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REPORT ON

CITY OF WALLA WALLA SHALLOW AQUIFER RECHARGE FEASIBILITY STUDY

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1.0 INTRODUCTION

This report documents the work completed as part of the evaluation of the feasibility of shallow aquifer recharge (SAR) at the Mill Creek Water Treatment Plant (WTP). SAR has been identified as a possible mechanism to restore groundwater levels in the shallow sand and gravel aquifer and augment flow in springs and streams in the Walla Walla area. SAR is being used investigated in the Walla Walla valley near the Oregon border to augment streamflows, restore springs, and restore declining groundwater levels in the shallow aquifer (Fountainhead 2006)

The work described in this report was completed at the WTP and included the installation of four shallow piezometers, installation of a staff gage, installation of instrumentation and monitoring in the piezometers, installation of temporary recharge piping and metering, and completion of a short-term recharge shakedown test. An existing infiltration pond at the WTP was used to recharge the sand and gravel aquifer to determine the infiltration rate and groundwater system response to recharge. The short-term test was planned to be followed by a longer-term test to evaluate the overall feasibility of SAR. However, the short-term recharge test was terminated after about two weeks because groundwater discharged about 3,500 feet west-southwest of the WTP. The planned longer-term recharge test was thus not completed.

Elsewhere in the vicinity of Walla Walla, recharge testing has occurred since 2004 at the Walla Walla Basin Watershed Council SAR site near Milton-Freewater. Surface water is being infiltrated to the shallow sand and gravel aquifer using large infiltration basins. Recharge occurred at rates of up to 28 to 30 cfs at the SAR site, with 1,870 acre-feet recharged in 2004-2005 (Walla Walla Basin Watershed Council, 2005). About 3,400 acre-feet were recharged in 2006-2007. Under a Limited License from the Oregon Water Resources department, up to 50 cfs can be diverted and infiltrated.

Site characterization and testing are also being completed the other SAR sites in the Walla Walla Valley (Hall-Wentland and Locher Road sites, Kennedy-Jenks, 2006a; 2006b).

1.1 Scope of Work

This memorandum fulfills Task 600 of the Agreement between the Washington State Department of Ecology and the City for water storage feasibility studies for Shallow Aquifer Recharge, Mill Creek. The objectives of this report are to evaluate the feasibility of SAR at the Mill Creek Water Treatment Plant (WTP) area and to present the results of hydrogeologic evaluations and recharge testing.

The evaluation of the feasibility of SAR at the Mill Creek WTP included the following:

- Development of a conceptual hydrogeologic model of the Mill Creek WTP area;
- Development of a SAR Pilot Test Plan, outlining the testing procedures, monitoring requirements, and water quality sampling;
- Installation of four shallow piezometers at the Mill Creek WTP, installation of groundwater level monitoring equipment, and installation of surface water staff gages; and
- Completion of a short recharge test and evaluation of the test results.

The results of the short-term recharge test indicated that large-scale testing was deemed not to be feasible at the site because of groundwater discharge downgradient of the test location. This report was prepared to document the work completed as part of the SAR feasibility evaluations.

1.2 Report Contents

This report is organized into several sections as follows:

- Section 2 contains details of the project, including project location and objectives, and an overview of site conditions.
- Section 3 contains information on four new piezometers that were installed to monitor groundwater levels in the uppermost saturated zone, and also includes information on three other existing piezometers or wells located at the Mill Creek WTP.
- Section 4 describes the hydrogeologic conditions in the area of the Mill Creek WTP, including geology, groundwater occurrence, and groundwater recharge and discharge.
- Section 5 describes the recharge shakedown test, including monitoring, groundwater level response, and groundwater temperature response.
- Section 6 presents the conclusions of the recharge shakedown test.
- Section 7 presents the feasibility shallow aquifer recharge at the Mill Creek WTP.
- Section 8 provides references.

Several appendices contain supporting information. Appendix A contains geologic and construction logs for the new piezometers. Appendix B contains the results of falling head tests completed during the drilling of one borehole used for piezometer completion (PZ-1) and on the completed piezometers.

2.0 PROJECT DETAILS

2.1 Project Location

The Mill Creek WTP is shown on Figure 2-1. Titus Creek is about 1,400 feet south of the Mill Creek WTP, and Mill Creek is about 2,600 feet south of the WTP. Titus Creek is a natural side channel of Mill Creek that is maintained by residents for irrigation purposes. A pushup dam on Mill Creek diverts water to Titus Creek (HDR/EES, 2006). The channelized portion of Mill Creek begins immediately south of the WTP.

2.2 Shallow Aquifer Recharge Objectives

The goal of the SAR pilot test program was to evaluate the feasibility of recharging the shallow alluvial aquifer adjacent to Mill Creek and Titus Creek during the winter months when excess water is available from Mill Creek. Water is diverted about 14.5 miles upstream of the Mill Creek WTP and conveyed to the WTP for treatment (ozonation) and sent to the distribution system. During the winter and spring, there is excess treated water available for the City's basalt aquifer system Aquifer Storage and Recovery program and for recharge of the shallow aquifer.

During operation of a full-scale SAR system, recharge water is infiltrated to the shallow aquifer using an infiltration pond. The recharge water is temporarily stored in the shallow aquifer and released under the natural hydraulic gradient to the streams to increase streamflow in the summer and fall months. The aim is to use the shallow sand and gravel aquifer to temporarily store the infiltrated water and to allow the water to discharge naturally to the creeks during the summer and fall months. It is hoped that the water discharging from the aquifer to the creeks will enhance salmonid habitat by increasing flows and decreasing water temperatures during the low flow periods of the year.

In order to design the full-scale SAR system, a short recharge shakedown test was performed. The objective of the shallow aquifer recharge shakedown test performed by the City is to evaluate the recharge capacity of the infiltration pond and to evaluate the response of the shallow aquifer to recharge, including groundwater level buildup, dissipation of the recharge mound, and groundwater travel time.

2.3 Shallow Aquifer Recharge Pilot Test Plan

A test plan was developed for the SAR pilot test (Golder Associates Inc., 2007a). The test plan described the objectives of the pilot test, project infrastructure, groundwater and surface water monitoring locations, monitoring frequencies, and water quality monitoring.

As a component of the SAR pilot test, a shakedown recharge test was planned to evaluate the infiltration capacity of the pond and the groundwater level response. Data collected during the shakedown test were to be used to develop specifications for full-scale pilot testing. No water quality sampling or surface water flow monitoring were performed during the shakedown test. Groundwater level monitoring during the shakedown test was limited to wells with dedicated pressure transducers and dataloggers.

2.4 Overview of Site Conditions

Information on the hydrogeological conditions at the Mill Creek WTP was presented in the conceptual hydrogeologic model (Golder Associates Inc., 2006) and is summarized here. The memorandum documented the pre-existing hydrogeologic conditions at the WTP and described a conceptual hydrogeologic model of shallow aquifer in the WTP area. The memorandum included an assessment of:

- How the shallow aquifer would respond during recharge, including infiltration of recharge water and changes in groundwater flow; and
- Preliminary estimates of the recharge mound hydraulics (water level rise) in the shallow aquifer

The existing data indicated that the shallow aquifer consists of interbedded silty and sandy gravel and cobbles overlying cemented gravels. Mixed clay and gravel underlie the cemented gravels. Below the clays and gravels, boulder rubble overlies the basalt bedrock. At the Mill Creek WTP, the sedimentary deposits are about 130 to 140 feet thick. The thickness of the sedimentary deposits increases to the west.

The sand and gravel aquifer is moderately to highly permeable, with an estimated transmissivity range of about 30 to 90,000 ft^2/d. The storativity of the sand and gravel aquifer is estimated to range from about 10 to 25 percent. Groundwater production to wells completed in the sand and gravel aquifers is reported to be highly variable, ranging from 5 to 500 gallons per minute (gpm). The average specific capacity is about 3 gpm/ft.

Prior to installation of the new piezometers, the depth to water in the area of the infiltration pond was thought to be about 15 to 20 feet below ground surface (bgs) based on test pitting during construction of the WTP (Golder 2007b).

3.0 MONITORING WELLS AND PIEZOMETERS

Four boreholes were drilled and completed as piezometers (PZ-1 through PZ-4, inclusive) at the Mill Creek WTP in the vicinity of the existing infiltration pond to evaluate the hydrogeologic conditions and provide monitoring points for the recharge testing. The piezometers were installed to target the first water bearing zone that will be affected by recharge. There are also two existing piezometers (MW-1 and MW-B1) at the WTP and an unused irrigation well (County Well) located west of the WTP, which are competed in the shallow aquifer. The locations of the piezometers are shown on Figure 2-1.

3.1 New Piezometers

The piezometers were drilled by St. George Drilling, a licensed well driller in the State of Washington, under a subcontractor agreement with Golder Associates Inc. The boreholes were drilled and piezometers installed between February 15 and 28, 2007. The boreholes were drilled at 6-inch diameter using air-rotary drilling methods with a casing advancer. The piezometers were completed using 6-inch diameter stainless steel screens installed in the first water-bearing zone. The piezometers were completed as follows:

- A 10-inch diameter borehole was drilled and temporarily cased to a depth of 18 feet;
- Six-inch diameter casing was telescoped inside the 10-inch casing to 18 feet;
- A 6-inch diameter borehole was drilled and cased to the final hole depth. Falling head tests were periodically conducted during drilling to evaluate the permeability of the formation materials;
- The borehole was backfilled, if needed, with bentonite chips and the casing pulled back to the bottom of the desired completion depth;
- A 6-inch diameter telescopic well screen with riser, "K"-packer, and tailpipe was installed inside the 6-inch casing and the casing pulled back to expose the well screen;
- Bentonite chips were installed the annular space between the 10-inch and 6-inch casing and the 10-inch casing was pulled back to form a surface seal; and
- The piezometers were developed using air-lift pumping methods.

Following completion of development, protective posts were installed around each piezometer and well caps installed. Completion details for the four new piezometers are summarized on Table 3-1, and the well logs are included in Appendix A. Table 3-1 also includes completion details for the existing wells and piezometers at the Mill Creek WTP.

Falling head tests were performed in PZ-1 during drilling and in each new piezometer following completion and development. The falling head tests were performed by adding 5 to 10 gallons of potable water to the wells and monitoring the water level decline with a water level sounder. The test data were analyzed using the Hvorslev method (Freeze and Cherry, 1979). The results of the falling head tests are summarized in Table 3-2, and the test analyses are in Appendix B.

The piezometers were surveyed by Anderson Perry and Associates on May 5, 2007. The piezometers were surveyed with a closed level loop method based on the City of Walla Walla's GPS control network and reported in Washington State Plane Coordinates.

Details of each new piezometer are provided in the following sections.

3.1.1 Piezometer 1

Piezometer 1 (PZ-1) was installed adjacent to the southwestern edge of the WTP infiltration pond. The PZ-1 borehole was advanced to 75 feet bgs in order to characterize the near-surface geology under the site and identify the extent of the shallow aquifer. In addition to logging drill cuttings, the moisture content of the drill cuttings and air-lift flow rates were estimated, and several qualitative falling head tests were performed during borehole advancement to determine the relative hydraulic conductivity of the geologic materials with depth. The tests were performed by pulling the drill string up off of the bottom of the hole and pouring 5 to 10 gallons of water into the hole, and measuring the water level decline with an electric water level tape. The tests were performed at depths of 21, 23, 36, 49, and 57 feet bgs. The test data were analyzed using the Hvorslev method.

The results of the tests are summarized on Table 3-3. The falling head tests indicated a wide range in hydraulic conductivity of the formation materials, ranged from about 45 ft/d to over 1,000 ft/d. The hydraulic conductivities estimated from the test data, particularly for the tests conducted at depths of 36 and 49 feet (hydraulic conductivities of 1,030 and 1,370 ft/d, respectively), are inconsistent with the descriptions of the geologic materials (silty sand and gravel) and observations of limited water production during drilling. The calculated hydraulic conductivities are much higher than would be expected for a silty sand and gravel. During drilling below the water table, wet cuttings were observed, but little water was airlifted during drilling. Water was airlifted from the borehole following breaks in drilling (such as when casing was added or following a falling head test), but sustained airlift flows did not occur. The results of the testing suggests that these two tests may have been affected by water leakage around the base of the casing during the testing, causing the water level in the casing to drop more quickly than if the water could seep out only through the bottom of the casing. If this occurred, the hydraulic conductivity would be overestimated.

The generalized near surface sedimentary stratigraphy was composed of dry to moist silty sand and gravel with large basaltic cobbles from the surface to approximately 25 feet bgs, water bearing gravel and sand layers with silty matrix from approximately 25 to 35 feet bgs (elevation 1,211 to 1,206 feet above mean seal level), and weathered sand and gravel with a more prevalent oxidized silt and clay matrix from approximately 35 to 75 feet bgs. After determining the shallow geology, the borehole was backfilled with bentonite to 35 feet bgs and the borehole was completed to screen the shallow aquifer between 27 and 32 feet bgs. An as-built construction and lithologic log for PZ-1 is provided in Figure A-1.

The results of the falling head test on the completed piezometer indicate the hydraulic conductivity of the gravel and silty sand and gravel materials in the screened section is about 169 ft/day (Table 3-2). The depth to water in PZ-1 was 12.10 feet below the top of casing (btc) on March 1, 2007, or an elevation of 1,239.76 feet above mean seal level (amsl).

3.1.2 Piezometer 2

Piezometer 2 (PZ-2) was installed approximately 250 feet south-southeast of the infiltration pond. The borehole was drilled to a total depth of 27 feet through silty sand and gravel with large basaltic cobbles. A water bearing zone was intersected between approximately 17 and 25 feet (1,219 to 1,214 feet amsl), and the piezometer was screened between 17 and 22 feet bgs. An as-built construction and lithologic log for PZ-2 is provided in FigureA-2.

The results of the falling head test on the completed piezometer indicate the hydraulic conductivity of the silty sand and gravel materials in the screened section is about 6.3 ft/day (Table 3-2). The depth to water in PZ-2 was 8.61 feet btc on March 1, 2007 or an elevation of 1,238.69 feet msl.

3.1.3 Piezometer 3

Piezometer 3 (PZ-3) was installed approximately 100 feet northeast of the infiltration pond. The borehole was drilled to a total depth of 28 feet bgs through silty sand and gravel with large basaltic cobbles from ground surface to approximately 18 feet bgs, silty water-bearing gravel from approximately 18 to 24 feet bgs (1,221 to 1,216 feet amsl), and sand and gravel with an oxidized silty matrix from approximately 24 to 28 feet bgs. The piezometer was screened between approximately 20 and 25 feet bgs. An as-built construction and lithologic log for PZ-3 is provided in Figure A-3.

