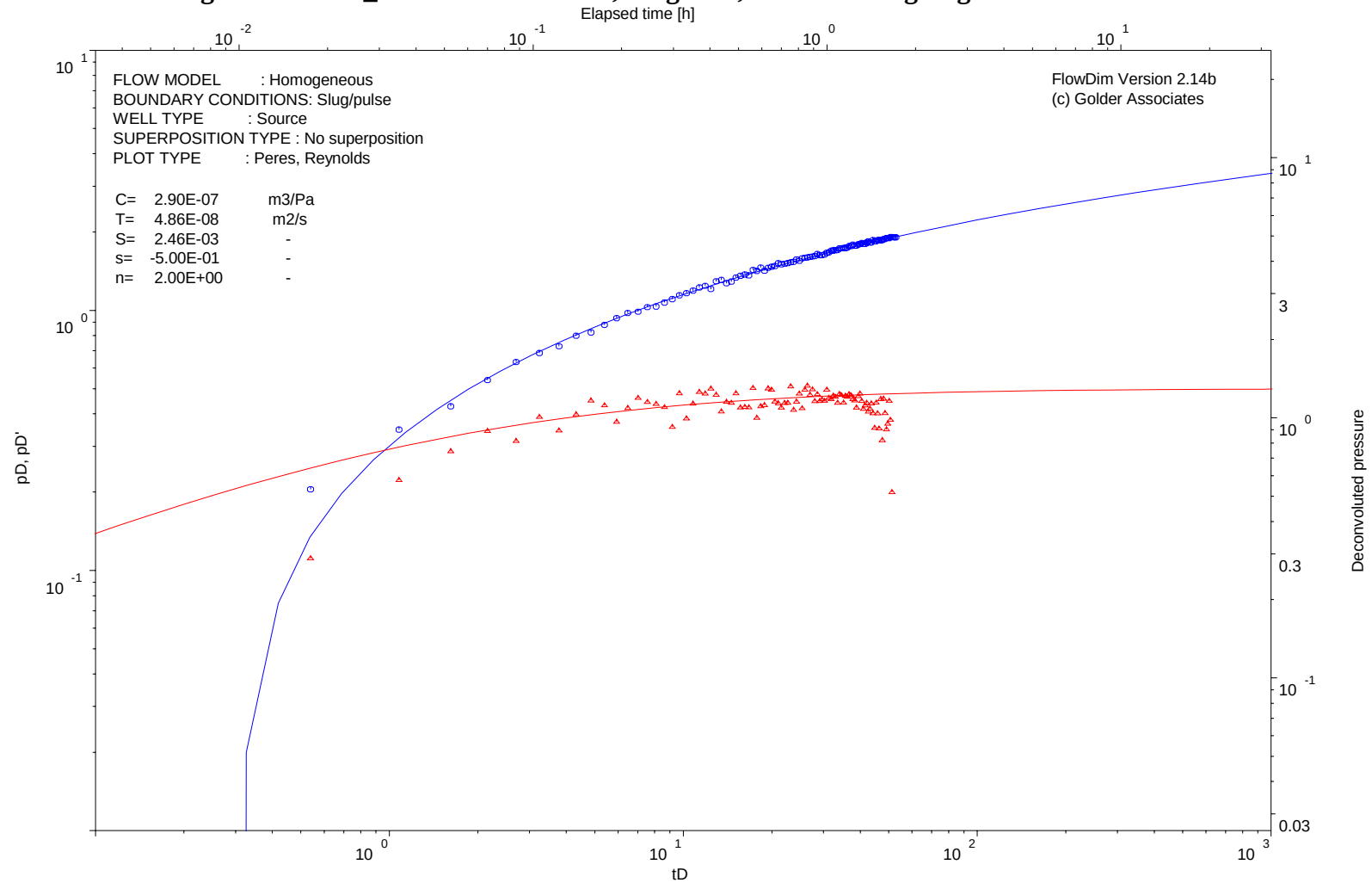


Figure 04EA-83_4A: 136.0 to 145.0 ft; Slug Test

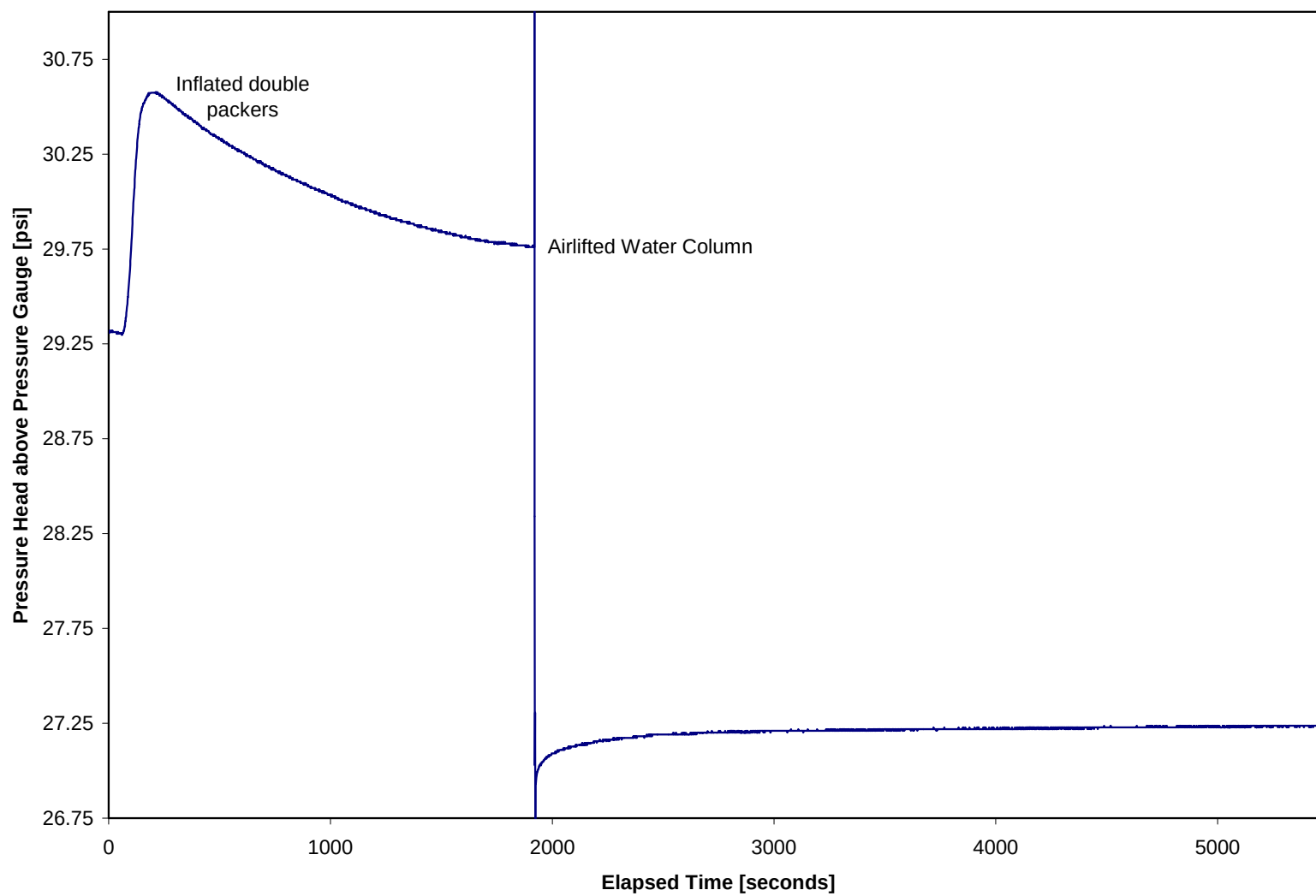
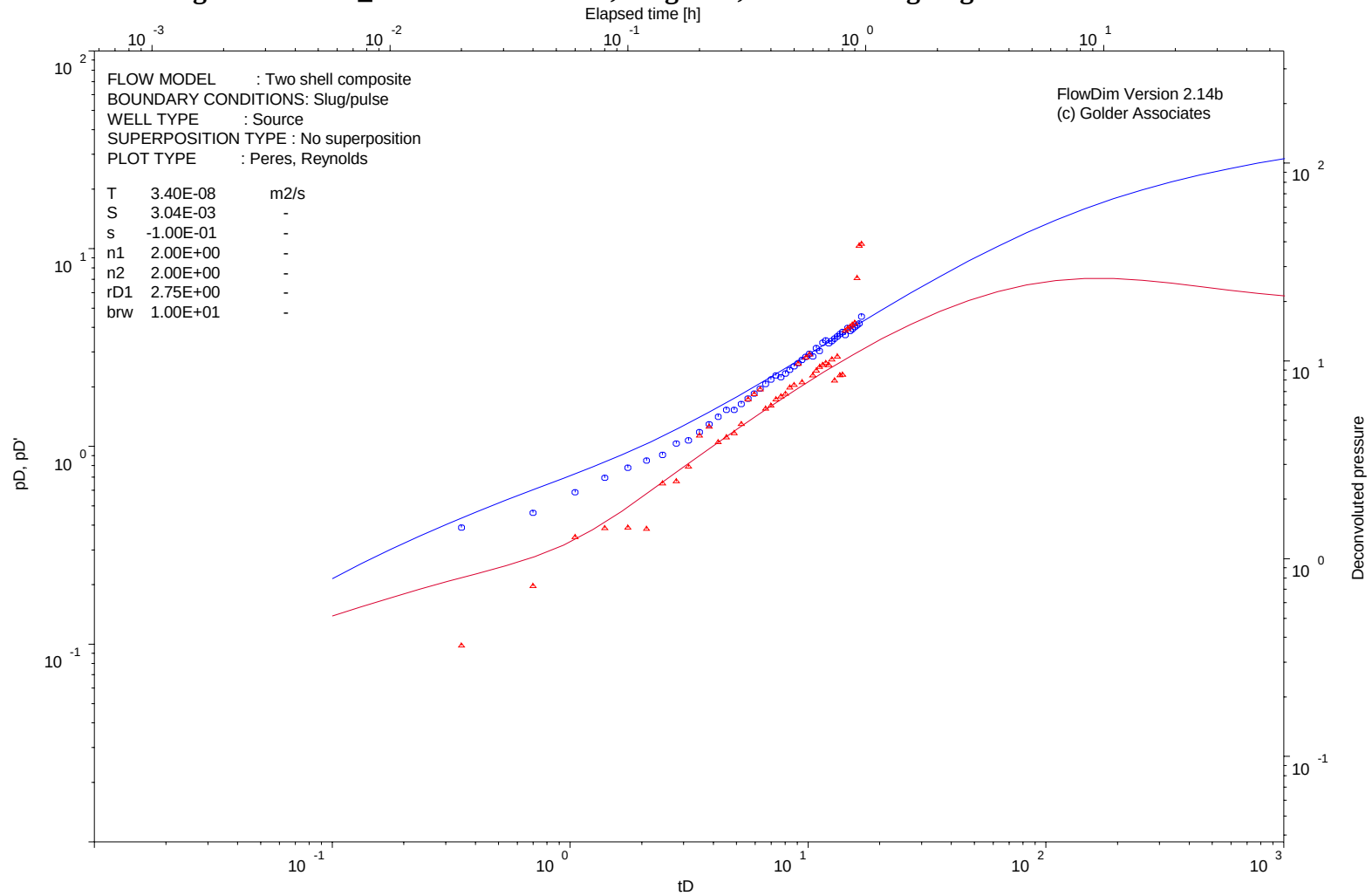