The results of the falling head test on the completed piezometer indicate the hydraulic conductivity of the silty gravel materials in the screened section is about 54 ft/day (Table 3-2). The depth to water in PZ-3 was 11.55 feet btc on March 1, 2007, or an elevation of 1,243.33 feet amsl.

3.1.4 Piezometer 4

Piezometer 4 (PZ-4) was installed approximately 300 feet southwest of the infiltration pond. The borehole was drilled to a total depth of 30 feet bgs through silty sand and gravel with intermittent basaltic cobbles from ground surface to approximately 18 feet bgs, silty and sandy water-bearing gravel from approximately 18 to 26 feet bgs, and sand and gravel with an oxidized silty matrix from approximately 26 to 30 feet bgs. The piezometer was screened between approximately 22 and 27 feet bgs (1,210 to 1,205 feet msl). An as-built construction and lithologic log for PZ-4 is provided in Figure A-4.

The results of the falling head test on the completed piezometer indicate the hydraulic conductivity of the silty sandy gravel materials in the screened section is about 135 ft/day (Table 3-2). The depth to water in PZ-4 was 8.51 feet below the top of casing (btc) on March 1, 2007, or an elevation of 1,234.14 feet amsl.

3.2 Existing Piezometers and Wells

3.2.1 MW-B1

Water Treatment Plant staff located an existing flush-mounted piezometer installed as part of the site investigations for the construction of the WTP. MW-B1 is located near the east side of the infiltration pond (Figure 2-1). MW-B1 is a 2 inch diameter PVC piezometer installed to a total depth of 25 feet bgs in October 1996. The Ecology well log (Appendix A) for MW-B1 indicates the piezometer was installed in silty gravel and cobbles, and is screened with a 20-slot PVC screen from 14 to 19 feet bgs (1,223 to 1,218 feet amsl).

The depth to water in MW-B1 was 10.87 feet btc on March 1, 2007, or an elevation of 1,241.22 feet amsl.

3.2.2 MW-1

MW-1 is an existing piezometer located adjacent to Well No. 1 that was originally installed to monitor groundwater levels in the shallow aquifer in response to pumping and ASR operations (Figure 2-1). MW-1 is completed at a greater depth than the other piezometers at the WTP (about 75 to 80 feet bgs, or at an elevation of about 1,189 to 1,184 feet amsl). Little shallow groundwater (above a depth of about 20 to 30 feet bgs) was encountered in MW-1 during drilling. The well was thus completed in a deeper, saturated zone that is separated from the shallow groundwater by sandy silt. The completion depth of MW-1 is about 22 to 35 feet deeper than the other piezometers at the WTP. The well log is included in Appendix A.

The depth to water in MW-1 was 64.36 feet below the top of casing (btc) on March 1, 2007, or an elevation of 1,201.87 feet msl. This is about 25 to 30 feet lower than the groundwater elevation in the other piezometers in the WTP area.

3.2.3 County Well

The County Well is located about 900 feet west of the Mill Creek WTP (Figure 2-1). The County Well is an unused irrigation well originally drilled for Willis Logan and completed in the deeper part of the sand and gravel aquifer. The well was transferred to the County as part of a road re-alignment project. The well was drilled to a depth of 182 feet bgs, and intersected silt and clay underlying gravels and cemented gravel at a depth of 172 feet bgs. The County Well is completed between 112 and 172 feet below ground (1,112 to 1,164 feet msl). This is about 98 to 111 feet below the completion depths of the shallow piezometers at the WTP and about 76 feet below the completion depth of MW-1.

The depth to water in the County Well was 9.82 feet below the top of casing (btc) on March 1, 2007, or 1,216.63 feet amsl.

4.0 SITE HYDROGEOLOGY

Information on the site hydrogeology was obtained from the new and existing piezometers and wells installed at the WTP, and existing hydrogeologic reports (Kennedy Jenks, 2004). The WTP site is underlain by unconsolidated sedimentary deposits consisting of interbedded silty to sandy gravel and boulders, silt and silty sand, cemented gravels, and mixed clay and gravel. The sedimentary deposits are about 140 feet thick in the area of the WTP, and thicken to the west. The sedimentary deposits are underlain by Columbia River Basalt.

Geologic cross-sections through the WTP area are shown on Figures 4-1 and 4-2. The locations of the sections are shown on Figure 2-1. Well logs used in the cross sections are included in Appendix A.

4.1 Geology

Unconsolidated sediments including Quaternary sand and gravel deposits, and Mio-Pliocene coarse and fine-grained deposits overlie basalt bedrock in the WTP area. In the Walla Walla area, the unconsolidated sediments range from about 100 feet to over 700 feet thick. The thickness of the unconsolidated materials increases to the west (Figure 4-1).

4.1.1 Coarse-Grained Materials – Quaternary and Mio-Pliocene

The coarse-grained materials at the WTP consist of silty to sandy gravels and boulders overlying silt and silty sand and cemented gravels. The new and existing piezometers and wells indicate a near-surface deposit of sand, gravels, and boulders that is about 20 to 35 feet thick at the WTP (Figures 4-1 and 4-2). These deposits are the Quaternary sands and gravels. These materials are underlain by Mio-Pliocene silty sands and gravels or cemented sand and gravel. Within the Quaternary and Mio-Pliocene deposits, there may be areas of cleaner (less silt) sand and gravel that may be former channels. The Mio-Pliocene coarse-grained deposits are equivalent to the units previously referred to as the Old Gravels (Newcomb 1965). The total thickness of the Quaternary and Mio-Pliocene coarse-grained materials at the WTP is about 90 to 175 feet thick in the WTP area.

4.1.2 Fine Grained Materials – Mio-Pliocene

Fine-grained materials underlie the coarse-grained materials at the Mill Creek WTP. The fine-grained materials occur at a depth of about 90 feet bgs at Well No. 1 (Figure 4-1). The depth to the top of the fine-grained materials increases to the west. The depth to the top of the fine-grained materials is about 172 feet bgs at the County Well. The Mio-Pliocene fine-grained deposits are equivalent to the units previously referred to as the Old Clay (Newcomb 1965).

4.1.3 Columbia River Basalt

Columbia River Basalt underlies the sedimentary materials. The depth to the top of the basalt is about 137 feet below ground at Well No. 1, and increases to the west (Figure 4-1).

4.2 Groundwater Occurrence

Groundwater occurs in the coarse-grained alluvial and Mio-Pliocene materials under unconfined to semi-confined conditions. Within the Mio-Pliocene materials, there are discontinuous lenses of silt and clay or cemented gravel that form confining layers.

In the area of the infiltration pond, groundwater was first produced during drilling of the new piezometers at depths of about 14 to 19 feet below ground, and the materials intersected below the water table remained saturated to the final drilling depths of 27 to 75 feet bgs, indicating unconfined conditions.

At MW-1, located about 1,300 feet east of the infiltration pond (Figure 2-1), groundwater was first produced between about 18 and 20 feet below ground interpreted as the water table. Below 20 feet, damp to moist, dense, sandy silt was intersected to a depth of 75 feet. A saturated, medium-grained sand with some gravel was intersected at a depth of 75 feet. Following completion of the well between 75 and 80 feet bgs, the depth to water was about 63 feet bgs, indicating confined conditions and an overall downward component of hydraulic gradient.

4.3 Hydraulic Properties

The unconsolidated alluvial and Mio-Pliocene materials are moderately to highly permeable. Transmissivity values for the alluvial and Mio-Pliocene materials range from about 30 to 90,000 ft^2/d based on well log specific capacity data. Kennedy/Jenks (2004) reported a transmissivity of 10,000 to 60,000 ft^2/d for similar unconsolidated materials in the Walla Walla area. The storativity of the unconsolidated materials likely ranges from about 10 to 25 percent.

Falling head tests were completed in the four new piezometers at the WTP to estimate the hydraulic conductivity of the screened section in each piezometer. The results of the tests are summarized on Table 3-2. The hydraulic conductivity ranged from about 6 to 170 ft/d (2.2×10^{-3} to 6.0×10^{-2} cm/s), with a geometric mean of 53 ft/d (1.9×10^{-2} cm/s). The falling head tests indicate the unconsolidated materials at the WTP are moderately permeable. The lowest permeability was observed in PZ-2. The geologic log for PZ-2 (Appendix A) indicted the piezometer is completed in sand and gravel with a silty matrix. The other piezometers (PZ-1, PZ-3, and PZ-4) are completed in silty sands and gravels with a larger proportion of sand and gravel than the materials intersected at PZ-2.

Table 3-2 also includes estimated transmissivity of the silty sand and gravel materials. The transmissivity has been calculated based on the hydraulic conductivity and estimated saturated thickness of the shallow aquifer. The transmissivity ranges from about 100 to 3,300 ft^2/d. This is at the low end of previous estimates from other studies (Kennedy/Jenks 2004).

4.4 Groundwater Flow

Groundwater flow in the uppermost saturated zone at the WTP is monitored by piezometers PZ-1 through PZ-4, inclusive, and MW-B1 (Figure 2-1). The depth to water in the piezometers completed in the uppermost saturated zone at the WTP is about 8 to 12 feet bgs or about 1,225 to 1,232 feet msl. Groundwater flow in the uppermost saturated zone is generally to the west-southwest (Figure 4-3), rather than south towards Titus and Mill Creeks. The horizontal hydraulic gradient is about 0.01 ft/ft in the WTP area. The vertical component of hydraulic gradient in the area of the infiltration pond is not known.

The depth to water in the County Well, which is completed in a deeper part of the aquifer, is about 8 feet bgs (1,226 feet msl).

In MW-1, which is competed about 75 feet bgs, the depth to water is about 62 feet bgs (1,202 feet msl), or about 24 to 30 feet deeper than in the other wells at the WTP (Table 3-1). A small amount of shallow groundwater was encountered in MW-1 at a depth of 18 to 20 feet bgs. Between 20 and 75 feet bgs, a damp to moist, dense, silty sand was intersected. Consequently, there is a downward component of vertical hydraulic gradient in the unconsolidated materials at MW-1. The vertical component of hydraulic gradient at MW-1 is about 0.76 ft/ft.

The groundwater flow and groundwater velocity below the infiltration pond was estimated using the range of hydraulic conductivities estimated from the falling head tests, the hydraulic gradient, and the assumed saturated thickness of the uppermost saturated zone of about 15 to 20 feet. The results are summarized on Table 4-1. The groundwater flow across the width of the pond (assumed to be about 200 feet wide) is estimated to be less than 1 to about 40 gallons per minute (gpm). The groundwater velocity is estimated to be about 0.5 to 20 ft/d (assuming an effective porosity of 10 percent).

4.5 Groundwater Recharge and Discharge

Shallow groundwater in the uppermost saturated zone is recharged by infiltration of precipitation, surface water from losing stream reaches, and by infiltration of irrigation water from return flows or seepage from canals. Washington Department of Ecology hydraulic continuity studies on Mill Creek above the flood diversion indicated that seepage from the creek to shallow groundwater was occurring based on measurements conducted between mid-July and mid October 2002 (Marti, 2005). Based on the groundwater elevations of about 1,224 to 1,230 feet measured in the new piezometers at the WTP and elevation of Titus Creek south of the WTP of about 1,240 to 1,250 feet, seepage from Titus Creek recharges the shallow groundwater system.

Figure 4-4 shows the groundwater elevation in PZ-1, completed in the uppermost saturated zone, and the County Well, which is completed a deeper portion of the sand and gravel aquifer (112 to 172 feet bgs). This figure covers the period from March 19 to July 17, 2007, prior to, during, and after recharge testing and demonstrates how the groundwater levels responded to recharge and other events.

Following 1.06 inches of precipitation over 3 days in late March 2007, groundwater levels in the County Well increased by about one foot. The maximum groundwater level rise occurred about week after the precipitation event. Groundwater level data are not available from PZ-1 for the March precipitation event to determine the response at the water table.

About 0.98 inches of precipitation occurred over about a week in early May 2007. This resulted in a groundwater level rise of about one foot in the County Well. The maximum groundwater level rise occurred about week after the mid-point of the precipitation event. In PZ-1, the groundwater level rose about two feet in response to the precipitation event, and the time to the maximum groundwater level rise occurred about 2 days after mid-point of the precipitation event. The difference in groundwater level rise and time to the maximum rise between the County Well and PZ-1 is because PZ-1 is completed at the water table, while the County Well is completed in a deeper part of the sand and gravel aquifer. There is thus a “lag time” between precipitation reaching the water table and the response of the County Well, attributed to the lower-permeability cemented gravels that separate the well from near-surface materials.

Groundwater in the sand and gravel aquifer discharges to gaining streams, to springs and seeps, to wells, and by evapotranspiration where the water table is close to the ground surface. The sand and gravel aquifer also discharges to the underlying basalt aquifer where a downward component of hydraulic gradient occurs, such as at the WTP (Golder Associates Inc., 2006).

5.0 RECHARGE SHAKEDOWN TEST

The City of Walla Walla completed a recharge shakedown test to evaluate the groundwater level rise and infiltration capacity of the pond in order to design the full-scale SAR system. The test was started on April 11, 2007, and run for 10 days. The test was terminated on April 20, 2007 after groundwater discharge occurred in a cut bank about 3,400 feet west-southwest of the infiltration pond, resulting in flooding of a parking lot.

5.1 Monitoring

Pressure transducers and dataloggers were installed in three of the new piezometers to measure groundwater level changes during recharge. A staff gage was installed on Titus Creek to monitor any changes in surface water flow attributable to recharge. An existing gage on Titus Creek that was installed by the WWBWC was also part of the monitoring network.

5.1.1 Groundwater

Three of the new piezometers (PZ-1, PZ-2, and PZ-4) were equipped with Instrumentation Northwest PT2X transducers and dataloggers. Existing wells MW-1 and the County Well were previously equipped with PT2X transducers and dataloggers as part of the Extended Area ASR evaluations (Golder 2006). The dataloggers were programmed to collect groundwater level measurements once an hour. Groundwater level measurements were not collected in the other piezometers that were not equipped with pressure transducers and dataloggers (MW-B1 and PZ-3).

5.1.2 Surface Water

A staff gage (TC-1) was installed by Golder on Titus Creek at the downstream side of the culvert under Looking Glass Lane at approximately river mile 1.3 (Figure 2-1). The staff gauge is located south of the WTP at an elevation of 1,246.65 feet msl, and upstream of any anticipated impact from SAR activities.

The Walla Walla Basin Watershed Council (WWBWC) installed a staff gage on Titus Creek (TC-2). The WWBWC gauge is located at approximately River Mile 0.2 of Titus Creek at an elevation of 1,173.46 feet msl, on the Walla Walla Community College campus (Figure 1-1). WWBWC installed a temperature and stage recorder at the gage.

No measurements of the Titus Creek staff gages were made during the test, and only water temperature data are available from the WWBWC gage on Titus Creek for the test duration.

5.1.3 Precipitation

Precipitation data for the Walla Walla area were obtained from a weather station located at Whitman College, located about 3.5 miles west of the Mill Creek WTP (http://www.weatherunderground.com/weatherstation/WXDailyHistory.asp?ID=KWAWALLA5).

About 0.35 inches of precipitation fell during the test, and about 0.3 inches of precipitation fell 2 days before the test started (Figure 4-4).

5.1.4 Surveying

The piezometers, wells and staff gauge sites on Titus Creek were surveyed by Anderson Perry and Associates of Walla Walla on May 5, 2007. The observation wells were surveyed with a closed level loop method based on the City of Walla Walla's GPS control network and reported in Washington State Plane Coordinates. The stream gauge site elevations were based on RTK-GPS observations only. The staff gage at the infiltration pond was not surveyed.

5.2 Recharge Shakedown Test

The City of Walla Walla completed a recharge shakedown test in April 2007 to evaluate the groundwater level rise and infiltration capacity of the pond in order to design the permanent infiltration system. The test was started on April 11, 2007, and run for 10 days. The test was terminated on April 20, 2007 after shallow groundwater discharge occurred in a cut bank about 3,400 feet west-southwest of the infiltration pond.

5.2.1 Test Setup

Water from the shakedown test was obtained from a fire hydrant at the Mill Creek WTP. The water was conveyed to the infiltration pond using temporary piping. An instantaneous and totalizing flowmeter was installed at the hydrant to measure flow rates (Figure 5-1). The City installed a staff gage in the pond to measure the pond stage during the test (Figure 5-2).

5.2.2 Recharge Rate

The average flow rate from the hydrant was 1,146 gallons per minute over the test duration and remained relatively constant. A total of 14.86 Mgal (45.6 AF) were recharged to the shallow aquifer during the test. The recharge pond has dimensions of about 80 feet by 175 feet, or an area of about 14,000 square feet. The flow rate is equivalent to a recharge rate of about 15.8 ft/d.

5.2.3 Infiltration Pond

The water level in the pond rose slowly during the test. Water was first observed ponding in the infiltration pond about 2 days after the test started. At the end of the test, the water level on the staff gage was about 0.47 feet, or an elevation of about 1,234.47 feet msl (Figure 5-3).

5.2.4 Groundwater Level and Temperature Response

Groundwater levels were monitored in the County Well, MW-1, PZ-1, PZ-2, and PZ-4 during the test (Figure 2-1). The pressure transducers and dataloggers installed in these wells also measured the groundwater temperature. The City of Walla Walla monitored the temperature of the raw water entering the Mill Creek WTP over the testing period. The temperature of the raw water before treatment ranged from about 6.7 to 7.7 degrees Celsius (Figure 5-4) during the test. The temperature of the raw water gradually increased over the test duration.

Groundwater levels were monitored for about 7 days prior to the start of the test in the new piezometers. Groundwater levels in MW-1 and the County Well have been monitored since 2005 as part of the extended area ASR evaluations (Golder Associates Inc. 2006). Monitoring in the piezometers and wells continued for about 80 days after the test ended.

Groundwater levels declined by about 1 foot in the shallow piezometers (PZ-1, PZ-2, and PZ-4) in the 7-day pre-test monitoring period. The decline in water levels is the result of little precipitation before the start of the test and possibly pumping from other wells. In the deeper wells (the County Well and MW-1), the County Well groundwater levels showed a similar decline of about 1 foot, while groundwater levels in MW-1 increased about 0.5 feet.

5.2.4.1 PZ-1

PZ-1 is located about 10 feet west of the infiltration pond (Figure 2-1), and is the closest piezometer to the pond. A test hydrograph is shown on Figure 5-5. PZ-1 responded immediately to the start of recharge. Groundwater levels rose about 5 feet in the first day of recharge. At the end of the 10-day recharge period, groundwater levels were about 7 feet higher than the pre-test level (about elevation 1,233.6 feet), or about 4.3 feet below ground. A slight increase in the rate of groundwater level rise was observed after about 7 days of recharge. This is because of infiltration of precipitation recharge from two precipitation events in the first 7 days of the test. This was also observed in PZ-2, PZ-4, and the County Well.

When recharge to the pond stopped on April 20, 2007, groundwater levels declined. Groundwater levels declined about 3.5 feet in the first day after recharge ended. About 5 days after recharge ended, groundwater levels had declined about 5 feet. The groundwater level remained relatively stable at an elevation of about 1,228.4 feet, or about 2 feet higher than the pre-recharge elevation until about May 9, 2007, or for about 2 weeks. During this period, there was about 0.36 inches of precipitation on May 2, 2007. The higher groundwater level may thus represent the combination of recharge from the pond and recharge from precipitation.

Starting on May 9, 2007, the groundwater level started to decline from an elevation of about 1,228.4 feet, reaching an elevation of about 1,224.8 feet on May 28, 2007. Part of the overall decline is a sharp decline of about 2.4 feet between May 24 and May 28. This decline was also observed in PZ-2, PZ-4, and the County Well. The overall groundwater level decline between May 9 and May 27, 2007 is the result of a combination of factors including the decay of the recharge mound, little recharge from precipitation during May 2007, and potentially pumping from other wells completed in the sand and gravel aquifer. It is likely that pumping was responsible for the steep water level decline between May 24 and May 28, because water levels rose starting May 28, 2007, but there was no recharge from precipitation at that time. There are two domestic wells along Looking Glass Lane across from the WTP that are completed in the sand and gravel aquifer and an irrigation well on Mill Creek Road across from the WTP that may be completed in the sand and gravel aquifer (Figure 2-1). These wells may have been responsible for the “sharp” groundwater level changes in late May. Logs for these wells are included in Attachment A.

Figure 5-6 shows the groundwater temperature and groundwater elevation at PZ-1. The groundwater temperature was about 8.4°C before recharge started. The recharge water temperature was about 6.8°C at the start of recharge, or about 1.6°C cooler than the groundwater. The water temperature in PZ-1 declined by about 1.2°C during the first 12 hours of recharge as the cooler recharge water infiltrated. Over the remaining duration of the recharge period, the groundwater temperature gradually increased about 0.4 to 0.5°C degrees because of gradually warming of the recharge water and equilibration of the recharge water and native groundwater. When recharge was stopped, the groundwater temperature increased by about 0.6 degrees in the first day after recharge ended, and remained relatively stable for about 60 days following the end of recharge.

5.2.4.2 PZ-2

PZ-2 is located about 250 feet south-southeast of the infiltration pond (Figure 2-1), and is the closest piezometer to Titus Creek. A test hydrograph is shown on Figure 5-7. Groundwater levels in PZ-2 responded immediately to the start of recharge. Groundwater levels rose about 2.5 feet in the first day of recharge. After about 7 days of recharge, the rate of water level rise increased, because of infiltration of precipitation that occurred during the first week of the test. At the end of the 10-day recharge period, groundwater levels were about 4.9 feet higher than the pre-test level (about elevation 1,234.6 feet), or about 1.2 feet below ground.

Once recharge to the pond stopped, groundwater levels declined. The groundwater level decline in PZ-2 was similar to the observed decline in PZ-1. About 5 days after recharge ended, groundwater levels had declined about 2.2 feet, to an elevation of 1,232.4 feet. The groundwater level remained relatively stable at an elevation of about 1,232.4 feet, or about 2.6 feet higher than the pre-recharge elevation, for about 2 weeks.

Starting on May 9, 2007, the groundwater elevation started to decline from an elevation of about 1,232.4 feet, reaching an elevation of about 1,228.8 feet on May 28, 2007. Part of the overall decline is a sharp decline of about 1.8 feet between May 24 and May 28. This decline was also observed in PZ-1, PZ-4, and the County Well. The overall groundwater level decline between May 9 and May 27 is the result of a combination of factors including the decay of the recharge mound, little precipitation recharge during May 2007, and potentially pumping from other wells completed in the sand and gravel aquifer. Similar to the assessment of water levels in PZ-1, it is likely that pumping was responsible for the steep water level decline between May 24 and 28, because water levels rose starting May 28, 2007, but there was no recharge from precipitation at that time.

Figure 5-8 shows the groundwater temperature and elevation at PZ-2. The groundwater temperature at PZ-2 was about 9.5°C before the start of recharge, or about 1°C warmer than groundwater at PZ-1. The recharge water temperature was about 6.8°C at the start of recharge, or about 2.7°C cooler than the groundwater. Over the duration of the recharge period, the groundwater temperature decreased about 0.9 degrees as a result of the infiltration of cooler recharge water. When recharge stopped, the groundwater temperature started to increase as the recharged water equilibrated with the native groundwater and the recharge mound decayed. Ten days after recharge ended, the groundwater temperature had increased by about 0.8 °C. The groundwater temperature continued to rise over the duration of the monitoring period. Fifty days after the end of recharge, the groundwater temperature was about 1 degree higher than the pre-test groundwater temperature.

5.2.4.3 PZ-4

PZ-4 is located about 300 feet southwest of the infiltration pond (Figure 2-1). A test hydrograph is shown on Figure 5-9. PZ-4 responded within 2 hours of the start of recharge. Groundwater levels rose about 2.8 feet in the first day of recharge. Similar to the other piezometers (PZ-1 and PZ-2) and the County Well, the rate of water level rise in PZ-4 increased slightly after about 6 days of recharge because of infiltration of precipitation. At the end of the 10-day recharge period, groundwater levels were about 5.6 feet higher than the pre-test level (about elevation 1,230.5 feet), or about 1.4 feet below ground.

Once recharge to the pond stopped, groundwater levels declined. About 5 days after recharge ended, groundwater levels had declined about 3.7 feet. The groundwater level remained relatively stable at an elevation of about 1,226.8 feet, or about 1.9 feet higher than the pre-recharge elevation, for about 2 weeks (until May 9, 2007).

Between May 9 and May 28, 2007, the groundwater level declined to an elevation of about 1,223.5. Part of the overall decline is a sharp decline of about 1.8 feet between May 24 and May 28. This decline was also observed in PZ-1, PZ-2 and the County Well. The overall groundwater level decline is the result of a combination of factors including decay of the recharge mound, little precipitation recharge during May 2007, and possibly pumping from other wells completed in the sand and gravel aquifer. Similar to the assessment of water levels in PZ-1, t is likely that pumping was responsible for the steep water level decline between May 24 and 28, because water levels rose starting May 28, 2007, but there was no recharge from precipitation at that time.

Figure 5-10 shows the groundwater temperature and elevation at PZ-4. The groundwater temperature at PZ-4 was about 7.5°C before the start of recharge, or 1 to 2°C cooler than the groundwater at PZ-1 and PZ-2. The groundwater temperature increased throughout the recharge period, unlike PZ-1 or PZ-2, where a decrease in groundwater temperature was observed. At the end of the recharge period, the groundwater temperature was about 8°C, or about 0.5°C higher than at the start of recharge. The groundwater temperature at PZ-4 continued to rise for about 60 days after recharge stopped, and then was stable at about 9.9°C for about 2 weeks between June 20 and July 5, 2007. This period of stability may represent the passage of the recharge water at PZ-4, because the stabilization cannot be attributed to precipitation or temperature changes because there was no recorded precipitation in the week before the period of stabilization and air temperatures were slowly increasing. After about 2 weeks of stable groundwater temperatures at PZ-4, the groundwater temperature started to increase again.

5.2.4.4 MW-1

MW-1 is located about 1,300 feet east (upgradient) of the infiltration pond (Figure 2-1). MW-1 is completed in a sand and gravel unit below the uppermost saturated zone. The aquifer unit that is screened in MW-1 is overlain by 55 feet of damp to moist sandy silt. A test hydrograph is shown on Figure 5-11. During the first 5 to 6 days of the recharge test, the groundwater level in MW-1 was relatively stable. After 6 days of recharge, the groundwater level began to increase. At the end of recharge, the groundwater level was about 0.9 foot higher than at the start of recharge. Groundwater levels in MW-1 were rising prior to the start of recharge. The rates of increase before and during the test were similar. Thus, it appears that the observed groundwater level rise most likely from seasonal groundwater level changes from infiltration of precipitation, and groundwater levels at MW-1 may not have been affected by the recharge test.

Figure 5-12 shows the groundwater temperature and elevation in MW-1. The groundwater temperature was stable throughout the recharge test and pre-and post test monitoring periods at about 11.4°C.

5.2.4.5 County Well

The County Well is located about 900 feet west of the infiltration pond (Figure 2-1). The County Well is completed between 112 and 172 feet below ground. The screened section is overlain by about 36 feet of cemented gravels. A test hydrograph is shown on Figure 5-13. The County Well started to respond after about 10 hours of recharge. Groundwater levels rose about 0.5 foot in the first day of recharge. Similar to the shallow piezometers (PZ-1, PZ-2, and PZ-4), the rate of water level rise in County Well increased slightly after about 6 days of recharge because of infiltration of precipitation. At the end of the 10-day recharge period, groundwater levels were about 4.5 feet higher than the pre-test level (about elevation 1,221.5 feet), or about 2.5 feet below ground.

Once recharge to the pond stopped, groundwater levels declined. About 5 days after recharge ended, groundwater levels had declined about 2.5 feet. The groundwater level remained relatively stable at an elevation of about 1,218.6 feet, or about 1.6 feet higher than the pre-recharge elevation, for about 2 weeks.

Between May 9 and May 28, 2007, the groundwater level declined to an elevation of about 1,216.3 feet. Part of the overall decline is a sharp decline of about 0.9 feet between May 24 and May 28. This decline was also observed in PZ-1, PZ-2 and PZ-4. The overall groundwater level decline is the result of a combination of factors including decay of the recharge mound, little precipitation recharge during May 2007, and possibly pumping from other wells completed in the sand and gravel aquifer. Similar to the assessment of water levels in PZ-1, it is likely that pumping was responsible for the steep water level decline between May 24 and 28, because water levels rose starting May 28, 2007, but there was no recharge from precipitation at that time.

Figure 5-14 shows the groundwater temperature and elevation in the County Well. The groundwater temperature was decreasing prior to recharge, and continues to decrease slightly during the recharge period. About 10 to 12 days after recharge stopped, the groundwater temperature started to rise. About 60 days after recharge ended, the groundwater temperature was about 1.4°C higher than the end of recharge.