Figure 04EA-83_4B: 136.0 to 145.0 ft; Slug Test; Match on Log Log Deconvolution Plot



BOREHOLE 04EA-84

Figure 04EA-84_1A: 50.0 to 991.0 ft; Slug Test

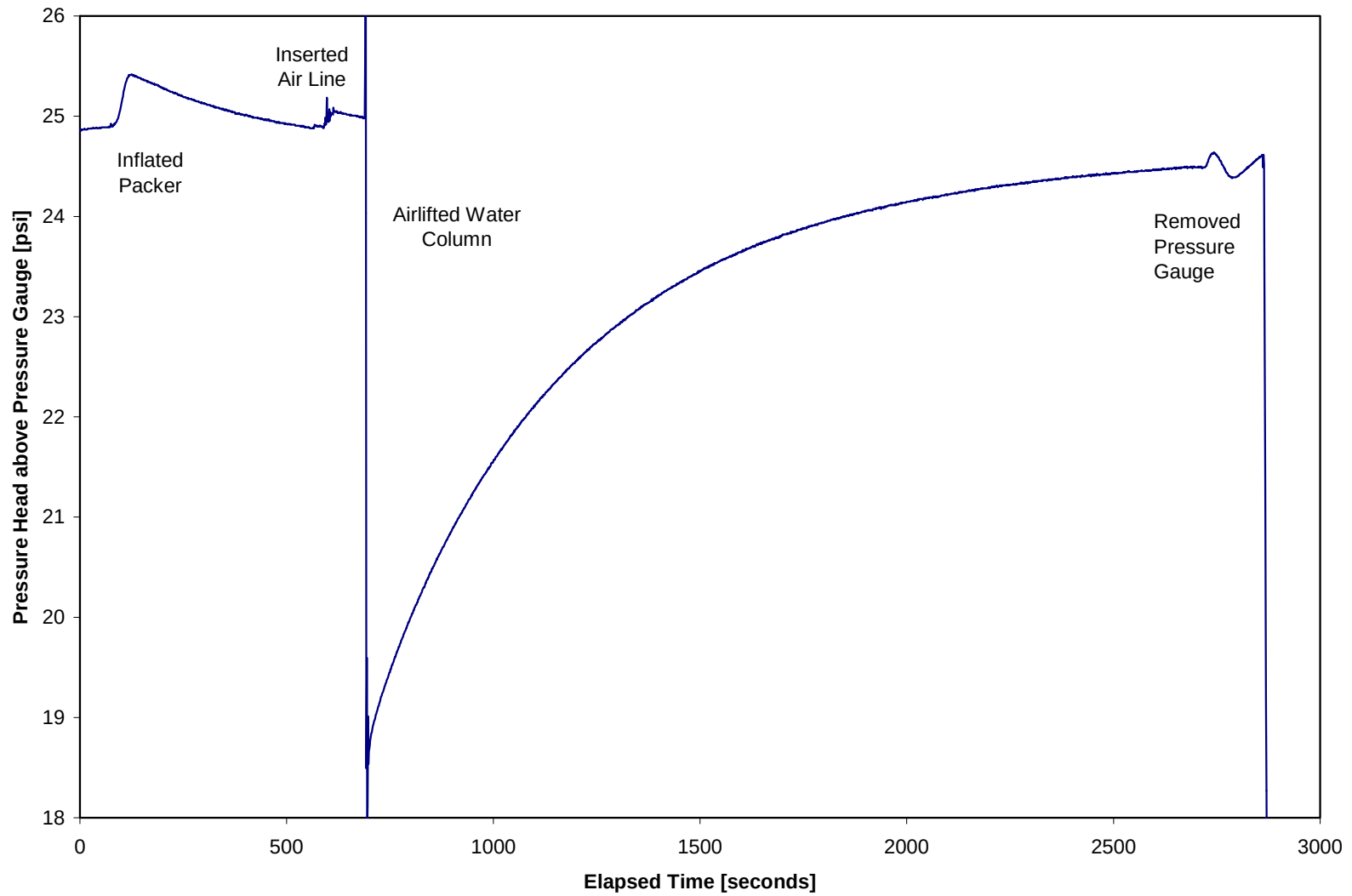


Figure 04EA-84_1B: 50.0 to 991.0 ft; Slug Test; Match on Log Log Deconvolution Plot