5.2.5 Summary of Groundwater Level and Temperature Changes

5.2.5.1 Groundwater Level Response

The following summarizes the groundwater level response during the test:

- The groundwater level declined about 1 foot in the shallow piezometers in the 7 days prior to the test. A similar decrease in groundwater levels was observed in the County Well, but not in MW-1.
- During the recharge test, groundwater levels increased in the shallow piezometers by about 4.9 to 7.1 feet. Groundwater levels in the County Well increased about 4.5 feet. Groundwater levels in MW-1 did not respond to recharge.
- The maximum water level rise in the shallow piezometers PZ-1, PZ-2, and PZ-4 occurred immediately before pond recharge was shut down. The maximum water level rise in the County Well occurred about 7 hours after recharge ended. The water level in the infiltration pond dropped below the pond floor about 4 hours after recharge stopped.
- Groundwater levels in the shallow piezometers declined between 2.2 and 3.7 feet in the first 5 days after recharge was stopped. The groundwater level in the County Well declined about 2.5 feet over the same time.
- Groundwater levels in the shallow piezometers and the County Well were stable for approximately 14 days, starting about 5 days after recharge ended. The groundwater levels during this period were about 1.9 to 2.6 feet above the pre-test groundwater level in the shallow piezometers, and about 1.6 feet above the pre-test level in the County Well. This period of stabilization indicates a net groundwater level increase from a combination of recharge water and precipitation that entered storage in the uppermost saturated zone.

- Groundwater levels in the shallow piezometers and County Well declined over about a 3-week period following the 2 week period of stabilized groundwater levels. In the shallow piezometers, the groundwater level decline was about 3.3 to 3.6 feet after the period of stabilization. A decline of about 2.3 feet was observed in the County Well over the same period. The decline in water levels could be the result of decay of the recharge mound, and also because of other changes in discharge or recharge in the shallow aquifer such as an increase in pumping.
- An immediate groundwater level response to pond recharge was observed in PZ-1, adjacent to the infiltration pond, and PZ-2, located about 250 feet cross-gradient from the pond. Piezometer PZ-4, located about 300 feet downgradient of the pond, responded after about 2 hours of recharge. Given that piezometers PZ-2 and PZ-4 both located a similar distance from the pond responded at very different times, the uppermost saturated zone is most-likely heterogeneous with preferential flowpaths (higher permeability channels) in the direction of PZ-2. These high-permeability channels may be former stream channels with cleaner sand and gravel (less silt) than other parts of the uppermost saturated zone.
- When recharge stopped, groundwater levels in PZ-1 and PZ-2 declined immediately. In PZ-4, there was a lag of about 2 hours before groundwater levels start to decline.
- There was no groundwater level response to pond recharge in MW-1 because this well is upgradient of the recharge pond and completed in a deeper part of the sand and gravel aquifer. In the County Well, there was a lag of about 12 hours between the start of pond recharge and an increase in groundwater level, and a lag of about 10 hours between the end of pond recharge and a groundwater level decline because of cemented gravels underlying the uppermost saturated zone and the deeper part of the aquifer where the well is completed.

5.2.5.2 Temperature Response

The following summarizes the temperature response during the test:

- The groundwater temperature in the shallow piezometers was generally stable or increased slightly (about 0.2°C) in the week prior to the start of the test. In the deeper wells, the groundwater temperature was either stable (MW-1) or decreased about 0.2°C in the week before the test started.
- The temperature of the recharge water was about 6.5 to 7.5°C. The shallow groundwater temperature ranged from about 7.5 to 9.5°C at the start of the test. The groundwater temperature in the County Well was about 8.5°C at the start of the test, and the groundwater temperature in MW-1 was about 11.4°C.
- During the recharge test, the groundwater temperature in the shallow piezometers PZ-1 and PZ-2 decreased about 0.7 to 1.2°C. In PZ-1, the maximum temperature decrease occurred about one day after the start of the test. After about one day of recharge, the temperature started to increase, with an increase of about 0.5°C over the test duration. In PZ-2, the maximum temperature increase occurred at the end of the recharge period. In shallow piezometer PZ-4, the temperature increased by about 0.5°C during the test. In the deeper wells, the groundwater temperature decreased slightly (0.1 to 0.2°C) in the County Well, and was stable in MW-1.
- In the shallow piezometers, the groundwater temperature increased after recharge stopped. In PZ-1, the temperature increased by 0.5°C 12 hours after recharge stopped. Following the immediate increase at the end of recharge, the groundwater temperature increased about 0.2°C over the next 60 days. In PZ-2, the temperature the groundwater temperature increased by about 0.8 °C over the 10 days after recharge was shutdown. In PZ-4, the temperature

increased during and after the recharge period. About 60 days after recharge ended, the temperature stabilized for about 2 weeks.

- In the County Well, the groundwater temperature started to increase about 10 days after recharge ended. About 60 days after recharge ended, the groundwater temperature was about 1.4°C higher than the end of recharge.

5.2.6 Titus Creek

No stage or flow measurements are available from Titus Creek during the shakedown test. Water temperature measurements collected during the recharge period are shown on Figure 5-15. The temperature was generally stable at about 10.6°C during the test, with small daily fluctuations.

5.2.7 Groundwater Flow

Groundwater levels increased in all of the monitored shallow piezometers during the test by about 4.9 to 7 feet. At the end of recharge, the depths to water in the piezometers near the pond (PZ-1, PZ-2, and PZ-4) were about 1.2 to 4.3 feet bgs.

The groundwater level in the County Well increased about 4.5 feet. The depth to water in the County Well was about 2.5 feet bgs at the end of recharge. Groundwater elevations at the end of the test are shown on Figure 5-18, and summarized on Table 5-1. Groundwater flow is to the west-southwest, similar to the pre-test groundwater flow direction. The hydraulic gradient near the pond at the end of the test is about 0.013 ft/ft, a slight increase of about 0.003 ft/ft from the pre-recharge condition.

5.2.8 Groundwater Discharge

After about 10 days of recharge, groundwater discharge occurred in a cut back about 3,400 feet west-southwest of the infiltration pond. Water was observed discharging from a bank of sand and gravel into the parking of a business (Figures 5-16 and 5-17). The discharge location is downgradient of the Mill Creek WTP (Figure 5-18). The discharge rate was not measured, but was visually estimated to be about 100 gpm by City of Walla Walla personnel. Groundwater discharge continued for about a week after pond recharge stopped.

A review of historic Walla Walla water system maps indicated a historic wood stave pipeline crossed the area of the infiltration pond and the area where the groundwater discharge occurred (Figure 5-18). The pipeline was constructed along the railroad grade from Walla Walla east to Tracy (now abandoned). The pipeline conveyed water from Mill Creek to Walla Walla prior to the construction of the Twin Reservoirs and a riveted iron pipeline (along a different alignment along Mill Creek Road) to serve the City in 1921. In 1953, two new welded iron pipelines were installed along the same alignment as the old wood stave pipeline. Assuming the pipeline alignment (trench) was backfilled with gravel materials, then these materials could have acted as a preferential pathway if the groundwater level rose and discharged to the pipeline trench.

5.2.9 Interpretation of Groundwater Temperature Data

The temperature data from the raw water and the groundwater temperatures in PZ-1 and PZ-2 were used to interpret the hydraulic properties in the uppermost saturated zone. The following relationship describing advective transport in groundwater was used to determine the “breakthrough” of recharge water in the piezometers (Freeze and Cherry 1979) and thus estimate the groundwater velocity and hydraulic conductivity of the shallow aquifer:

$C/C_0 = C_m - C_b / C_r - C_b$ (Equation 1)

Where:

C/C_0 is the relative proportion of recharge water in the native groundwater (dimensionless);

C_m is the measured temperature of the native groundwater (°C);

C_b is pre-recharge temperature of the native groundwater (°C); and

C_r is the temperature of the recharge water (°C).

This relationship was developed to describe the transport of conservative (non-reactive) species in a porous media. It assumes the concentration of the constituent being evaluated is constant in the groundwater and recharge water, and the constituent does not react with the aquifer mass or the groundwater. When C/C_0 is equal to one, the water is 100% recharge water. In the absence of diffusion or reactions between the recharge water and native groundwater or aquifer mass, a C/C_0 value of 0.5 corresponds to the breakthrough of recharge water and can be used to estimate the groundwater travel time from the source to the piezometer.

This method assumes the temperature of native groundwater and recharge water are constant. During the recharge test, the temperature of the recharge water and native groundwater increased, and the temperature of the recharge water likely started to equilibrate with the aquifer matrix and native groundwater, which was warmer than the recharge water. C/C_0 was calculated for temperature at PZ-1 and PZ-2, where a temperature change was observed within the first few hours of the test and thus there would be limited interaction between the recharge water and the aquifer matrix.

In PZ-4, the groundwater temperature did not change during the test. About 60 days after the test ended, a 2-week period of stable groundwater temperatures occurred that may represent the passage of the recharge water plume.

5.2.9.1 PZ-1

PZ-1 is located about 40 feet from the center of recharge pond (Figure 2-1). In PZ-1, breakthrough ($C/C_0 = 0.5$) occurred about 330 minutes after recharge started (Figure 5-19). The breakthrough time can be used to estimate the groundwater velocity using the following relationship (Freeze and Cherry 1979):

$v = d/t$ (Equation 2)

where

v is the groundwater velocity (ft/d)

d is this distance from the piezometer to the recharge pond (feet)

t is the time when C/C_0 equals 0.5 (days)

Thus, the estimated groundwater velocity is about 175 feet per day.

The hydraulic conductivity of the uppermost saturated zone can be estimated using the following relationship (Freeze and Cherry 1979):

$K = vn/i$ (Equation 3)

where

K is the hydraulic conductivity (ft/d)

v is the groundwater velocity (ft/d)

n is effective porosity (dimensionless)

i is the hydraulic gradient

The hydraulic gradient at time of breakthrough is unknown because the water level in the infiltration pond was below the ground surface (about 1,234 feet msl). The hydraulic gradient was therefore estimated assuming the groundwater elevation was between 1 to 3 feet below the pond base. The effective porosity of the formation materials was estimated to range from 10 to 20%. Using these assumptions, the hydraulic conductivity is estimated to range from about 200 to over 1,000 ft/d (Table 5-2). Based on the descriptions of the geologic materials and the falling head test completed in the piezometer (hydraulic conductivity equal to 169 ft/d), the likely range of hydraulic conductivities is about 200 to 400 ft/d. The higher hydraulic conductivities estimated based on the temperature data may reflect the presence of larger-scale preferential pathways of higher hydraulic conductivity such as relict stream channels within the uppermost saturated zone.

5.2.9.2 PZ-2

PZ-2 is located about 250 feet south-southeast of the infiltration pond and the water level response in this piezometer to recharge suggests that there may be preferential pathways in this direction. In PZ-2, the groundwater temperature started to decrease about 17.5 hours after recharge started, and the minimum groundwater temperature was observed after about nine days of recharge (Figure 5-8). Breakthrough did not occur at PZ-2 (maximum C/C_0 = 0.3 occurred about 7 days after recharge started). This suggests that PZ-2 may be located on the edge of the recharge water plume, where limited mixing between the recharge water and native groundwater occurred. This is consistent with the groundwater flow directions interpreted from the groundwater elevation data (Figure 5-18) that shows generally southwesterly groundwater flow from the recharge pond.

The temperature data has been used to make a semi-quantitative estimate of the groundwater velocity and hydraulic conductivity. This was completed by assuming the maximum C/C_0 of about 0.3 represented breakthrough. The maximum C/C_0 occurred about 7 days after the start of recharge. Applying equation (1) to the assumed breakthrough time results in an estimated groundwater velocity about 36 ft/d. This represents a maximum velocity because breakthrough (C/C_0 = 0.5) did not occur at PZ-2. The groundwater velocity thus may be in the range of 20 to 30 ft/d and the hydraulic conductivity may be in the range of 100 to 300 ft/d. This is much greater than the falling head test results, and suggests a locally low permeability zone near the piezometer with a much more permeable preferential pathway between the pond and the piezometer.

5.2.9.3 PZ-4

In PZ-4, located about 300 feet west (down-gradient) of the recharge pond, the groundwater temperature increased throughout the testing period and for about 60 days after testing stopped. About 60 days after recharge stopped, a stabilization in groundwater temperature was observed. This may be the result of the passage of cooler recharge water past the piezometer. The piezometer is about 300 feet from the pond. If the stabilization of the groundwater temperature represents the passage of recharge, the groundwater velocity is estimated to be about 5 feet per day. Assuming the hydraulic gradient between PZ-4 and the pond is 0.010 ft/ft and the effective porosity of the aquifer ranges from 10 to 20%, the hydraulic conductivity is estimated to be 50 to 100 ft/d. The estimated hydraulic conductivity of 50 to 100 ft/d is consistent with the hydraulic conductivities estimated from the falling head tests (Table 3-2).

5.3 Recharge Test Interpretation

The shallow aquifer at the WTP consists of an uppermost saturated zone that consists of sand and gravel with a variable amount of silt. These materials are interpreted to be alluvial materials. The uppermost saturated zone is about 15 to 20 feet thick (extending from 25 to 30 feet bgs with a depth to water of about 10 feet bgs), and is underlain by lower permeability cemented gravels or silty sands and gravels extending to a depth of about 137 feet in the WTP area. The materials underlying the uppermost saturated zone are saturated but because of the lower permeability, do not readily accept recharge water, and thus the recharge water preferentially flows horizontally within the uppermost saturated zone.

The groundwater level and temperature response indicates the uppermost saturated zone is heterogeneous, with areas of higher permeability that act as preferential pathways for the recharge water. The recharge test suggests that the area around the pond (PZ-1) and south of the pond (PZ-2) is higher conductivity than the area west of the pond (PZ-4). In addition, the alignment of a historical buried wood stave pipeline crossed the area south of the recharge pond. The pipeline alignment may have provided a man-made preferential pathway for recharge water within the groundwater flow system.

A groundwater mound height of about 5 to 7 feet was observed in the piezometers at the end of the 10-day recharge test. Previous estimates of groundwater mounding were developed as part of the conceptual hydrogeologic model (Golder 2007b). These estimates assumed:

- A transmissivity of 10,000 to 60,000 ft^2/d;
- A specific yield of 0.25;
- A depth to water of 15 feet and an aquifer saturated thickness of 17 feet; (from 15 to 32 feet bgs)
- Recharge at rates of 0.25 to 1 cfs over 180 days; and
- An infiltration basin area of 150 by 50 feet (7,500 square feet).

The results of the groundwater mounding analysis presented in the conceptual hydrogeological model memorandum indicated a potential groundwater level rise of about 0.3 to 4.6 feet after 10 days of recharge using the Hantush (1967) method, and about 0.9 to 19 feet using the Jacob (1946) method.

The new piezometers indicate that the depth to water is about 10 feet bgs and the shallow aquifer is about 20 feet thick (extending from 10 to 30 feet bgs). Falling head tests indicate that the hydraulic conductivity of the uppermost saturated zone is in the range of about 6 to 170 ft/d, and the results of the hydraulic conductivity estimates based on the temperature data suggest a hydraulic conductivity of about 50 to 100 ft/d based on data in PZ-4, and about 200 to 400 ft/d based on PZ-1. Based on available data, the overall transmissivity of the shallow aquifer is estimated to be in the range of 2,000 to 8,000 ft^2/d. This range is lower than the transmissivity estimates used for groundwater mounding estimates as part of the conceptual hydrogeological model evaluation.

Given the improved understanding of the groundwater conditions and aquifer hydraulic parameters at the WTP site, the mounding calculations were re-run using the hydrogeologic data collected in the new piezometers. The analysis assumed:

1. Aquifer saturated thickness of 20 feet;
2. A recharge rate of 1,146 gpm (about 2.5 cfs);
3. Pond dimensions of 80 by 175 feet (14,000 square feet)
4. Aquifer transmissivity of 5,000 ft^2/d to 10,000 ft^2/d (equivalent to a hydraulic conductivity of 250 ft/d to 500 ft/d {assuming a 20-foot thick aquifer}); and
5. Aquifer specific yield of 0.25.

The results of the analysis are summarized in Table 5-3. The Hantush analysis predicts a groundwater level rise of about 10 to 18 feet at the center of the pond and about one foot at a distance of 1,300 feet from the pond. The predicted groundwater level rise with a transmissivity of 7,500 ft^2/d to 10,000 ft^2/d is similar to the observed groundwater level rise of about 7 feet at PZ-1, located about 50 feet from the center of the pond. This indicates that the overall transmissivity of the shallow aquifer may be in this range.

The decay of the recharge mound following the recharge test was also evaluated using the Hantush method and the principle of superposition. In this analysis, recharge is assumed to occur at a rate of 2.5 cfs, and the Hantush solution is used to predict the groundwater level rise over the recharge period (and continuing out for 40 days assuming that recharge was not terminated). In order to simulate the decay of the recharge mound at the end of the 10-day test period, the Hantush solution was used to predict the “drawdown” resulting from negative recharge (i.e. pumping) occurring at the same location starting 10 days after the start of recharge. The rate used to predict the water level drawdown following the recharge test was -2.5 cfs. The predicted buildup and drawdown are summed to evaluate the decay of the recharge mound after recharge ends.

The decay of the recharge mound after recharge ends was evaluated for a range of aquifer transmissivities from 5,000 to 10,000 ft^2/d. Analysis indicates that there would be a rapid groundwater level decline of about 9 to 15 feet in the first five days after recharge ends. Five days after recharge ends, the residual groundwater level buildup would be about 1.5 to 3 feet above the pre-test level (Figure 5-20). Over the remaining 30 days, the groundwater level would decline slowly. Thirty days after recharge ends, the residual groundwater level buildup would be about 0.7 foot above the pre-test level. This is similar to the response observed in the shallow piezometers.

6.0 CONCLUSIONS OF SHORT-TERM RECHARGE TEST

The following are the conclusions from the short-term recharge test:

- Silty sands and gravels comprise the uppermost water bearing zone at the Mill Creek WTP extending from the water table (approximate depth 10 feet bgs) to a depth of about 30 feet. The material is heterogeneous as a result of the depositional conditions.
- Groundwater levels in the shallow piezometers completed in the uppermost saturated zone downgradient of the pond responded to recharge within 2 hours of the start of the test. A groundwater level rise was observed in all of the shallow piezometers downgradient of the infiltration pond. At the end of recharge, the groundwater level increased between 4.9 and 7.1 feet. Groundwater levels also increased about 4.5 feet in the County Well, completed in a deeper part of the aquifer. MW-1, a well located upgradient of the infiltration pond and screened below the uppermost saturated zone at a depth of 75 to 80 feet bgs, did not respond to recharge.
- The depth to water at the end of recharge was about 2.2 to 4.3 feet bgs in the shallow piezometers. The depth to water in the County Well was about 3 feet bgs at the end of recharge.
- The groundwater levels in the shallow piezometers declined for about 5 days after recharge was stopped. After the period of decline following the end of recharge, groundwater levels stabilized for about 2 weeks. The stabilized groundwater levels were about 1.9 to 2.6 feet higher than the pre-test level. Following this 2-week period of stabilization, the groundwater levels declined over the next three weeks.
- Groundwater flow in the uppermost saturated zone is to the west-southwest. The groundwater flow direction at the end of the test was similar, with a slightly steeper hydraulic gradient.
- The temperature data from PZ-1, PZ-2, and PZ-4 were used to estimate the groundwater velocity and hydraulic conductivity of the shallow aquifer. Based on the breakthrough of the temperature at PZ-1, the groundwater velocity near the pond is about 175 ft/d, and the likely range of hydraulic conductivity is about 200 to 400 ft/d. At PZ-2, the groundwater velocity is estimated to range from about 20 to 30 ft/d and the hydraulic conductivity of about 100 to 300 ft/d. At PZ-4, the groundwater velocity was estimated to be about 5 ft/d and the hydraulic conductivity about 50 to 100 ft/d.
- About 10 days after recharge started, groundwater discharge was observed in a cut bank about 3,400 feet west of the recharge pond. Approximately 100 gpm discharged from the bank for about a week after recharge stopped.
- The results of the recharge test indicate the uppermost saturated zone is heterogeneous with moderate to high permeability ranging from about 50 to 400 ft/d. The overall large-scale transmissivity of the shallow aquifer is likely in the range of 7,500 to 10,000 ft^2/d. The highest hydraulic conductivity measurements may be associated with abandoned and infilled stream channels.
- Because of the high permeability of the shallow aquifer, the infiltration pond has the capacity to infiltrate a large volume of water (at least 1,000 gpm). However, because of the aquifer hydraulic properties and shallow depth to groundwater, recharge results in a rapid increase in groundwater levels in the shallow aquifer and discharge of water to the surface at a nearby local warehouse distributor. The pathway for water to discharge may be associated with a high-permeability gravel-filled trench previously enclosing a buried wood-stave water line.

7.0 SHALLOW AQUIFER RECHARGE FEASIBILITY

The development of a full-scale shallow aquifer recharge facility at the Mill Creek WTP to provide recharge to Titus Creek is not feasible. This is because:

- The uppermost saturated zone is relatively thin (15 to 20 feet) and of moderate transmissivity;
- The water table at the Mill Creek WTP is about 10 feet below the ground surface;
- The uppermost saturated zone is underlain by lower-permeability cemented or silty sands and gravels;
- The geological conditions, hydraulic properties, and shallow depth to groundwater of the uppermost saturated zone result in a rapid rise in water levels to near ground surface limiting the amount of water that can be stored in the shallow aquifer;
- Groundwater flow at the Mill Creek WTP is to the west-southwest toward the City;
- A man-made feature (the former wood-stave pipeline alignment) appears to act as a preferential pathway for recharge from the infiltration pond which would severely limit recharge rate and duration; and
- Water entering the sub-surface rapidly discharges at the toe of a cut-bank in a nearby parking lot rather than reaching Titus Creek.

These conditions all contribute to limit the amount of recharge that can be introduced to the shallow aquifer at the WTP site, and thus diminish the overall effectiveness of a shallow aquifer recharge program.

8.0 REFERENCES

Cooper, H. H., Jr. and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. *Transactions, American Geophysical Union*, Vol. 27, No.4.

Fountainhead, 2006, Strategic Plan, Shallow Aquifer Recharge, Strategy for Restoring and Seasonally Recharging Shallow Gravel Aquifer(s) and Spring-Fed Streams of the Walla Walla Watershed.

Freeze, R.A., and J.A. Cherry, 1979, Groundwater, Prentice Hall, New Jersey.

Golder Associates Inc., 2006, City of Walla Walla Updated Conceptual Hydrogeologic Model for Extended Area Aquifer Storage and Recovery Evaluation.

Golder Associates Inc., 2007a, Walla Walla Shallow Aquifer Recharge Project Pilot Test and Monitoring Plan.

Golder Associates Inc., 2007b, Shallow Aquifer Recharge Project; Mill Creek Water Treatment Facility – Conceptual Hydrogeologic Model.

Hantush, M.S., 1967. Growth and Decay of Groundwater-mounds in Response to Uniform Percolation, Water Resources Research, vol. 3, no. 1, pp. 227-234.

HDR/EES, 2005, Walla Walla Watershed Plan.

Kennedy Jenks, 2004, Hydrogeologic Assessment of the Mill Creek and Yellowhawk Creek Areas, Walla Walla, Washington.

Kennedy-Jenks, 2006a, Results of the First Season of Shallow Aquifer Recharge Testing at the Hall-Wentland Site, Umatilla County, Oregon, and Walla Walla County, Washington.

Kennedy-Jenks, 2006b, Technical Memorandum, Locher Road SAR Site Project Activities.

Newcomb, R.C., 1965, Geology and Ground-water Resources of the Walla Walla River Basin, Washington and Oregon, Washington Division of Water Resources Water Supply Bulletin 21.

Marti, P.B., 2005, Assessment of Surface Water and Groundwater Interchange in the Walla Walla Watershed, Washington State Department of Ecology Publication 05-3-020.

Walla Walla Basin Watershed Council, 2005, Provisional Hudson Bay Aquifer Recharge Testing Project 2005 Annual Report.

TABLES

TABLE 3-1

Piezometer and Well Construction Details

Well	Year of Construction	Northing	Easting	Total Depth (feet bgs)	Screened Interval (feet bgs)	Screened Interval (feet msl)	Screened Length (feet)	Depth to Groundwater (feet btc)[c]	Aquifer Thickness (Approx.) (feet)	Measuring Point Elevation (feet msl)	Groundwater Elevation (feet msl)	Instrumentation
MW-1	2006	283,250.34	2,209,881.74	83.2	75 to 80	to	5	64.36	5	1,266.23	1,201.87	INW PT2X
PZ-1	2007	282,851.89	2,208,562.85	75	26.9 to 31.9	to	5	12.10	19.80	1,239.76	1,227.66	INW PT2X
PZ-2	2007	282,578.83	2,208,712.68	27	17.3 to 22.3	to	5	8.61	18.4	1,238.69	1,230.08	INW PT2X
PZ-3	2007	283,036.21	2,208,727.44	27.7	19.6 to 24.6	to	5	11.55	16.2	1,243.33	1,231.78	Manual Measurements
PZ-4	2007	282,634.54	2,208,373.79	29.8	21.8 to 26.8	to	5	8.51	21.3	1,234.14	1,225.63	INW PT2X
MW-B1[a]	1996	282,816.02	2,208,897.03	25	14 to 19	to	5	10.87	14.1	1,241.22	1,230.35	Manual Measurements
County Well[b]	1992	282,412.03	2,207,830.87	182	112 to 172	to	60	9.82	60	1,226.45	1,216.63	INW PT2X

Notes:
a. MW-B1 was installed by Environmental West Exploration, Inc. in 1996, reportedly to help monitor shallow groundwater during construction of the Mill Creek WTP. The depth to water is referenced to the top of casing, which is mounted in a flush-mount monument.
b. The County Well was originally owned by Willis Logan (well log ID 430215).
c. Depth to water measurements obtained on March 1, 2007.
Well logs included in Attachment A.

Completed Piezometer Falling Head Test Results

Well Number	Completion Depth (feet bgs)	Hydraulic Conductivity (ft/d)	Hydraulic Conductivity (cm/s)	Saturated Thickness (feet)	Transmissivity (ft^2/d)	Geologic Material
PZ-1	26.9 - 31.9	169	0.060	19.8	3,346	Gravel and silty sand and gravel
PZ-2	17.3 - 22.3	6.3	0.002	18.4	116	Silty sand and gravel
PZ-3	19.6 - 24.6	54	0.019	16.2	872	Silty gravel
PZ-4	21.8 - 26.8	135	0.048	21.3	2,874	Silty sandy gravel
Geometric Mean	-	53	0.019		993	-

Falling Head Test Results - Drilling of PZ-1

Depth (feet below ground)	Hydraulic Conductivity (ft/d)	Hydraulic Conductivity (cm/s)	Geologic Material
21	74	0.026	Silty sand, gravel, and cobbles
23	45	0.016	Silty sand and gravel
36	1,030	0.363	Silty sand and gravel
49	1,370	0.483	Silty sand and gravel
57	315	0.111	Silty sand and gravel
Geometric Mean	272	0.096	-

Note:
Tests completed at 36 and 49 feet may be affected by leakage around the casing and results are suspect.

TABLE 4-1

Groundwater Flow Estimates

Hydraulic Conductivity (ft/d)	Assumed Saturated Thickness (feet)	Hydraulic Gradient (ft/ft)	Groundwater Flow (ft^3/d)	Groundwater Flow (gpm)	Groundwater Velocity (ft/d)
5	15	0.01	150	0.8	0.5
50	15	0.01	1,500	7.8	5
100	15	0.01	3,000	15.6	10.0
200	15	0.01	6,000	31.2	20.0
5	20	0.01	200	1.0	0.5
50	20	0.01	2,000	10.4	5.0
100	20	0.01	4,000	20.8	10.0
200	20	0.01	8,000	41.6	20.0

Note:
Groundwater flow calculated over a width of 200 feet
Effective porosity assumed to be 0.1 (10%)

TABLE 5-1

Groundwater Level Rise at End of Test

Well	Year of Construction	Northing	Easting	Measuring Point Elevation (feet msl)	Ground Elevation (feet msl)	Pre-Test Measurement[a]		End of Recharge Measurement[b]		Change in Water Level (feet)
						Depth to Groundwater (feet btc)	Groundwater Elevation (feet msl)	Depth to Groundwater (feet btc)	Groundwater Elevation (feet msl)	
MW-1	2006	283,250.34	2,209,881.74	1,266.23	1,263.73	61.20	1,205.03	60.36	1,205.88	0.85[c]
PZ-1	2007	282,851.89	2,208,562.85	1,239.76	1,237.96	13.10	1,226.66	6.05	1,233.71	7.05
PZ-2	2007	282,578.83	2,208,712.68	1,238.69	1,235.99	8.87	1,229.82	3.94	1,234.75	4.93
PZ-4	2007	282,634.54	2,208,373.79	1,234.14	1,231.84	9.23	1,224.91	3.65	1,230.49	5.58
County Well	1992	282,412.03	2,207,830.87	1,226.45	1,223.95	9.41	1,217.04	4.96	1,221.49	4.45

Notes

a. Pre-test measurement 4/11/07 at 11:00

b. End of recharge measurement 4/20/07 at 11:45

c. MW-1 is upgradient well in deeper part of system, groundwater levels were rising in MW-1 before test

TABLE 5-2

Groundwater Velocity and Hydraulic Conductivity Estimates

Location	Distance from Pond Center (feet)	Time when $C/C_0 = 0.5$ (days)	Groundwater Velocity (ft/d)	Groundwater Elevation Below Pond Center (feet msl)	Hydraulic Gradient (ft/ft)	Effective Porosity (percent)	Hydraulic Conductivity (ft/d)	Hydraulic Conductivity (cm/s)
PZ-1	40	0.23	175	1,231.0	0.033	10%	524	0.185
						15%	786	0.277
						20%	1,048	0.370
PZ-1	40	0.23	175	1,232.0	0.058	10%	299	0.106
						15%	449	0.158
						20%	599	0.211
PZ-1	40	0.23	175	1,233.0	0.083	10%	210	0.074
						15%	314	0.111
						20%	419	0.148