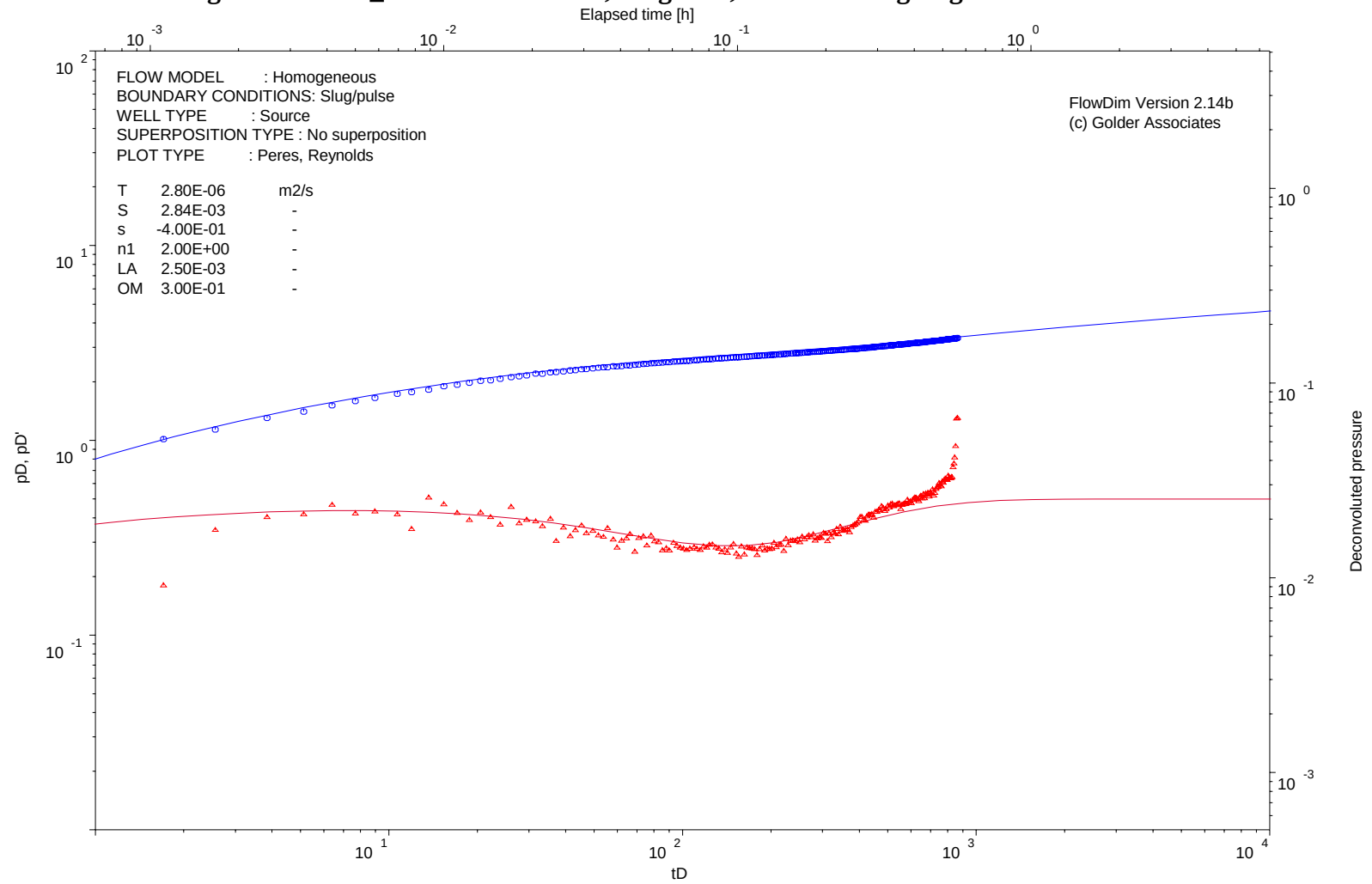


Figure 04EA-84_2A: 331.0 to 991.0 ft; Slug Test

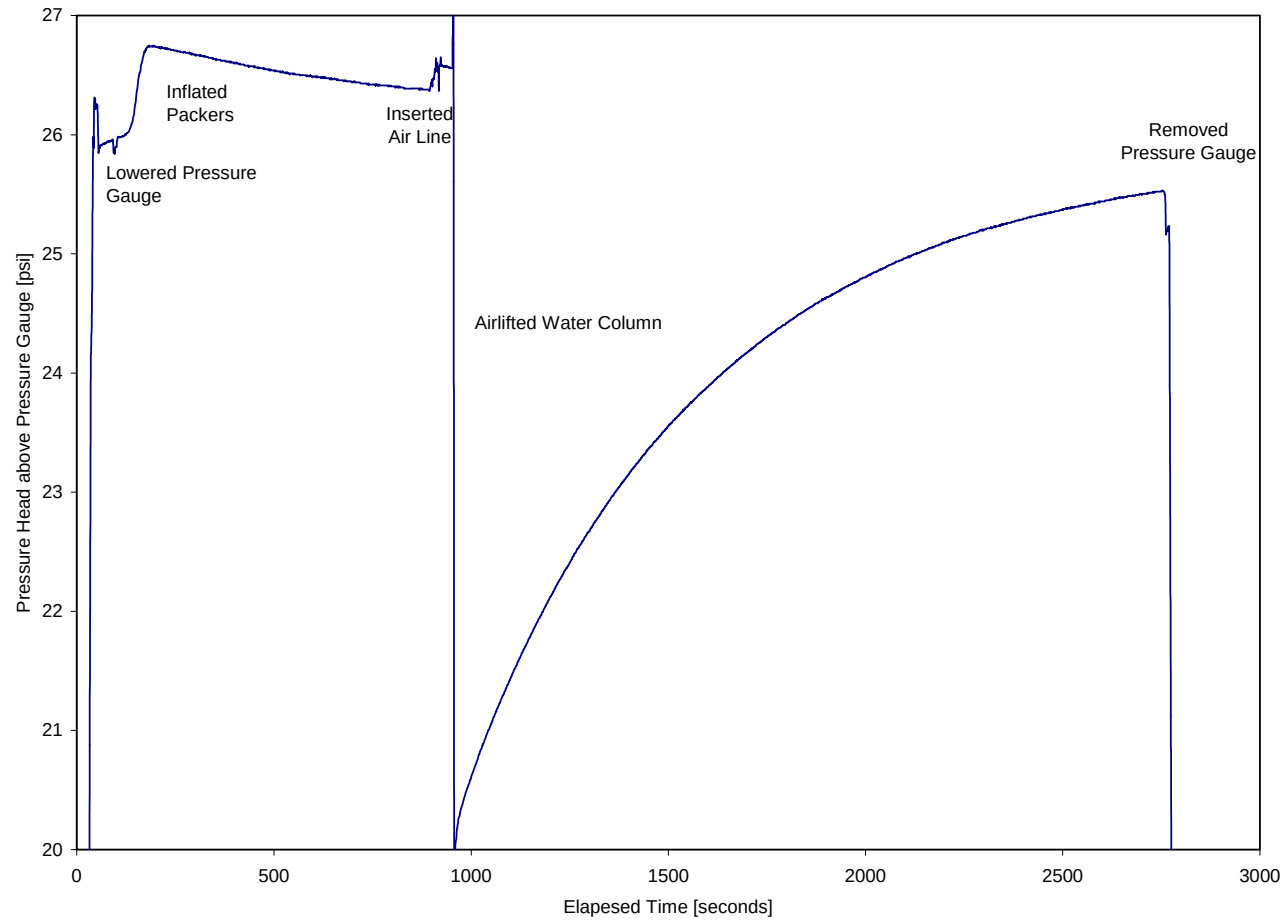


Figure 04EA-84_2B: 331.0 to 991.0 ft; Slug Test; Match on Log Log Deconvolution Plot

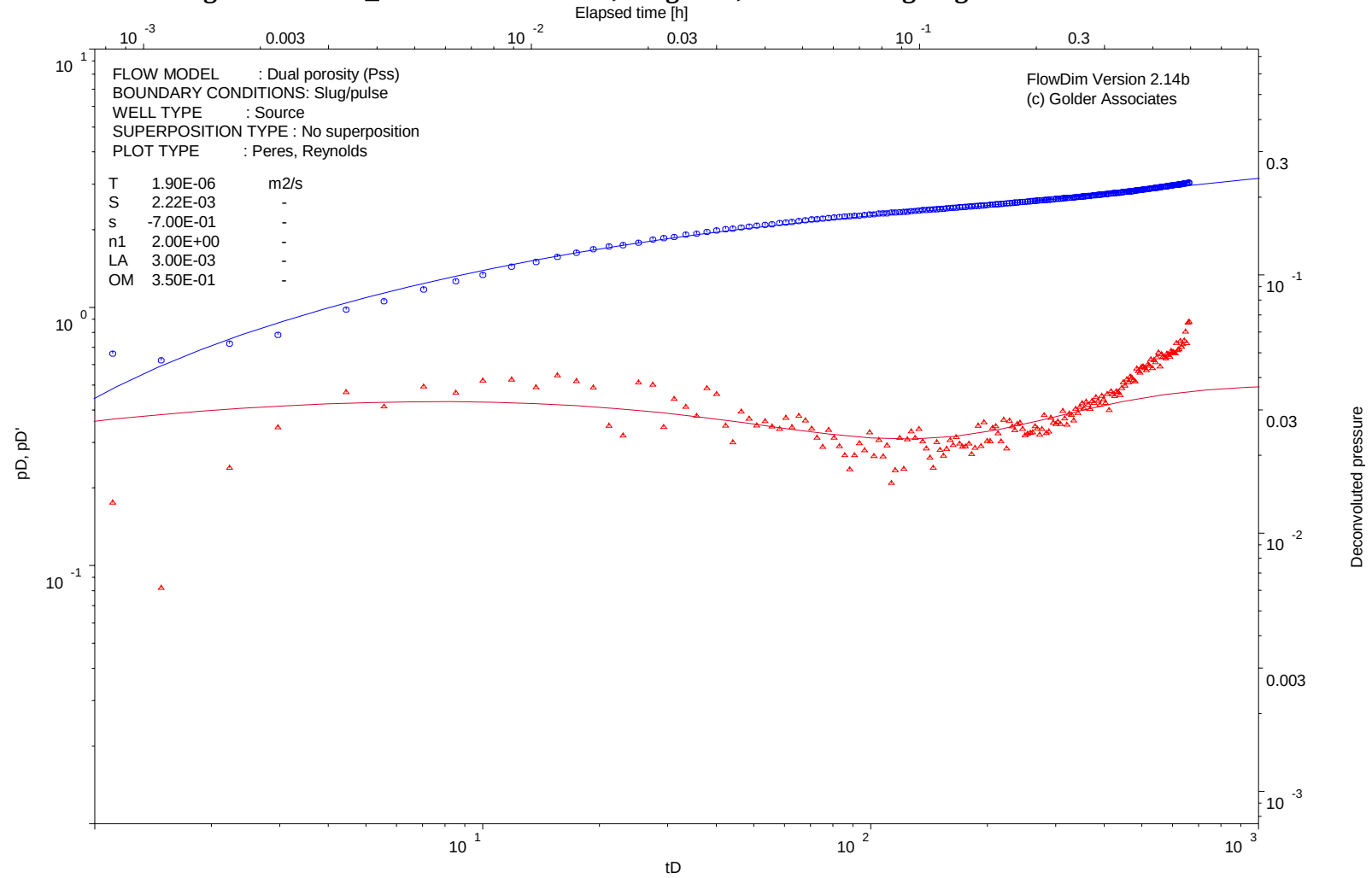


Figure 04EA-84_3A: 701.0 to 991.0 ft; Slug Test

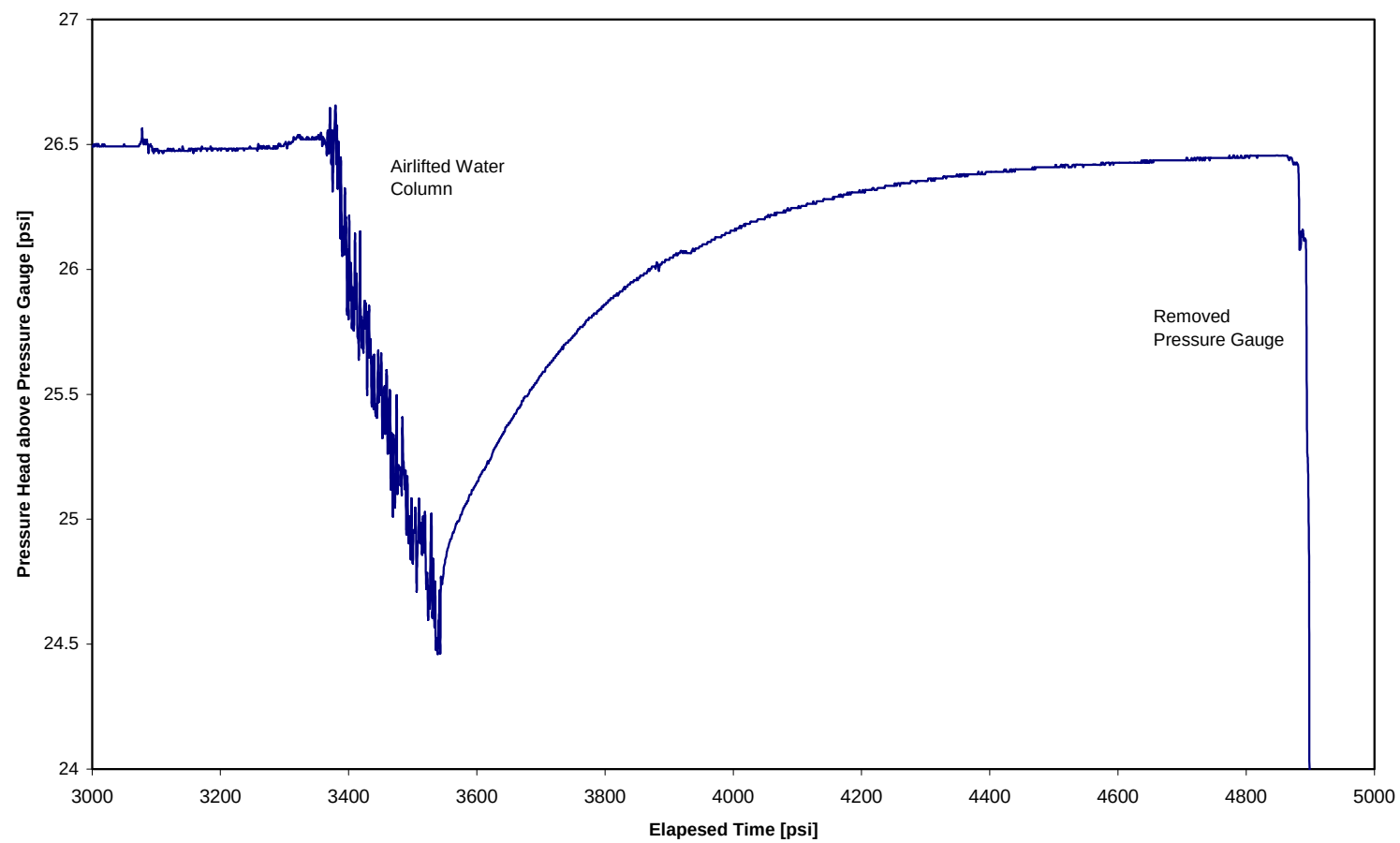


Figure 04EA-84_3B: 701.0 to 991.0 ft; Slug Test; Match on Log Log Deconvolution Plot

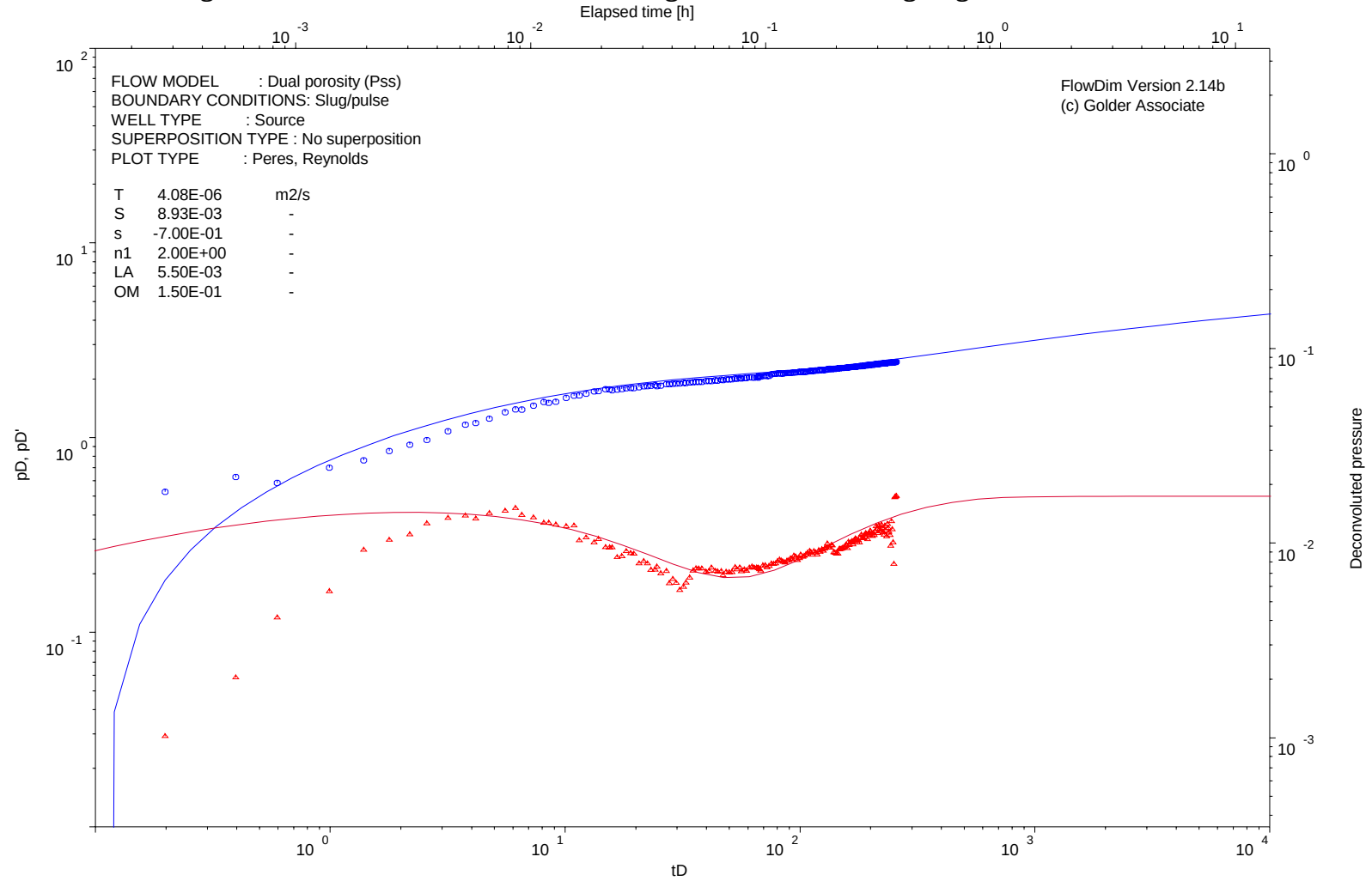


Figure 04EA-84_4A: 845.0 to 854.0 ft; Constant Rate Pumping Test

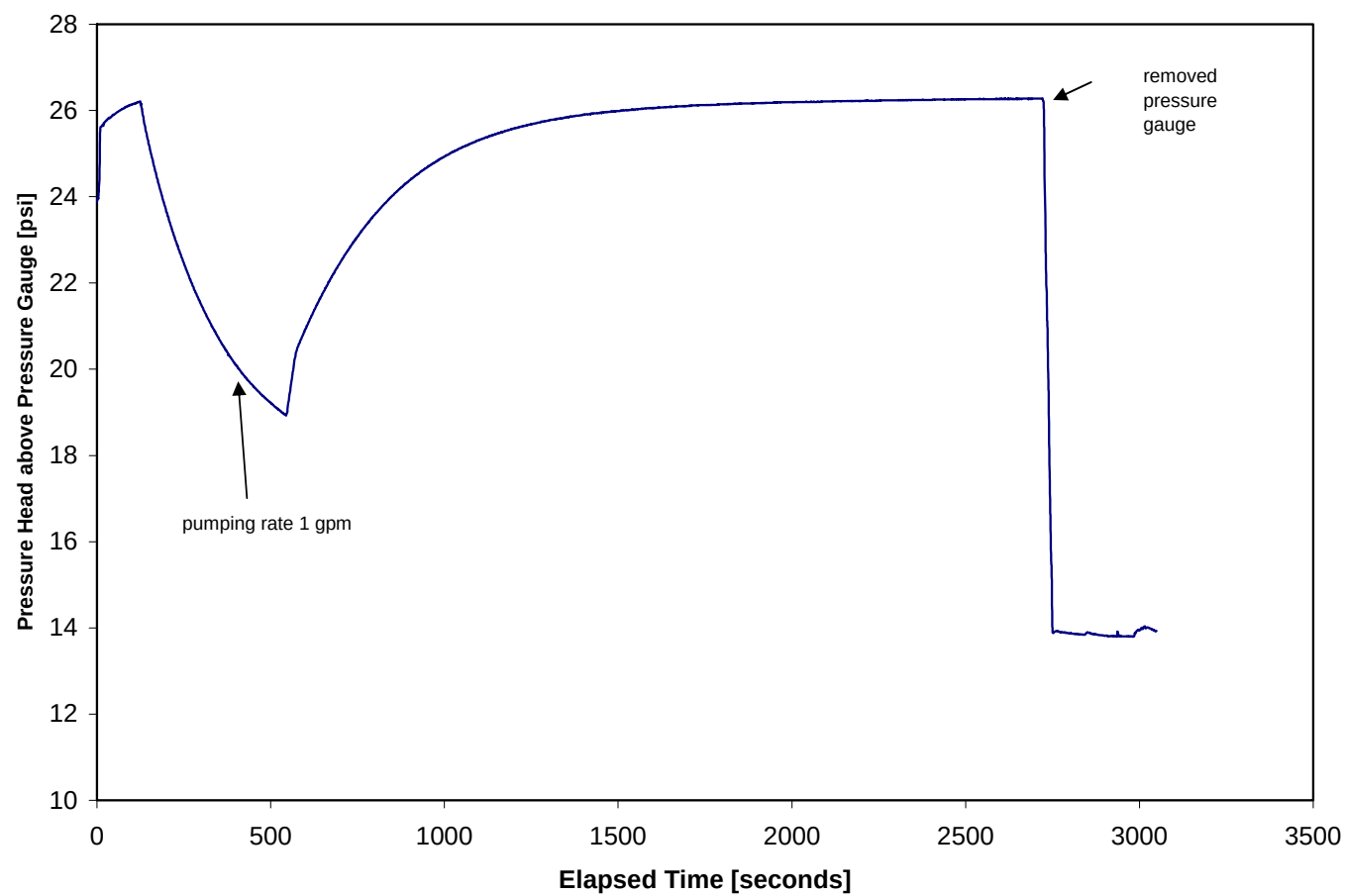


Figure 04EA-84_4B: 845.0 to 854.0 ft; Constant Rate Pumping Test; Log Log Match

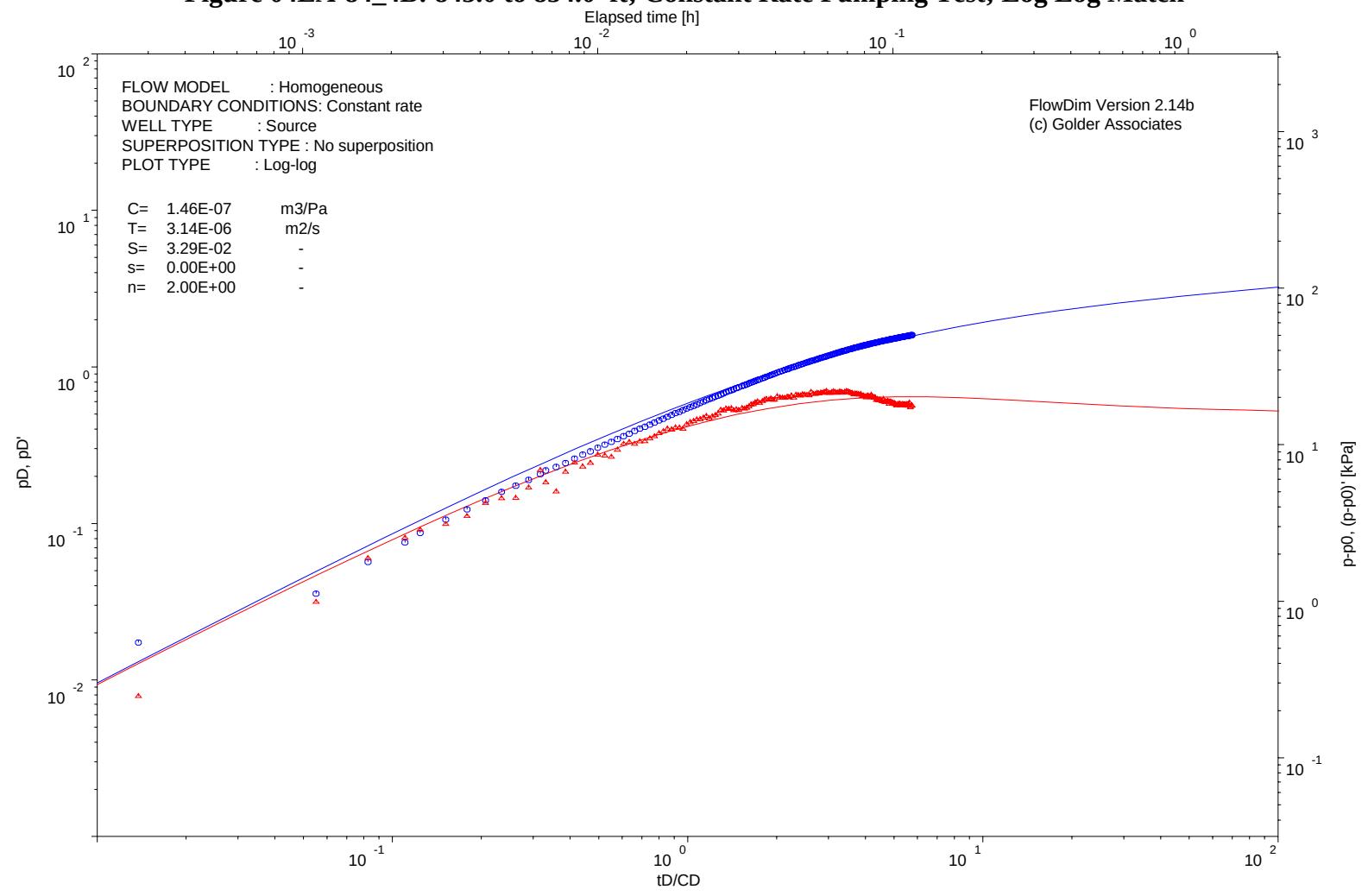


Figure 04EA-84_5A: 361.0 to 370.0 ft; Slug Test

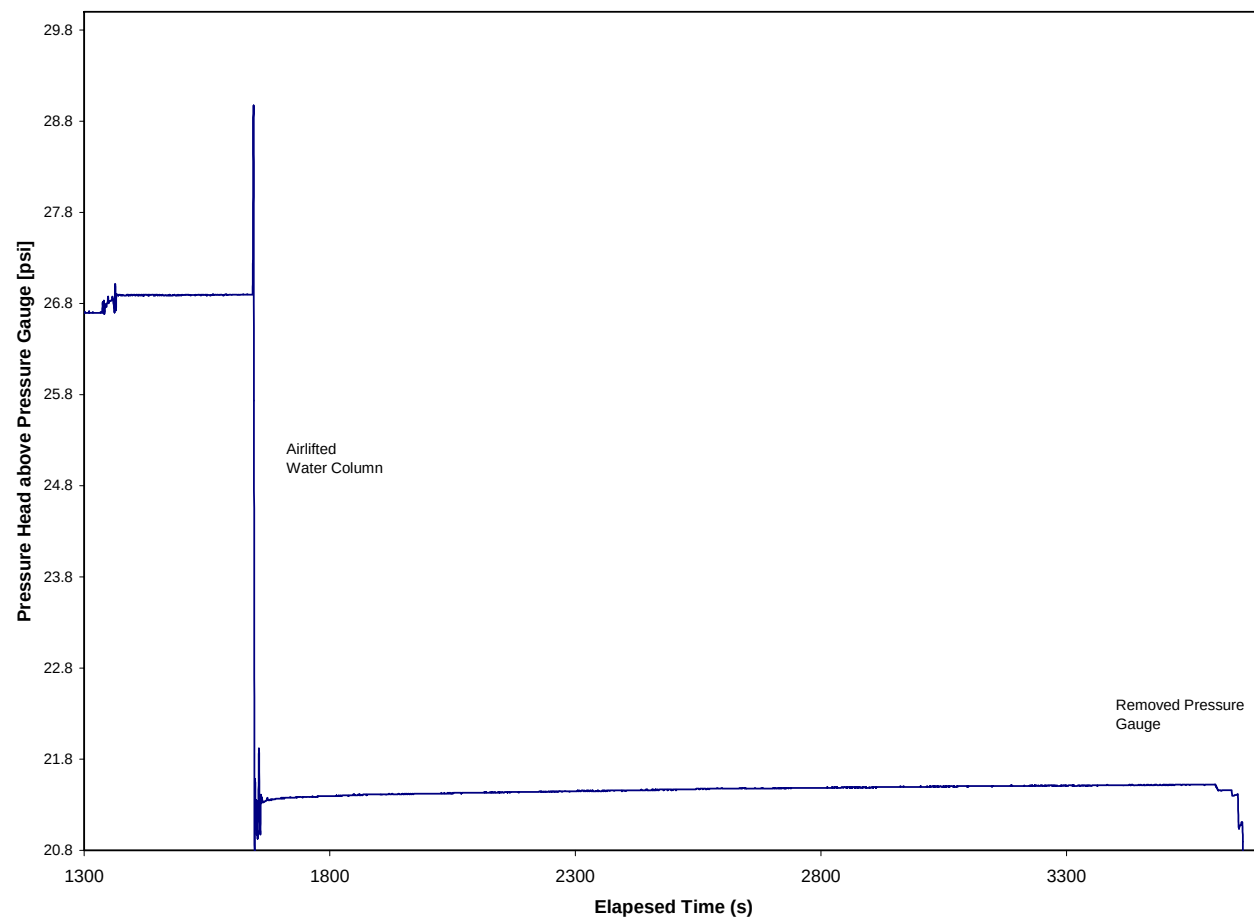
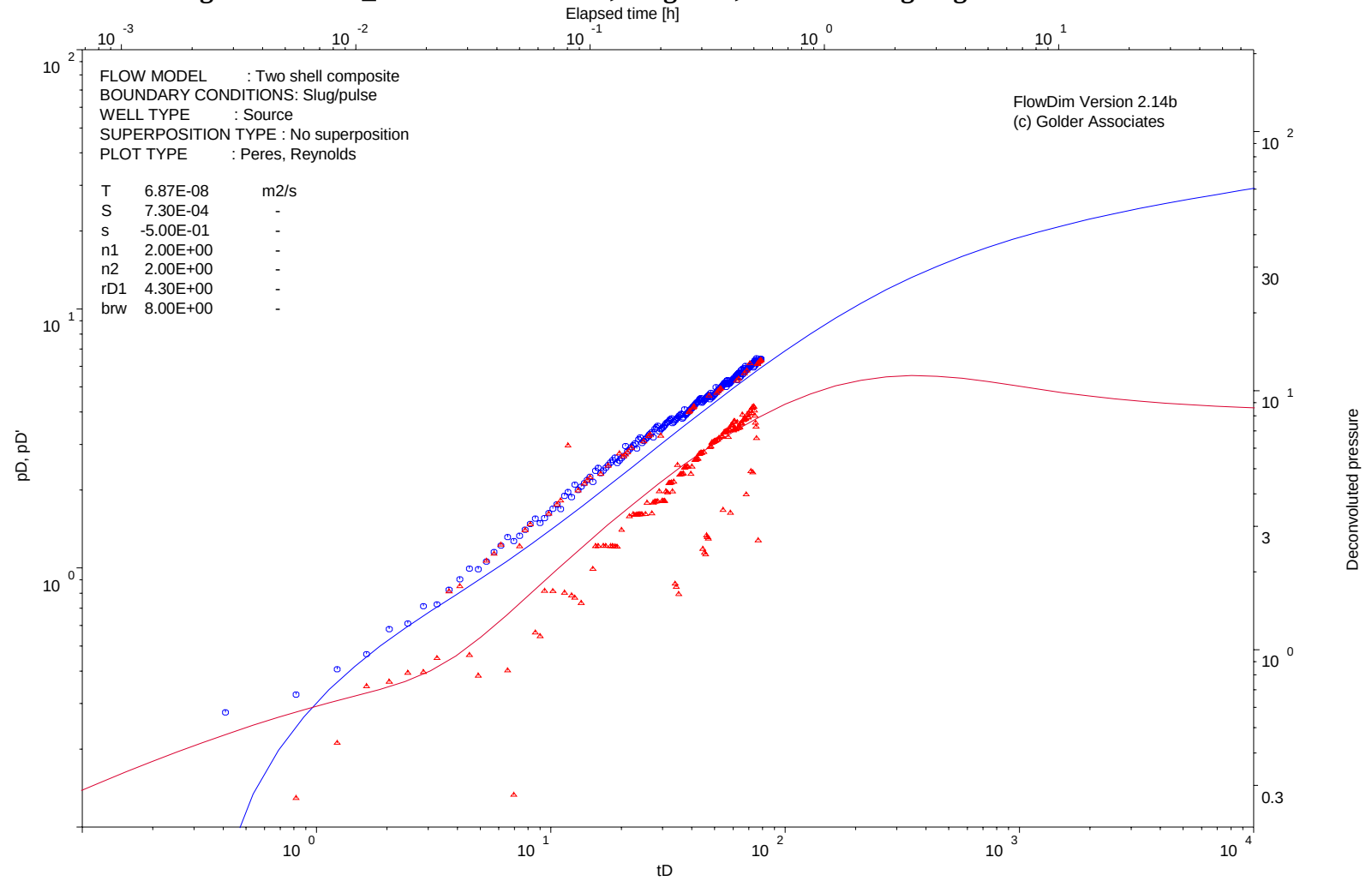


Figure 04EA-84_5B: 361.0 to 370.0 ft; Slug Test; Match on Log Log Deconvolution Plot



APPENDIX C
CALIBRATION CERTIFICATES
FOR PRESSURE GAUGES



48 Spencer St. Lebanon, N.H. 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Type: - DDate of Calibration: September 30, 2004Serial Number: 01-6193 / 66465Temperature: 22.7 °CPressure Range: 17 kPa†Barometric Pressure: 995.2 mbarCal. Std. Cntrl. #(s): 524, 529, 511, 506, 216, 468, 402, 428Technician: Elise

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	4953	4951	4952	-0.034	-0.20	0.001	0.00
3.4	5737	5738	5738	3.414	0.08	3.405	0.03
6.8	6515	6513	6514	6.822	0.13	6.802	0.01
10.2	7289	7289	7289	10.22	0.14	10.20	0.00
13.6	8060	8058	8059	13.60	0.02	13.60	0.01
17.0	8826	8827	8827	16.97	-0.17	17.00	0.00

(kPa) Linear Gage Factor (G): -0.004389 (kPa/ digit)Regression Zero: 4960Polynomial Gage Factors: A: 1.515E-08B: 0.004180C: -21.076Thermal Factor (K): -0.009138 (kPa/ °C)(psi) Linear Gage Factor (G): -0.0006366 (psi/ digit)Polynomial Gage Factors: A: 2.19792E-09B: 0.0006063C: -3.0569Thermal Factor (K): -0.0013254 (psi/ °C)

Calculated Pressures:

Linear, $P = G(R_0 - R_1) + K(T_1 - T_0) - (S_1 - S_0)**$ Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)**$ †Barometric pressures are absolute. Barometric compensation is not required with vented and differential pressure transducers.

Factory Zero Reading:

GK-401 Pos. B or F(R₀): 4935Temp(T₀): 24.4 °C†Baro(S₀): 995.0 mbarDate: September 30, 2004

*Initial zero readings must be established in the field following the procedures described in the Instruction Manual. If the Polynomial equation is used the field value of C must be calculated by plugging the initial zero reading into the polynomial equation with the value of P set to zero.