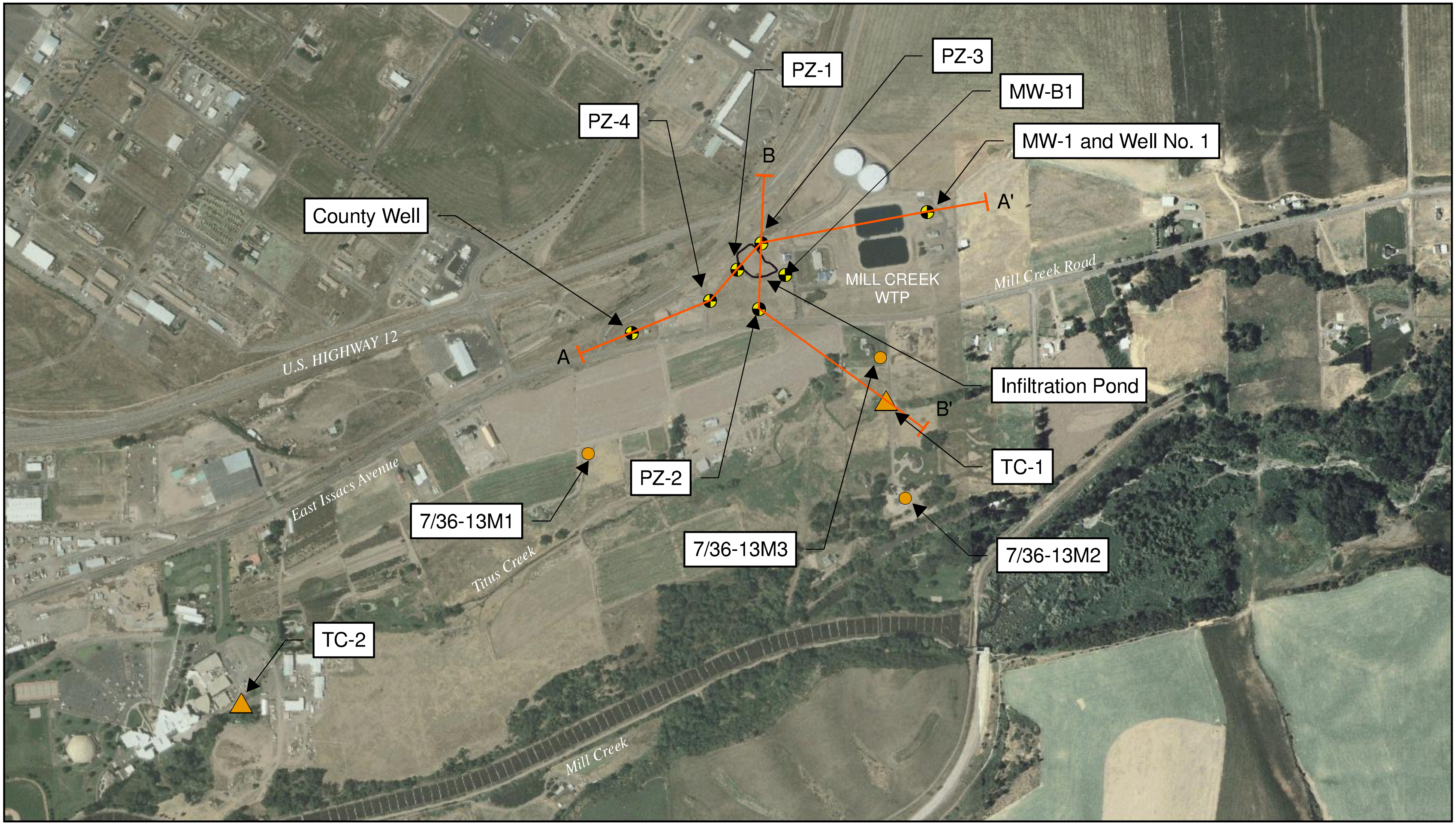
Note:
Groundwater elevation in PZ-1 1,229.67 msl at end of test.

Revised Groundwater Mounding Estimates

Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)[1]	Mound Height at Pond (feet)[2]	Mound Height at Pond (feet)[3]	Impact Radius (feet)[4]
5,000	250	18.2	18	1,227
7,500	375	13.1	13	1,294
10,000	500	10.3	10	1,318

Notes:
1. Based on a 20-foot aquifer thickness.
2. Calculated using Hantush (1967) method
3. Calculated using Jacob (1946) method
4. Defined as a water level rise of 1 foot.

FIGURES



LEGEND

- Monitoring Wells
- Stream Gages
- Other Wells Completed in Sand and Gravel Aquifer
- A A' Geologic Cross Section Location

Note: TC-2 installed by Walla Walla Basin Watershed Council. TC-1 installed by Golder.

0 1000
Scale in Feet

Map Projection:
Washington State Plane,
South Zone, NAD 83, Feet

Source: NAIP, Golder

N

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

FIGURE **2-1**

MONITORING WELL AND STREAM GAGE LOCATIONS

WALLA WALLA/SHALLOW AQUIFER RECHARGE/WA

0631345300F04R03.mxd | 11/15/2007 | KDEROUEN

Golder Associates

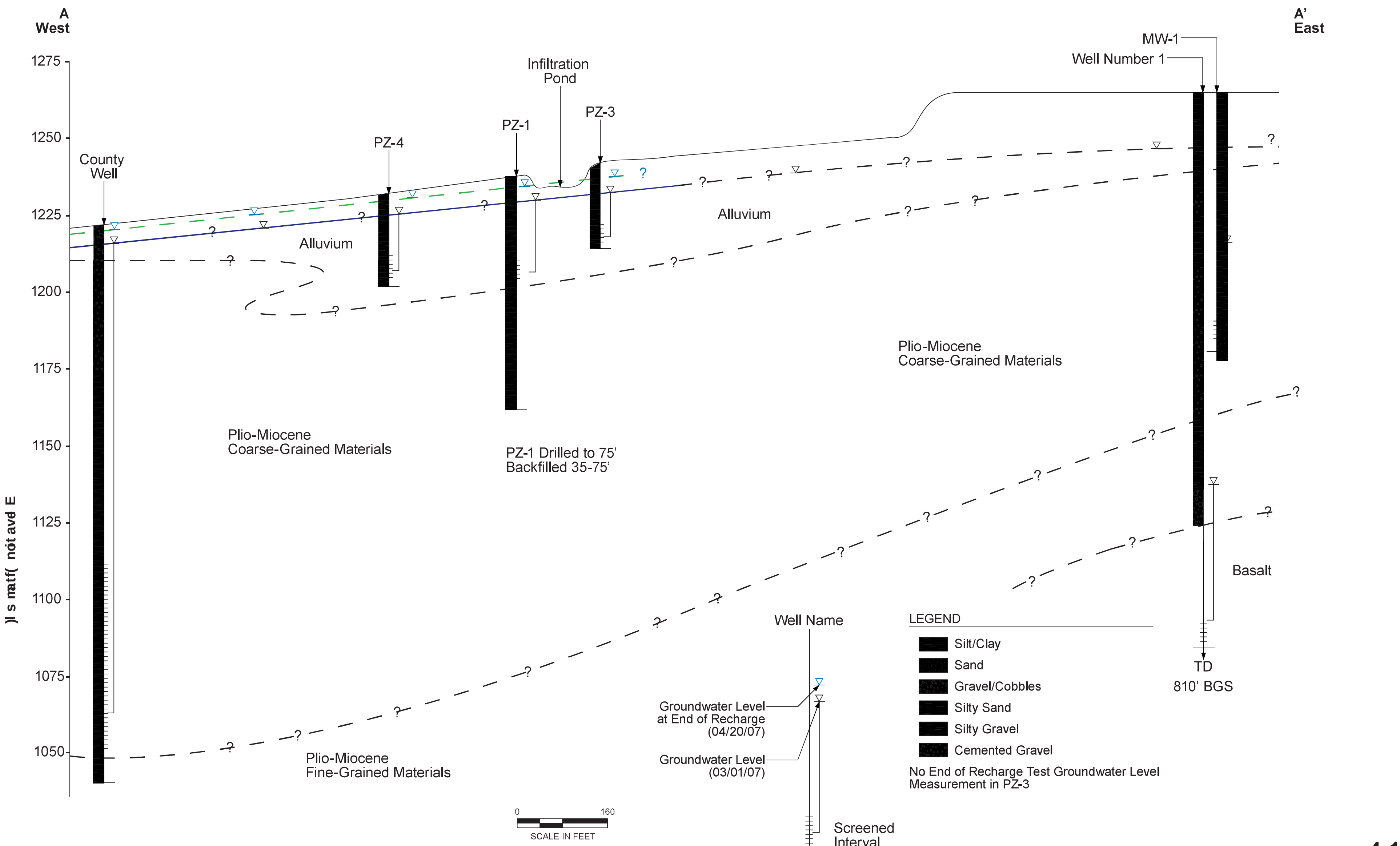


FIGURE 4-1
GEOLOGIC CROSS SECTION A-A'
WALLA WALLA/SHALLOW AQUIFER RECHARGE/WA

0631345600fig4-1.ai | Mod: 11/15/07 | AMP

Golder Associates

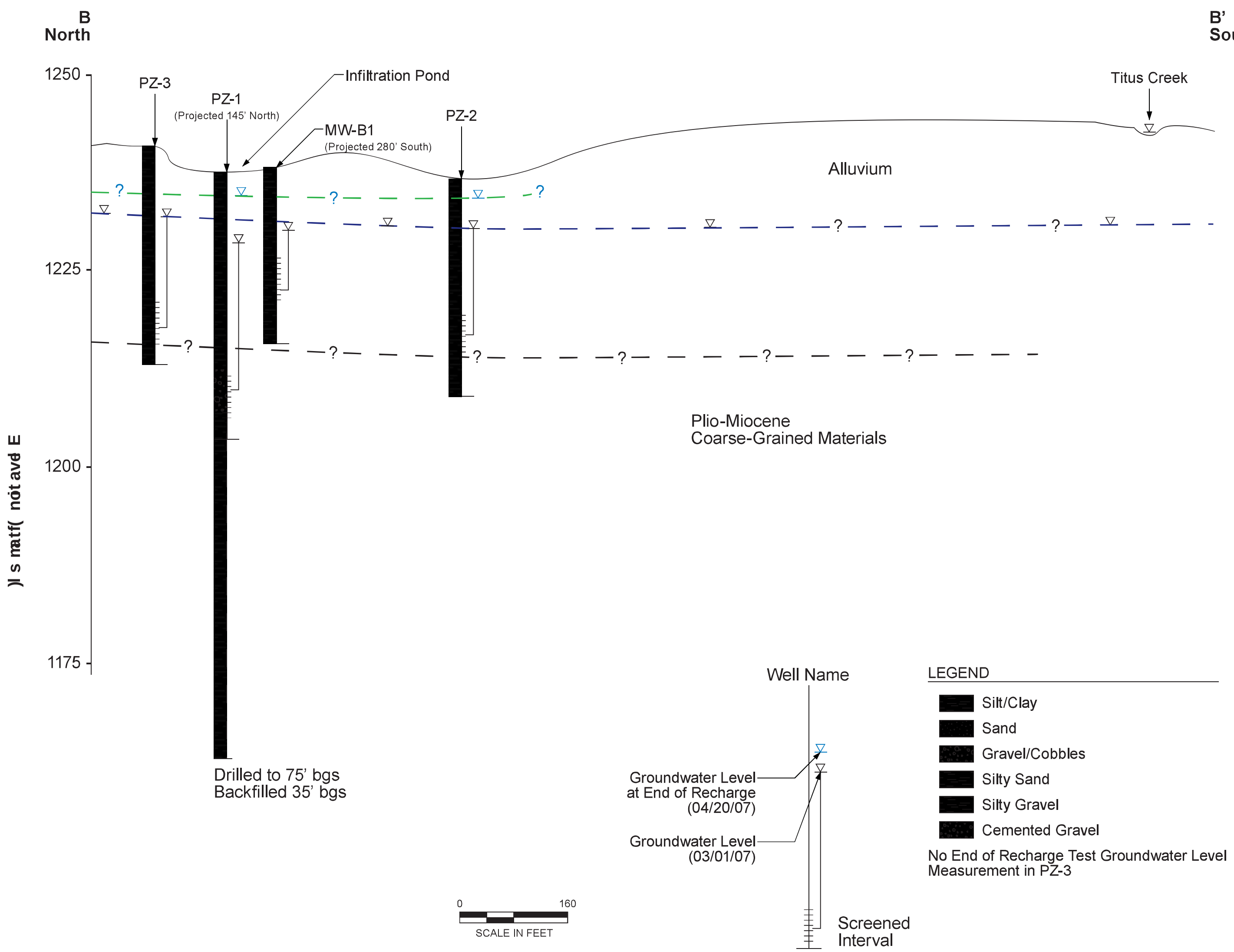
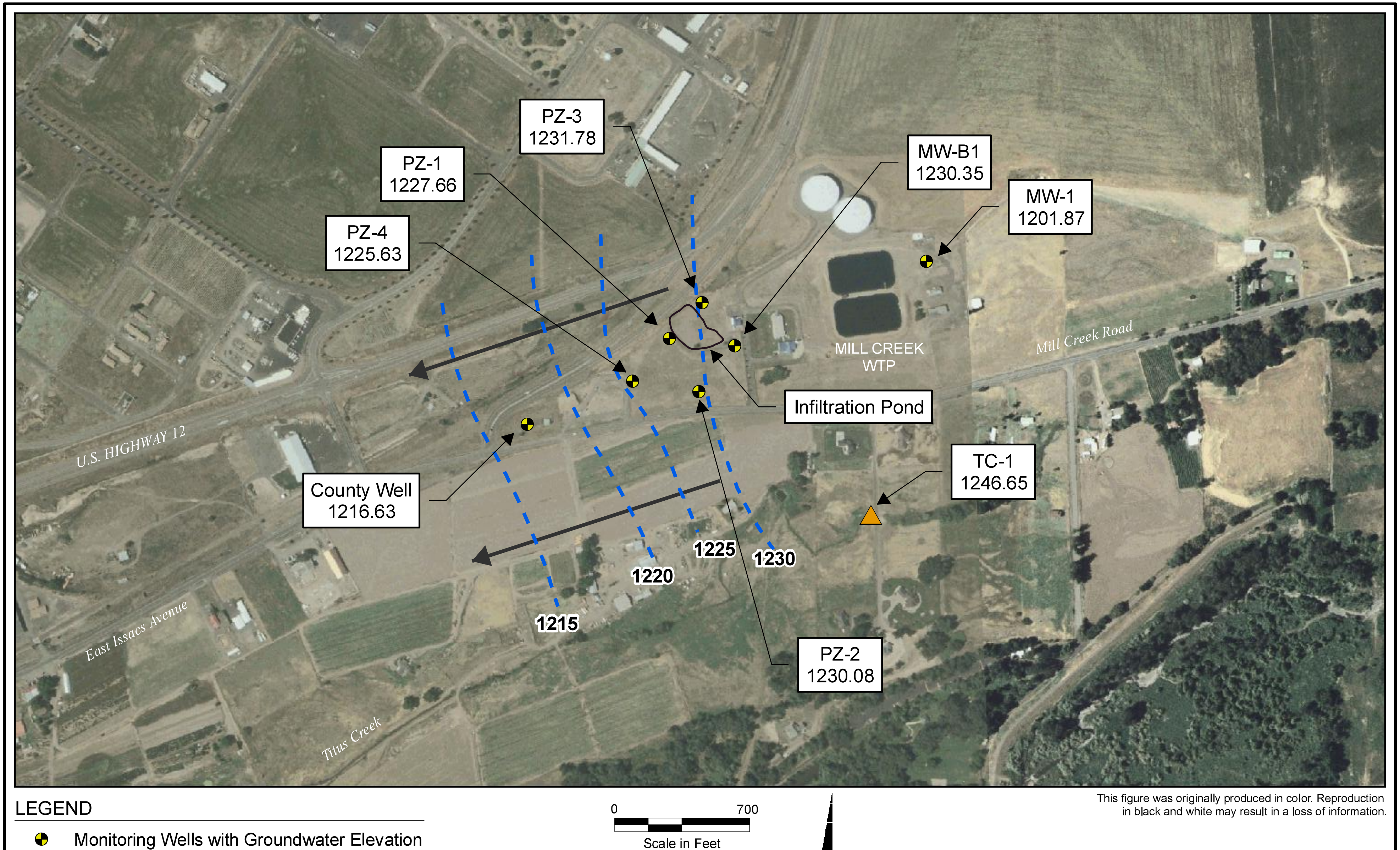