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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CalReport

Page 1 of 1



Calibration Report

Report Number: 2004092810435977

210 S. Third Street, Laramie WY 82073-0920 U.S.A. Visit us at www.in-situ.com
 307-742-8213, 1-800-446-7488 (Toll Free U.S. & Canada), FAX: 1-307-721-7598

☐	Calibration Result:	☐												
<table border="1"> <tr> <td>Instrument Type:</td> <td>miniTROLL</td> </tr> <tr> <td>Calibration Date:</td> <td>2004-09-28</td> </tr> <tr> <td>Model Number:</td> <td>SSP-100</td> </tr> <tr> <td>Full Scale Pressure Range:</td> <td>206.8427 kPa (30 PSI) Gauge</td> </tr> <tr> <td>Manufacturer:</td> <td>In-Situ, Inc.</td> </tr> <tr> <td>Serial Number:</td> <td>5977</td> </tr> </table>			Instrument Type:	miniTROLL	Calibration Date:	2004-09-28	Model Number:	SSP-100	Full Scale Pressure Range:	206.8427 kPa (30 PSI) Gauge	Manufacturer:	In-Situ, Inc.	Serial Number:	5977
Instrument Type:	miniTROLL													
Calibration Date:	2004-09-28													
Model Number:	SSP-100													
Full Scale Pressure Range:	206.8427 kPa (30 PSI) Gauge													
Manufacturer:	In-Situ, Inc.													
Serial Number:	5977													

Calibration Procedures and Equipment Used: Standards used in this calibration are traceable to the National Institute of Standards and Technology.

1. Instrulab model 4312A-15 s/n 41014
2. Instrulab model 832 s/n 12070 (RTD-03)
3. Mensor model PCS-400 s/n 181278
4. Mensor model PCS-400 s/n 181278
5. Automated software calibration procedures used.

Range of Applied Temperature: -5.17 C to 49.76 C

Range of Applied Pressure: 0.0000 kPa (0.0000 PSI) to 206.8427 kPa (30.0000 PSI)

Temperature Calibration:

Temperature Accuracy Specification: +/- 0.25 C

Temperature Calibration Results: **PASSED**

Pressure Calibration: Range For 30psig: 21.1m, 69.20ft.

	At 15.0 C	Over entire temperature range
Pressure Accuracy Specification:	+/- 0.050 %FS	+/- 0.100 %FS
Pressure Calibration Result:	PASSED	PASSED

Post-Calibration Check:

Temperature		Pressure	
Applied	Reported	Applied	Reported
35.26 C	35.29 C	0.0010 PSI	0.0004 PSI
		9.9000 PSI	9.8946 PSI
		20.1000 PSI	20.0907 PSI
		30.0000 PSI	29.9889 PSI
		20.1000 PSI	20.0942 PSI
		9.9000 PSI	9.8972 PSI
		0.0000 PSI	0.0014 PSI

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Test Performed By: JRB

Test Verified By:

Page 1 of 1

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**In-Situ Inc.**

Calibration Report

Report Number: 2001100402006542

210 S. Third Street, Laramie WY 82073-0920 U.S.A. Visit us at www.in-situ.com
307-742-8213, 1-800-446-7488 (Toll Free U.S. & Canada), FAX: 1-307-721-7598**miniTROLL**

Calibration Result:

PASSED

Instrument Type:	miniTROLL
Calibration Date:	2001-10-04
Model Number:	SSP-100
Full Scale Pressure Range:	2068.4271 kPa (300 PSI) Absolute
Manufacturer:	In-Situ, Inc
Serial Number:	006542

Calibration Procedures and Equipment Used:

1. Digital Pressure Controller, MENSOR PCS400, s/n 180695
2. Multi-Channel Thermometer, INSTRULAB 4312A, s/n 41014
3. Pt RTD, INSTRULAB 832-151X-01, s/n 12068
4. Pt RTD, INSTRULAB 832-151X-01, s/n 12073
5. Automated software calibration procedures used.

Range of Applied Temperature: -5.17 C to 49.77 C

Range of Applied Pressure: 2.7476 kPa (0.3985 PSI) to 2068.4960 kPa (300.0100 PSI)

Temperature Calibration Coefficients:

1	-7.432622e+1
2	1.303078e-2
3	-1.74112e-8
4	-7.677183e-13

Temperature Accuracy Specification:

+/-0.25 C

Temperature Calibration Result:

PASSED**Pressure Calibration Coefficients:**

	1	2	3	4
1	-1.189528e+2	9.441557e-4	-2.554365e-7	1.185146e-11
2	9.465381e-3	-1.563765e-7	1.98202e-11	-9.247303e-16
3	-1.17194e-8	4.406736e-12	-6.448217e-16	2.980888e-20
4	2.465555e-13	-9.346742e-17	1.291487e-20	-5.800607e-25

Pressure Accuracy Specification: **+/-0.10 %FS** over full temperature range.Pressure Calibration Result: **PASSED** over full temperature range.

Post-Calibration Check: Temperature (Applied, Reported) Pressure (Applied, Reported)

14.81 C, 14.80 C 0.3985 PSI, 0.4400 PSI

99.9990 PSI, 100.0169 PSI

199.9975 PSI, 199.9833 PSI

300.0000 PSI, 299.9523 PSI

199.9985 PSI, 200.0119 PSI

100.0000 PSI, 100.0361 PSI

0.4005 PSI, 0.4232 PSI

Test Performed By: PWM

Test Verified By:

APPENDIX D
FIELD WELL REPORT
FOR QUATERNARY MONITORING WELL QAL023

APPENDIX E

WATER QUALITY LABORATORY RESULTS

FOR SAMPLES COLLECTED AT 845.0 TO 854.0 FT

IN BOREHOLE 04EA-84

TRIMATRIX LABORATORIES INC.



ANALYTICAL REPORT

Client: **Golder Associates, Inc.**
Project: **Eagle**

Sampled: 10/08/04 @ 15:20
Sampler: M. Lemon
Received: 10/14/04 @ 08:50

Submittal #: **36730-1**
Submittal: **October 8, 2004 Sample**

Sample ID: **04EA-084 (8.45'- 8.54')**
Sample #: **373427**
Matrix: **Water**

Percent Solids: **n/a**

Parameter	Analytical Result	Reporting Limit	Unit	Analysis Date	Chem	Reference Citation
Alkalinity, Bicarbonate	62	2.0	mg/L	10/21/04	VAS	310.1/SM 2320 B
Alkalinity, Carbonate	<2.0	2.0	mg/L	10/21/04	VAS	310.1/SM 2320 B
Chloride	676	10	mg/L	10/18/04	TAM	325.2/4500-CL E
Sulfate	<5.0	5.0	mg/L	10/18/04	TAM	EPA-375.4/9038
Fluoride	0.35	0.10	mg/L	10/22/04	VAS	SM 4500 F-C
Residue, Dissolved @ 180°C	1590	250	mg/L	10/14/04	INR	160.1/SM 2540 C
Calcium, Dissolved	31	0.50	mg/L	10/27/04	KLVM	EPA-200.7/6010B
Magnesium, Dissolved	22	0.50	mg/L	10/27/04	KLVM	EPA-200.7/6010B
Potassium, Dissolved	12	0.50	mg/L	10/27/04	KLVM	EPA-200.7/6010B
Sodium, Dissolved	360	0.50	mg/L	10/29/04	DWJ	EPA-200.7/6010B
Aluminum, Dissolved	<100	100	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Antimony, Dissolved	<5.0	5.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Arsenic, Dissolved	6.8	2.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Barium, Dissolved	<20	20	ug/L	10/27/04	DSC	EPA-200.8/6020
Beryllium, Dissolved	<1.0	1.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Boron, Dissolved	1590	100	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Cadmium, Dissolved	<0.5	0.5	ug/L	10/27/04	DSC	EPA-200.8/6020
Chromium, Dissolved	<5.0	5.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Cobalt, Dissolved	<10	10	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Copper, Dissolved	<5.0	5.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Iron, Dissolved	190	20	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Lithium, Dissolved	49	10	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Manganese, Dissolved	220	20	ug/L	10/27/04	KLVM	EPA-200.7/6010B
Molybdenum, Dissolved	53	10	ug/L	10/27/04	DSC	EPA-200.8/6020
Nickel, Dissolved	59	25	ug/L	10/27/04	DSC	EPA-200.8/6020
Lead, Dissolved	<1.0	1.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Selenium, Dissolved	7.3	1.0	ug/L	10/27/04	DSC	EPA-200.8/6020
Silver, Dissolved	<0.2	0.2	ug/L	10/27/04	DSC	EPA-200.8/6020
Zinc, Dissolved	88	10	ug/L	10/27/04	DSC	EPA-200.8/6020

QUALITY CONTROL REPORT

Parameter: **Alkalinity, Bicarbonate**

Method: Alkalinity, Automated-Titrimetric

310.1/SM 2320 B WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/21/04	223374	VAS	<2.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/21/04	223374	VAS	238	235	99	93-105

QUALITY CONTROL REPORT

Parameter: **Alkalinity, Carbonate**

Method: Alkalinity, Automated-Titrimetric

310.1/SM 2320 B WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/21/04	223374	VAS	<2.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/21/04	223374	VAS	377	377	100	77-110

QUALITY CONTROL REPORT

Parameter: **Aluminum, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<100

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	2500	2521	101	90-110

QUALITY CONTROL REPORTParameter: **Antimony, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<2.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	41.2	103	90-110

QUALITY CONTROL REPORT

Parameter: **Arsenic, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	42.2	106	90-110

QUALITY CONTROL REPORTParameter: **Barium, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223621	DSC	<10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223621	DSC	40	42.3	106	90-110

QUALITY CONTROL REPORT

Parameter: **Beryllium, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223620	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223620	DSC	40	43.2	108	90-110

QUALITY CONTROL REPORT

Parameter: **Cadmium, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<10

QUALITY CONTROL REPORT

Parameter: **Cadmium, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<0.2

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	42.8	107	90-110

QUALITY CONTROL REPORT

Parameter: **Chloride**

Method: Colorimetric, Automated Ferricyanide 325.2/4500-CL E WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/18/04	223261	TAM	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/18/04	223261	TAM	78.1	78.97	101	92-109

QUALITY CONTROL REPORT

Parameter: **Chromium, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<50

QUALITY CONTROL REPORTParameter: **Chromium, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	43.3	108	90-110

QUALITY CONTROL REPORT

Parameter: **Cobalt, Total**
Method: Atomic Emission-ICP
Units: ug/L

EPA-200.7/6010B WATER

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	500	497	99	90-110

QUALITY CONTROL REPORTParameter: **Copper, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	43.2	108	90-110

QUALITY CONTROL REPORT

Parameter: **Fluoride**

Method: Potentiometric, Ion Selective Electrode SM 4500 F-C WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/22/04	223379	VAS	<0.10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/22/04	223379	VAS	3.43	3.31	97	88-116

QUALITY CONTROL REPORT

Parameter: **Iron, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<20

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	500	514	103	90-110

QUALITY CONTROL REPORT

Parameter: **Lead, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<50

QUALITY CONTROL REPORT

Parameter: **Lead, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223621	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223621	DSC	40	40.1	100	90-110

QUALITY CONTROL REPORT

Parameter: **Lithium, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	500	512	102	90-110

QUALITY CONTROL REPORTParameter: **Magnesium, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<0.50

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	5.0	5.13	103	90-110

QUALITY CONTROL REPORTParameter: **Manganese, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	500	511	102	90-110

QUALITY CONTROL REPORT

Parameter: **Nickel, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	42.8	107	90-110

QUALITY CONTROL REPORT

Parameter: **Potassium, Total**
Method: Atomic Emission-ICP
Units: mg/L

EPA-200.7/6010B WATER

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<0.20

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223665	KLVM	5.0	5.03	101	90-110

QUALITY CONTROL REPORT

Parameter: **Residue, Dissolved @ 180°C**

Method: Residue-Gravimetric, Dried @ 180°C 160.1/SM 2540 C WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/14/04	223088	INR	<2.5

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/14/04	223088	INR	1000.0	1040	104	90-108
10/14/04	223088	INR	1000.0	984	98	90-108

QUALITY CONTROL REPORT

Parameter: **Selenium, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<1.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	42.5	106	90-110

QUALITY CONTROL REPORT

Parameter: **Silver, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<0.2

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	43.1	108	90-110

QUALITY CONTROL REPORT

Parameter: **Sodium, Total**

Method: Atomic Emission-ICP

EPA-200.7/6010B WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223665	KLVM	<0.50
10/29/04	223765	DWJ	<0.50

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/29/04	223765	DWJ	5.0	4.86	97	90-110

QUALITY CONTROL REPORTParameter: **Sulfate**

Method: Turbidimetric Method (Manual)

EPA-375.4/9038 WATER

Units: mg/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/18/04	223265	TAM	<5.0

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/18/04	223265	TAM	15.8	16.2	103	85-113

QUALITY CONTROL REPORT

Parameter: **Zinc, Total**

Method: ICP Mass Spectrometry (ICP-MS)

EPA-200.8/6020 WATER

Units: ug/L

Instrument Blank

Test Date	Analytical Batch Number	Analyst	Blank Conc
10/27/04	223634	DSC	<10

Laboratory Control Sample

Test Date	Analytical Batch #	Analyst	Spike Qty	Spike Result	Recovery	QC Limits
10/27/04	223634	DSC	40	43.1	108	90-110

STATEMENT OF DATA QUALIFICATIONS

All analyses have been validated and comply with our Quality Control Program. No qualifications required.

Page 1 - End of Statement of Data Qualifications

Note: This document is included as a part of the analytical report for the above referenced project and submittal, and should be retained as a permanent record thereof.



5560 Corporate Exchange Court SE Grand Rapids, MI 49512
Phone (616) 975-4500 Fax (616) 942-7463
www.trimatrixlabs.com

Chain of Custody Record

COO No. 104395

For Lab Use Only

Cart 3

VOA Rack/Tray NA

Receipt Log No. 31-9

Project Chemist JH

Laboratory Project No. 30730-1

Test Matrix Laboratory Sample Group Code Number 01 W 373427

Client Name COLIER ASSOC.
Address 414 Union Blvd. STE 300
LAKEWOOD, CO 80228
Phone (303) 980-0540
Fax (303) 985-2080
Project Name FALSE
Client Project No./P.O. No. 037-2651
Invoice To [] Client [] Other (comments)
Contact/Report To SGT MILLER

Analyses Requested

Page 1 of 1

PRESERVATIVES
A NONE pH-7
B HNO₃ pH-2
C H₂SO₄ pH-2
D 1+1 HCl pH-2
E NaOH pH>12
F ZnAc/NaOH pH>9
G MeOH
H Other (note below)

Container Type (corresponds to Container Packing List)

Number of Containers Submitted

Total

Sample Comments

Metals W/FE

FIND FILTER

Sampled By (print)

Margaret S. Brown
Sampler's Signature

Philippa D. Jones
Company

How Shipped? Hand Carrier FedEx
Tracking No.

1. Relinquished By Date Time
2. Received By Date Time

1. Relinquished By Date Time
2. Received By Date Time

1. Relinquished By Date Time
2. Received By Date Time

Comments

Barium, Calcium, Chromium, Cobalt, Copper, Iron, Lithium, Manganese, Ni, Pb, Selenium, Silver, Zinc.

TOTAL DISSEMINATION - TABLE 4.

See CHETAS PARAMETERS - TABLE 4.

See CHETAS PARAMETERS - TABLE 4.

TriMatrixCOC -- COC

WHITE COPY - REPORT

YELLOW COPY - LABORATORY

PINK COPY - FIELD

JAF 10-14-04 08:30

BROOKS RAND



October 29, 2004

North Jackson Company
Attn.: Peter Sabee
420 Rail Street
PO Box 30
Negaunee, MI 49866

RE: Brooks Rand Project: NJC002; Tracking #: 04BR762
Lab Services Agreement 101201NJ01; Client Project: Eagle

Dear Mr. Sabee:

This report is for the mercury analysis of one water sample collected on 10/8/04 and received at Brooks Rand on 10/14/04. This sample has have been assigned the BRL tracking number 04BR762.

All samples were received, stored, prepared and analyzed according to Brooks Rand LLC Standard Operating Procedures and EPA Method 1631E.

Special Note: The COC indicated dissolved analysis and after speaking with the client they stated that they really needed total Hg via EPA Method 1631.

All results were blank corrected, as outlined in the calculations section of EPA Method 1631E. All QA criteria were met and no qualification of the data was required. Brooks Rand certifies that the reported test results meet all requirements of NELAC.

If there are any questions please feel free to contact me.

Sincerely,

Misty D. Mayer
Project Manager
misty@brooksrand

Reported by

Brooks Rand LLC

Contact: Elizabeth Madonick

3958 6th Avenue NW

Seattle, WA 98107

Tel: 206-632-6206 Fax: 206-632-6017

Summary of Results for

North Jackson Company

Contact: Peter Sabee

420 Rail Street

Nagaunee MI 49866

Tel: 906-475-9882

Lab Project # NJC002

Lab Tracking # 04BR762

Lab Services Agreement 101201NJ01

Client Project Eagle

Sample/Sampling/Receiving Info

North Jackson Company

BRL

Sample

Identification

04EA-084(845'-854')

Sampling Date

10/8/2004

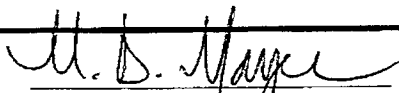
Sample Number

04BR762 - 1

Receiving Date

10/14/2004

Friday, October 29, 2004


Project Manager

Reported by

Brooks Rand LLC

Contact: Elizabeth Madonick

3958 6th Avenue NW

Seattle, WA 98107

Tel: 206-632-6206 Fax: 206-632-6017

Summary of Results for

North Jackson Company

Contact: Peter Sabee

420 Rail Street

Nagaunee MI 49866

Tel: 906-475-9882

Lab Project # NJC002

Lab Tracking # 04BR762

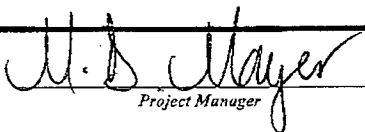
Lab Services Agreement 101201NJ01

Client Project Eagle

Hg

Sample Identification	BRL Number	Preparation date	Analysis date	Batch #	Result	Units	Qualifier (Q)
04EA-084(845'-854')	04BR762 - 1	10/25/2004	10/26/2004	04-855	89.100	ng/L	

Friday, October 29, 2004


Project Manager

BRL QA Summary

Batch #: 04-855

Method #: EPA 1631.E

Analyte: Hg

Matrix: Water

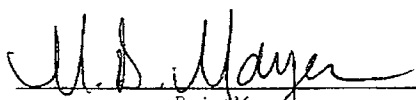
BIAS Criteria: Recovery = 79-121%			
Laboratory Control Samples			
LCS ID	Certified Value ng/L	Measured Value ng/L	Recovery %
QCS	10.00	9.32	93.2%

BIAS Criteria: Recovery = 77-123%			
Ongoing Precision and Recovery (OPR)			
LCS ID	Certified Value ng/L	Measured Value ng/L	Recovery %
OPR1	5.00	5.31	106.2%
OPR2	5.00	5.31	106.2%

BIAS Criteria: Recovery = 71-125%, RPD < 24%								
Matrix Spikes/Matrix Spike Duplicates (MS/MSD)								
Sample ID	Sample Value ng/L	Matrix Spike			Matrix Spike Duplicate			Duplicate RPD
		Spiked Value ng/L	Measured Value ng/L	MS Recovery %	Spiked Value ng/L	Measured Value ng/L	MSD Recovery %	
04BR764-1	54.1	40.1	94.0	99.5%	39.4	94.4	102.5%	0.4%
04BR773-1	2.01	36.9	41.2	106.2%	40.1	43.3	103.0%	5.1%

Method Blanks (MB) Criterion: < MB (0.5% BrCl) < 0.5 ng/L								Detection Limits	
MB1		MB2		MB3		MB4		MB MDL	MB POL
ng/L	BrCl%	ng/L	BrCl%	ng/L	BrCl%	ng/L	BrCl%	ng/L	ng/L
0.213	0.5%	0.249	0.5%	0.405	1.0%	NA	NA	0.10	0.25

10/29/2004


Project Manager

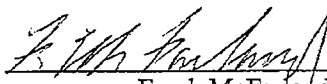
QUALITY ASSURANCE REPORT

Batch: 04-855
Analysis: Mercury by EPA 1631.E (CVAFS)
Tracking: 04BR760, 04BR762, 04BR764, 04BR773, 04BR782, 04BR816,
04BR817, & 04BR818
Project: USG003, NJC002, H2M002, LOV001, MEL002, ADS001, &
BCT001
Matrix: Water
Batch Size: 17 Samples
Analysis Date: October 26, 2004
Calibration Date: October 26, 2004

- 1 **SAMPLE PREPARATION** – Acceptable
- 2 **CALIBRATION** – Acceptable
- 3 **CALIBRATION VERIFICATION** – Acceptable
- 4 **QUALITY CONTROL SAMPLES (QCS)** – Acceptable
- 5 **BLANKS** – Acceptable
- 6 **METHOD DUPLICATE ANALYSIS** – Not Applicable
- 7 **SPIKE / SPIKE DUPLICATE ANALYSIS** – Acceptable
- 8 **LIMITS OF DETECTION** – Acceptable
- 9 **OVERALL DATA QUALITY** – Acceptable

No qualification of the data was required based on this review.