FIGURE 4-2
GEOLOGIC CROSS SECTION B-B'
WALLA WALLA/SHALLOW AQUIFER RECHARGE/WA

Golder Associates

0631345600fig4-2.ai | Mod: 11/15/07 | AMP



Note: Water Levels Measured March 1, 2007

Map Projection:
Washington State Plane,
South Zone, NAD 83, Feet

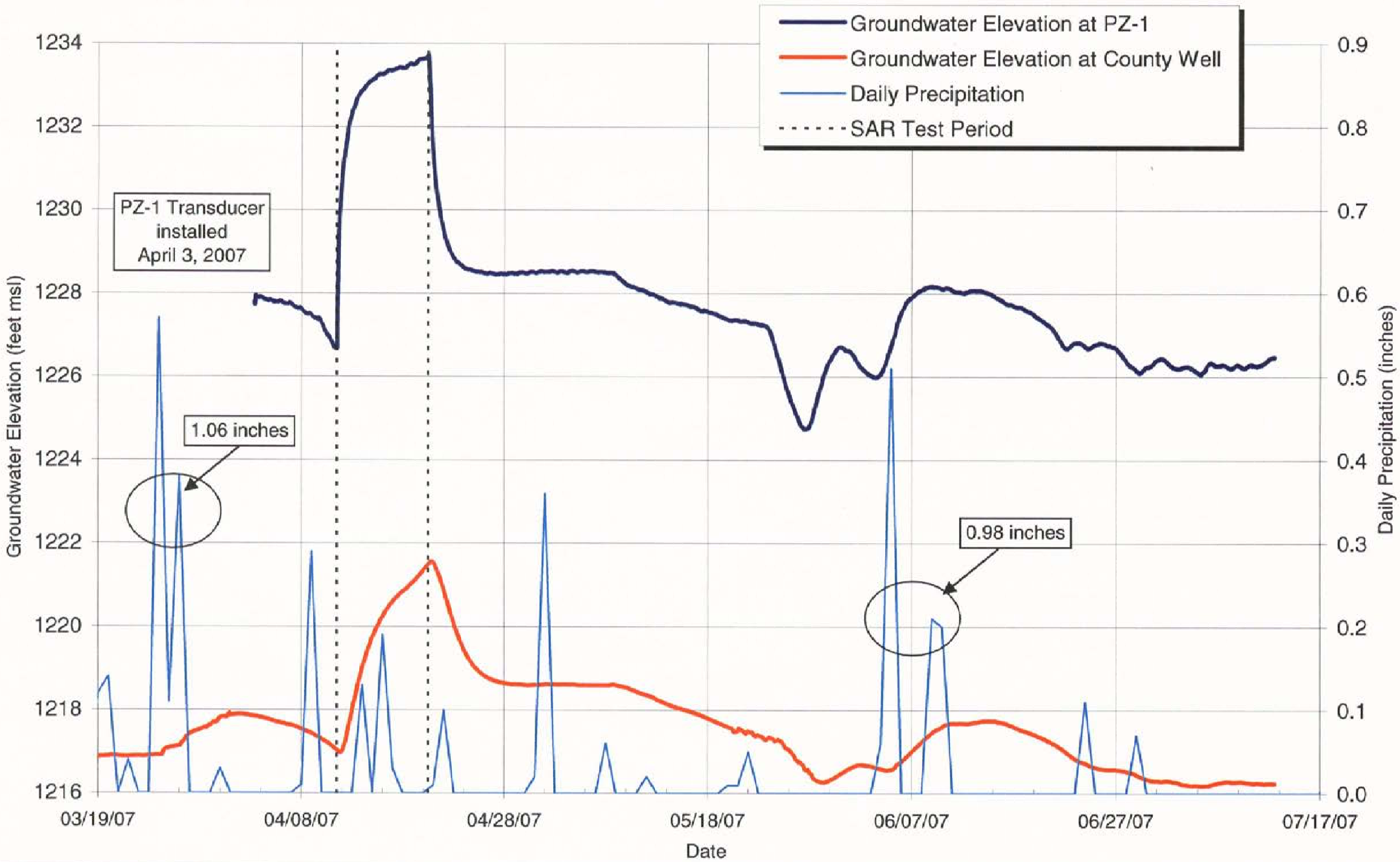
Source: NAIP, Golder

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

FIGURE **4-3**
GROUNDWATER FLOW
WALLA WALLA/SHALLOW AQUIFER RECHARGE/WA

0631345300F03R02.mxd | 11/9/2007 | KDEROUEN

Golder Associates



Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Groundwater Levels and Precipitation

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	4-4

FIGURE 5-1. Test Setup at Hydrant

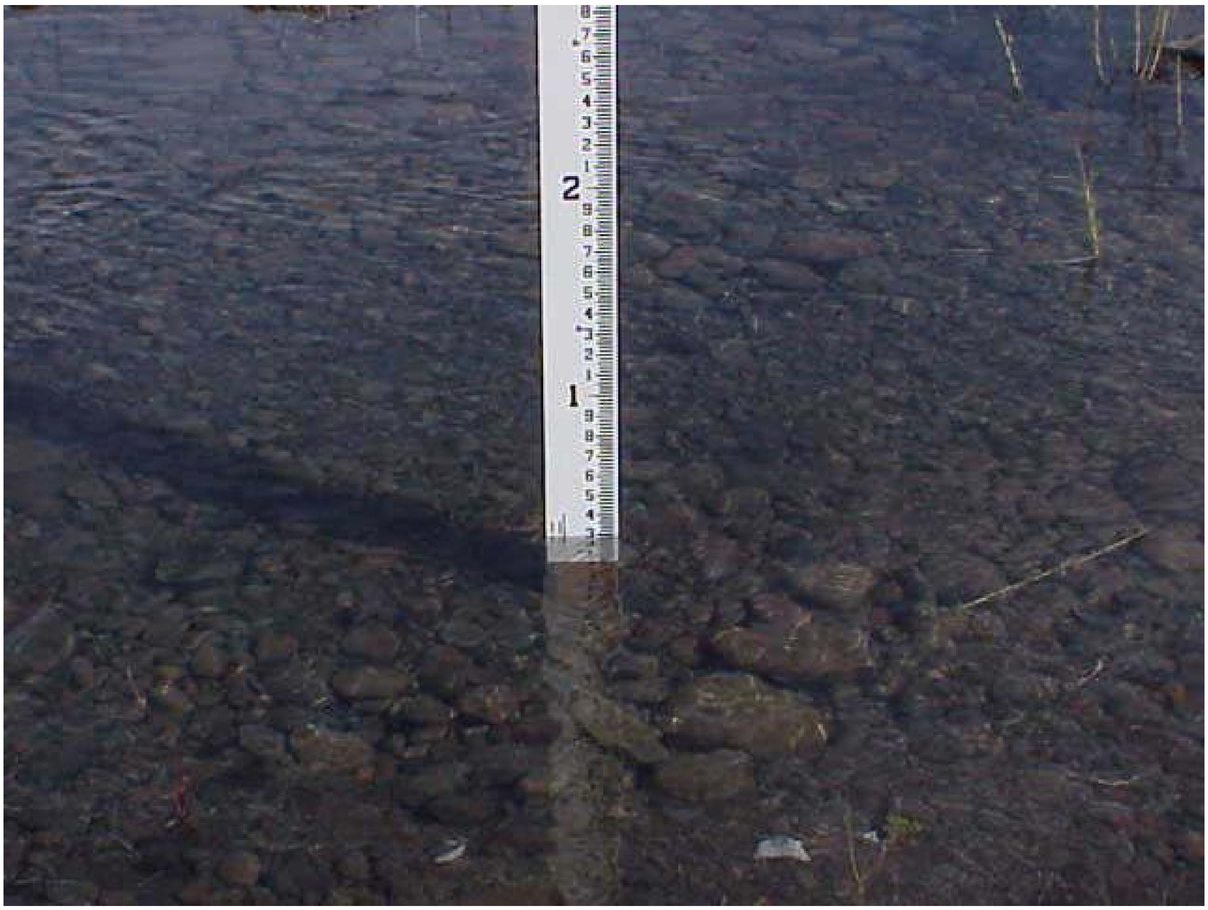
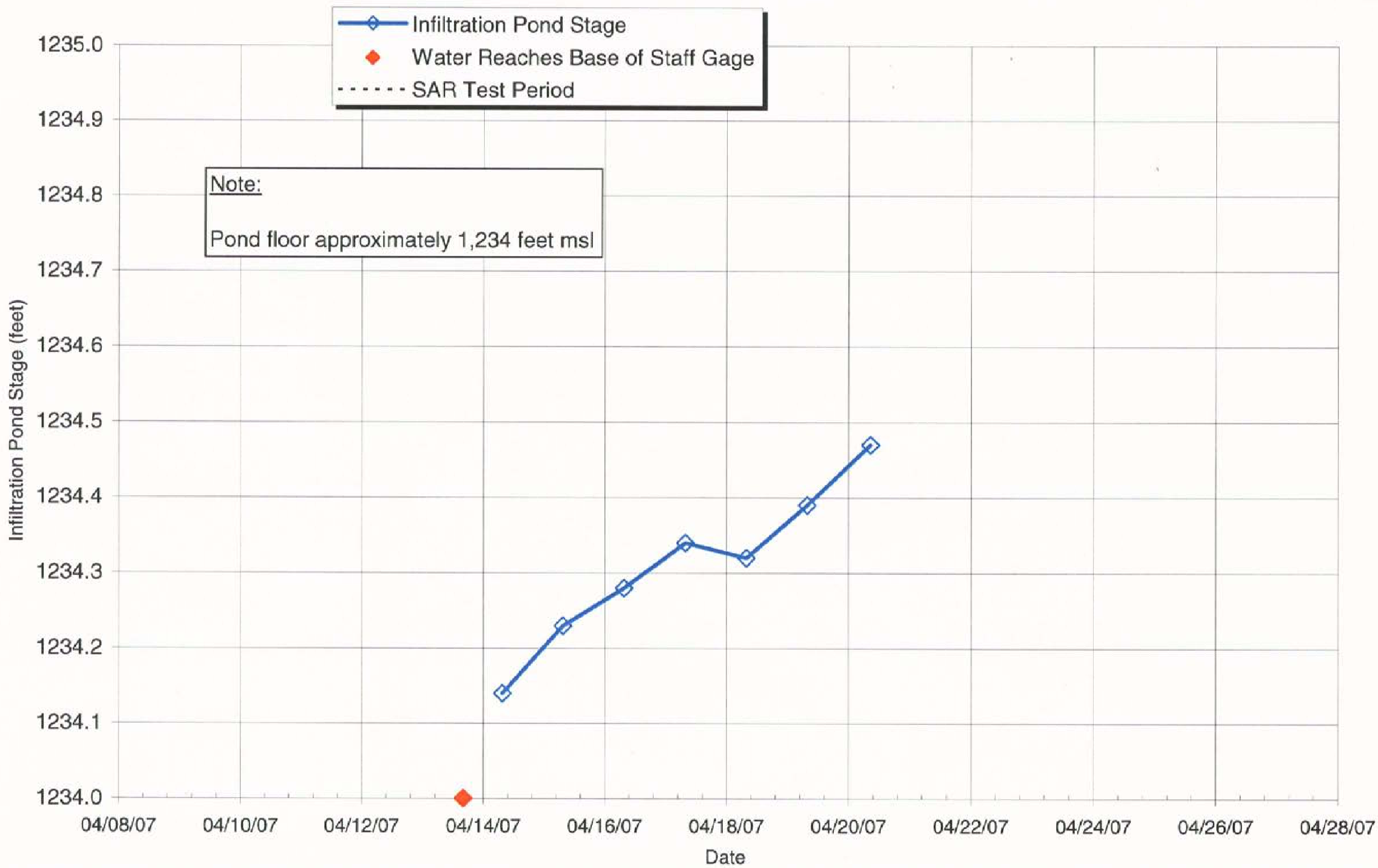