I certify that, to the best of my knowledge and belief, the data are reported as true and accurate.
The Laboratory Director, or his designee, has authorized release of data contained in this Quality
Assurance Report as verified by the following signature(s).

 10/29/04
Frank McFarland
Quality Assurance Manager

Hg Analysis Results
Batch #04-855(1631E), Tracking #04BR760,762,764,773,782,816,817,818

Analyst: ETS			Date: 10/26/2004			Matrix: Water		Analysis: Hg	
Projects: ADS001, BCT001, H2M002, LOV001, MEL002, NJC002, USG003									
SAMPLE CALCULATIONS 0.5% BrCl									
			Sample	Dilution	Analyzed			Uncorrected	MB corrected
			Volume	Volume	Vol.			Result	Result
Run	Tracking #	ID #	(mL)	(mL)	(mL)	PA	pg	ng/L	ng/L
15	04BR773	1	150	150.30	84.42	2835	188	2.24	2.01
16	04BR773	1MS	54.21	54.51	37.61	23274	1548	41.4	41.2
17	04BR773	1MSD	49.82	50.12	37.54	24437	1626	43.6	43.3
18	04BR782	1	250	250.50	85.23	42227	2810	33.0	32.8
19	04BR817	2	250	250.50	82.50	131	8.53	0.104	-0.127
20	04BR818	1	250	250.50	85.98	5419	360	4.20	3.97
Method Blank 0.5% BrCl									
			Sample	Dilution	Analyzed				
			Volume	Volume	Volume	Measured	Total	Result	
Run	(mL)	(mL)	(mL)	PA	pg	pg	ng/L		
12	204.19	205.59	87.63	281	18.5	43.4	0.213		
13	201.49	202.89	92.30	346	22.8	50.2	0.249		
Average:					20.7	46.8	0.231		
StDev:					3.06	4.79	0.026		
SAMPLE CALCULATIONS 1.0% BrCl									
			Sample	Dilution	Analyzed			Uncorrected	MB corrected
			Volume	Volume	Vol.			Result	Result
Run	Tracking #	ID #	(mL)	(mL)	(mL)	PA	pg	ng/L	ng/L
21	04BR764	1	150	151.35	28.93	23479	1562	54.5	54.1
22	04BR764	1MS	49.82	50.47	21.79	30526	2031	94.4	94.0
23	04BR764	1MSD	50.81	51.46	15.04	21169	1408	94.8	94.4
24	04BR760	17	30	30.33	9.00	53773	3578	402	402
25*	04BR760	18	53	53.48	19.28	587335	39082	2045	2045 *
26	04BR760	19	16	16.16	9.90	148684	9893	1009	1009
27	04BR760	20	10	10.16	10.08	12631	840	84.7	84.3
28	04BR760	21	50	50.70	25.35	127139	8460	338	338
30	04BR760	23	55	55.80	5.00	3884	258	52.4	52.0
31	04BR760	24	25	25.35	5.00	6249	416	84.3	83.9
32	04BR760	25	55	55.80	5.00	29032	1932	392	392
33	04BR762	1	250	252.25	5.00	6668	444	89.5	89.1
34	04BR816	1	250	252.25	5.00	27494	1829	369	369
35	04BR817	1	150	151.35	5.00	3546	236	47.6	47.2
36	04BR760	22	35	35.55	5.00	7425	494	100	99.9
37	04BR760	18	53	53.48	0.100	8636	574	5797	5796
* Over calibration.									
Method Blank 1.0% BrCl									
			Sample	Dilution	Analyzed				
			Volume	Volume	Volume	Measured	Total	Result	
Run	(mL)	(mL)	(mL)	PA	pg	pg	ng/L		
14	205.42	208.22	82.87	500	33.1	83.1	0.405		

Hg Analysis Results
Batch #04-855(1631E), Tracking #04BR760,762,764,773,782,816,817,818

QC CALCULATIONS									
Calibration Results									
Instrument Calibration (10/26/04)						Calibration Blanks			
Run	pg	PA	Calibration Coefficient	Average:	2.75	PA	Run	PA	pg
5	25	360	0.06998	95.1%	recovery		1	11	0.732
6	100	1535	0.06526				2	0	0.000
7	500	7254	0.06895				3	0	0.000
8	2500	38777	0.06448				4	0	0.000
9	10000	156168	0.06403				Average:	2.75	0.183
R:	1.0000	Average:	0.06654				StDev:	5.50	0.366
		RSD:	4.1%						
Calibration Checks									
Quality Control Standard						Blank tests			
	pg	PA	pg	%		Run	PA	pg	
	pg	PA	measured	recovery		29	22	1.46	
11	1000	14016	932	93.2%					
Ongoing Precision Recovery									
Run	pg	PA	pg	%					
	pg	PA	measured	recovery					
10	500	7983	531.0	106.2%					
38	500	7986	531.2	106.2%					
Bias									
Summary of Matrix Spike Recoveries									
			spike +						
			Spike	sample	sample	spike			
			Conc.	measured	measured	measured	%		
Run	Tracking #	ID #	ng/L	ng/L	ng/L	ng/L	Rec.	RPD%	
16	04BR773	1MS	36.89	41.17	2.01	39.16	106.2%		
17	04BR773	1MSD	40.14	43.34	2.01	41.33	103.0%	5.1	
22	04BR764	1MS	40.14	94.02	54.08	39.94	99.5%		
23	04BR764	1MSD	39.36	94.44	54.08	40.36	102.5%	0.4	

Brooks Rand LLC Sample Receiving Log

Tracking # **04BR762**

Customer: North Jackson Company
Contact: Peter Sabee
Project Ref. #: NJC002
Collection Date 10/8/2004
QA Level Standard

Sample Condition Intact
Shipping container intact? Yes

Shipping container type: cooler
Shipping container temp: 0.7°C
Shipping container coolant: Ice

Sample preservation: 0.5% BrCl

Acid lab # 04-279

Hg Concentration:

Sample storage area: Hg Lab Bin 1

Sample Turnaround Time:

Contract Turnaround Time: 28 days

Comments: See non-conformance form.

Due Date: 11/11/2004
Receiving Date: 10/14/2004
Receiving Time: 9:00 AM
Logged-in by: Margaret Langley
Log-in Date: 10/14/2004
Log-in Time: 4:00 PM

Airbill present? Yes
Airbill # 847861861598
Carrier: Fed EX

Custody seal present? Yes
Custody seal intact? Yes
COC Present? Yes
COC Number: N/A

Case #:
SDG #:

Analysis request form? No

COC/Sample log agree? Yes

Lab ID:	Sample Tag #	Container #	Size:	pH	Matrix/Sub-Matrix	Comments:
1	04EA-084(845'-854')	04-259	250 mL Bottle	<2		
Analysis / Method:		Hg	EPA 1631			

Sample Custodian signature

Date

Exhibit A
Non-Conformance/Resolution Form

Initiation of Form

Initiated by: Annie

Date of Occurrence: 10-14-04

Affected Samples: 04EA-084(845'-854')
04BR762-1

Matrix/Analyte: water

Description of Non-Conformance

Symptom Observed: COC mistake

Detailed Description of Problem: The COC said "Mercury-Dissolved"
under "Analyses Required". Elizabeth contacted
customer for further clarification and the
customer only wanted total mercury (1631).
No filtration was ~~not~~ done.

Communication and Discussion of Problem

Lab Manager Notified: [Y/N]

Meeting Held: [Y/N]

Project Manager Notified: [Y/N]

Client Notified: [Y/N]

Date: Names of Attendees:

Summary of Discussion and Action to be taken:

Action Taken

Name/Date/Description of Action and Findings:

Preventative Measures:

Resolution Approval

Initiator:

(signature/date)

Manager:

(signature/date)

Brooks Rand LLC Chain Of Custody Record

Page 1 of 1

Client: <i>Golden Associates</i>		Email address: <i>smiller@golden.com</i>		Ship to: Brooks Rand LLC	
Contact: <i>Scott Miller</i>		PO #: <i>033-2651</i>		3958 6 th Avenue NW	
Address: <i>44 Union Blvd, Ste 300 Lakeview, CO 80228</i>		Sampler's signatures: <i>Michael A. Jensen</i>		Seattle, WA 98107	
Phone #: <i>303-980-0540</i>		Fax COC for receipt confirmation? (Y/N)		Phone: 206-632-6206	
Fax #: <i>303-985-2080</i>		Client project ID: <i>033-2651</i>		Fax: 206-632-6017	
		BRL project ID: <i>150002</i>		Email: <i>brl@brooksrnd.com</i>	
For BRL use only		Cooler temp (°C): <i>0.7</i>	Custody seals present? (Y/N)	Custody seals intact? (Y/N)	Date: <i>10-14-04</i> Initials: <i>KL</i>

Sample ID	Collection		Miscellaneous			Field Preservation				Analyses required				Comments
	Date	Time	Sampler (initials)	Matrix type	# of containers	Sample field filtered, Y/N	Unpreserved or ice only	HNO ₃	HCl	BrCl	Other (specify)			
1	10-8-04	15:20	MSL	W	1	N	X							
2														
3														
4														
5														
6														
7														
8														
9														
10														

Shipping carrier: <i>Fed Ex</i>		# of coolers: <i>1</i>	
Relinquished by: <i>Michael A. Jensen</i>	Date: <i>10-13-04</i>	Received by:	Date:
Relinquished by:	Time: <i>1430</i>	Received at BRL:	Time: <i>9:00</i>

White: LAB COPY Yellow: CUSTOMER COPY

ILLINOIS GEOLOGICAL SURVEY



Illinois State Geological Survey

Natural Resources Building, 615 East Peabody Drive,
Champaign, Illinois 61820-6964
217/333-4747 • FAX 217/244-7004 • TTY 217/244-6677



Isotope Analysis Report

TO:	Scott Miller Golder Associates 44 Union Blvd., STE 300 Lakewood, CO 80228	FROM:	Keith C. Hackley, PhD. Illinois State Geological Survey 615 E. Peabody Champaign, IL 61820
-----	--	-------	---

Date: 11/5/04

Sample ID	ISGS #	³ H (TU)*	Std Dev (TU)
04EA084	1426	9.20	±0.22

* TU = Tritium Unit. One TU is defined as one tritium atom per 10¹⁸ hydrogen atoms, or 7.088 dpm/ kg H₂O, or 3.193 pCi/ kg H₂O.

Isotope Geochemistry Section