FIGURE 5-2. Pond Staff Gage



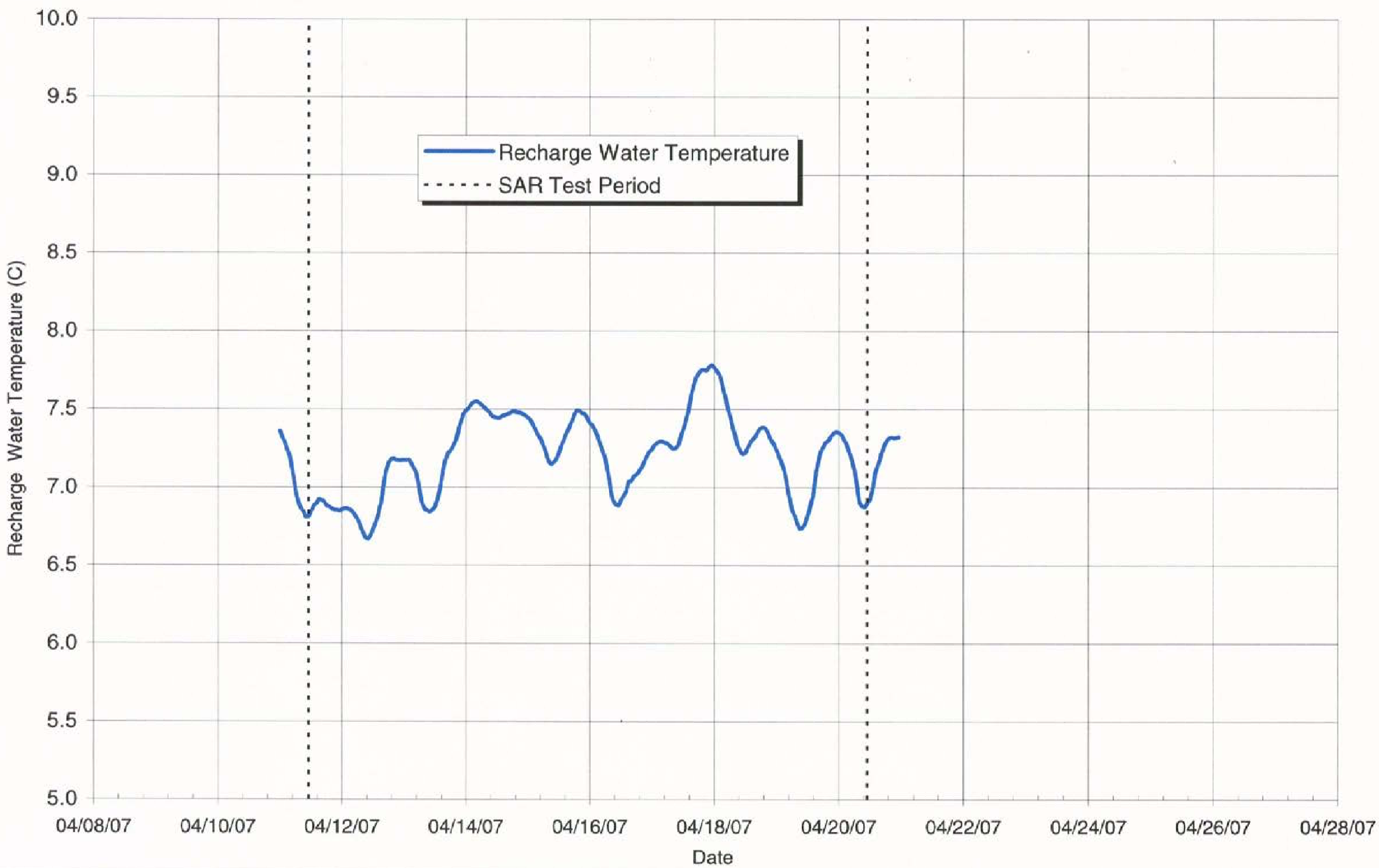
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Recharge Pond Stage

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	**5-3**



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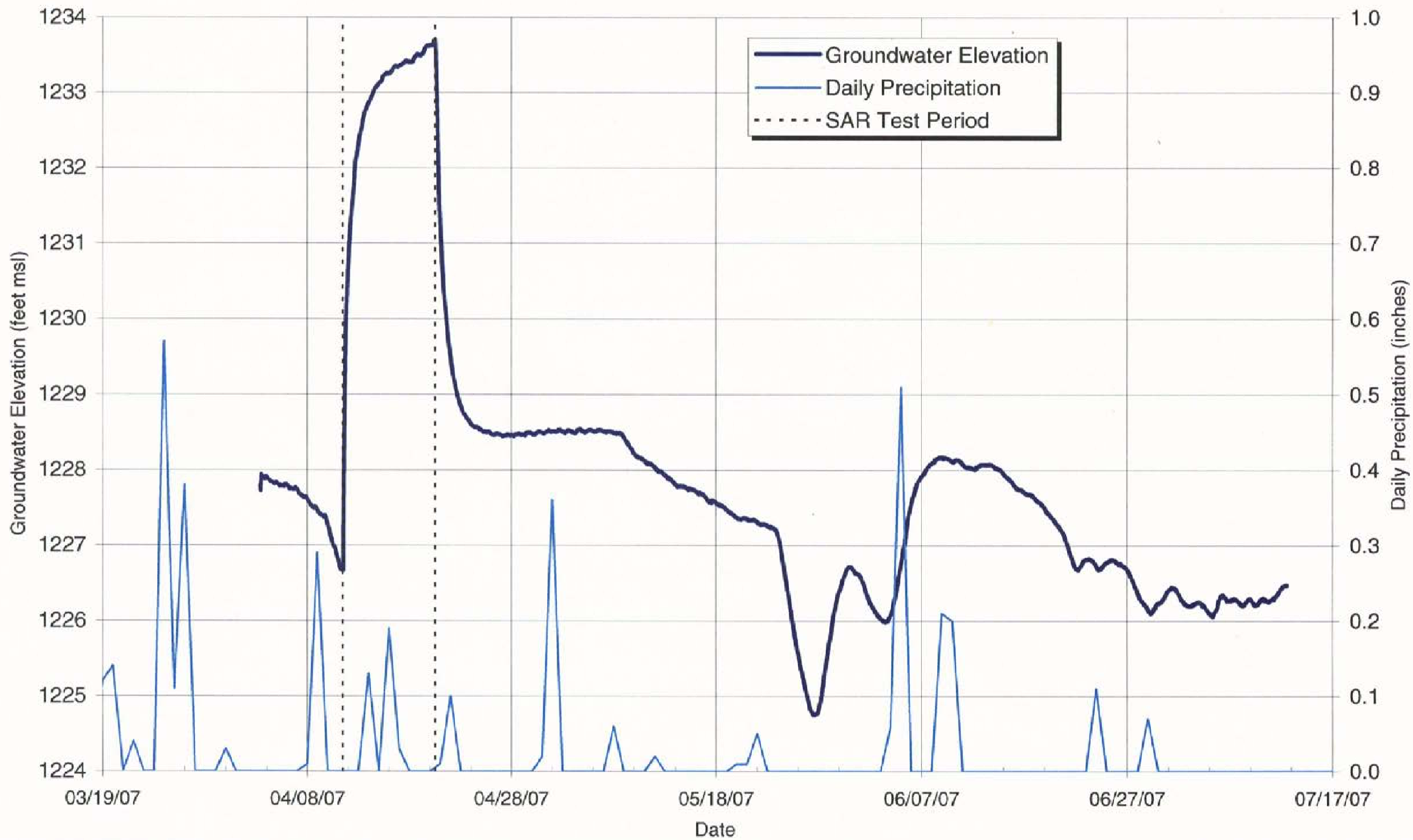
Walla Walla/Shallow Aquifer Recharge

TITLE

Mill Creek Raw Water Temperature

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	5-4



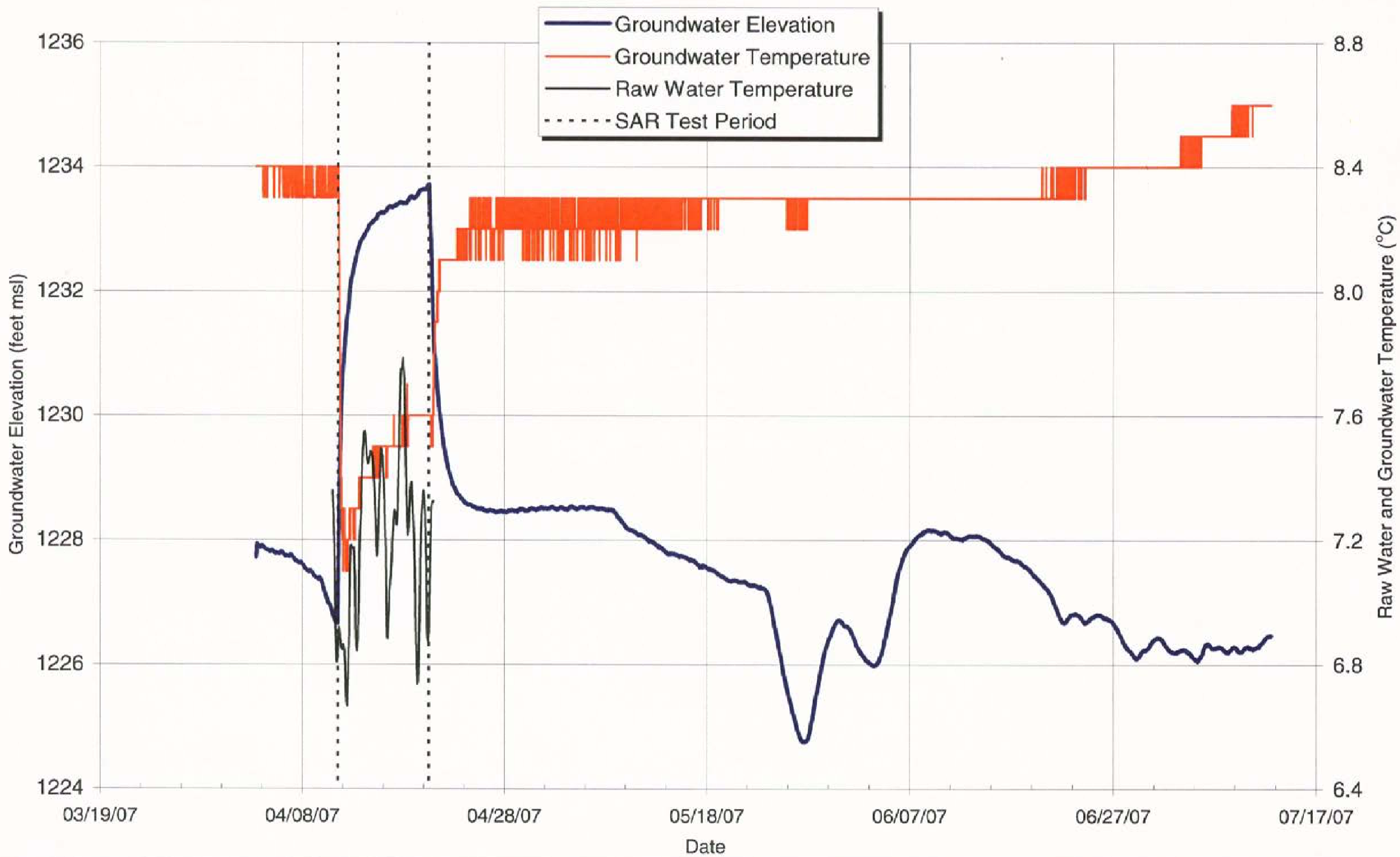
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Test Hydrograph - PZ-1

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	5-5



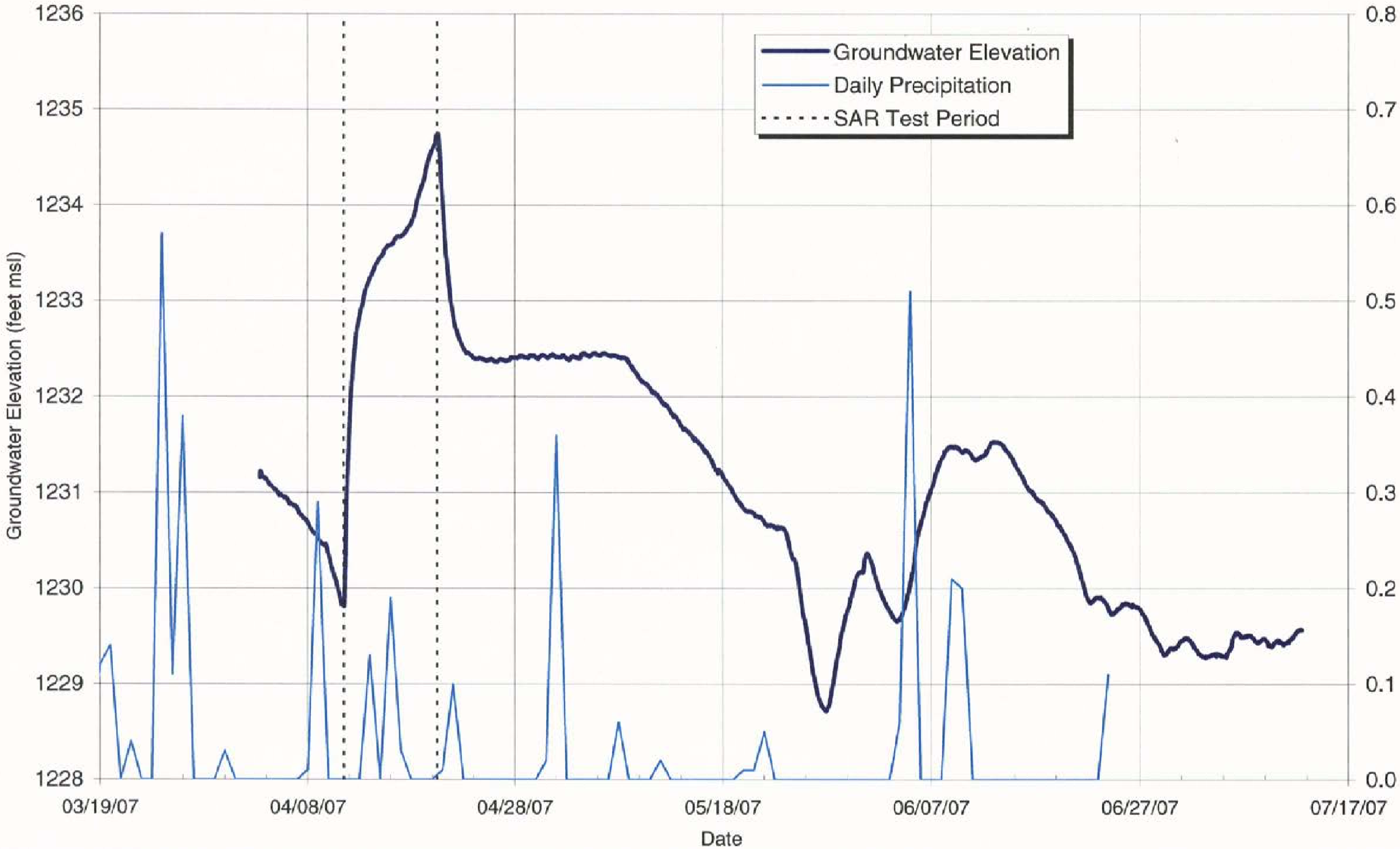
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Groundwater Temperature - PZ-1

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	5-6



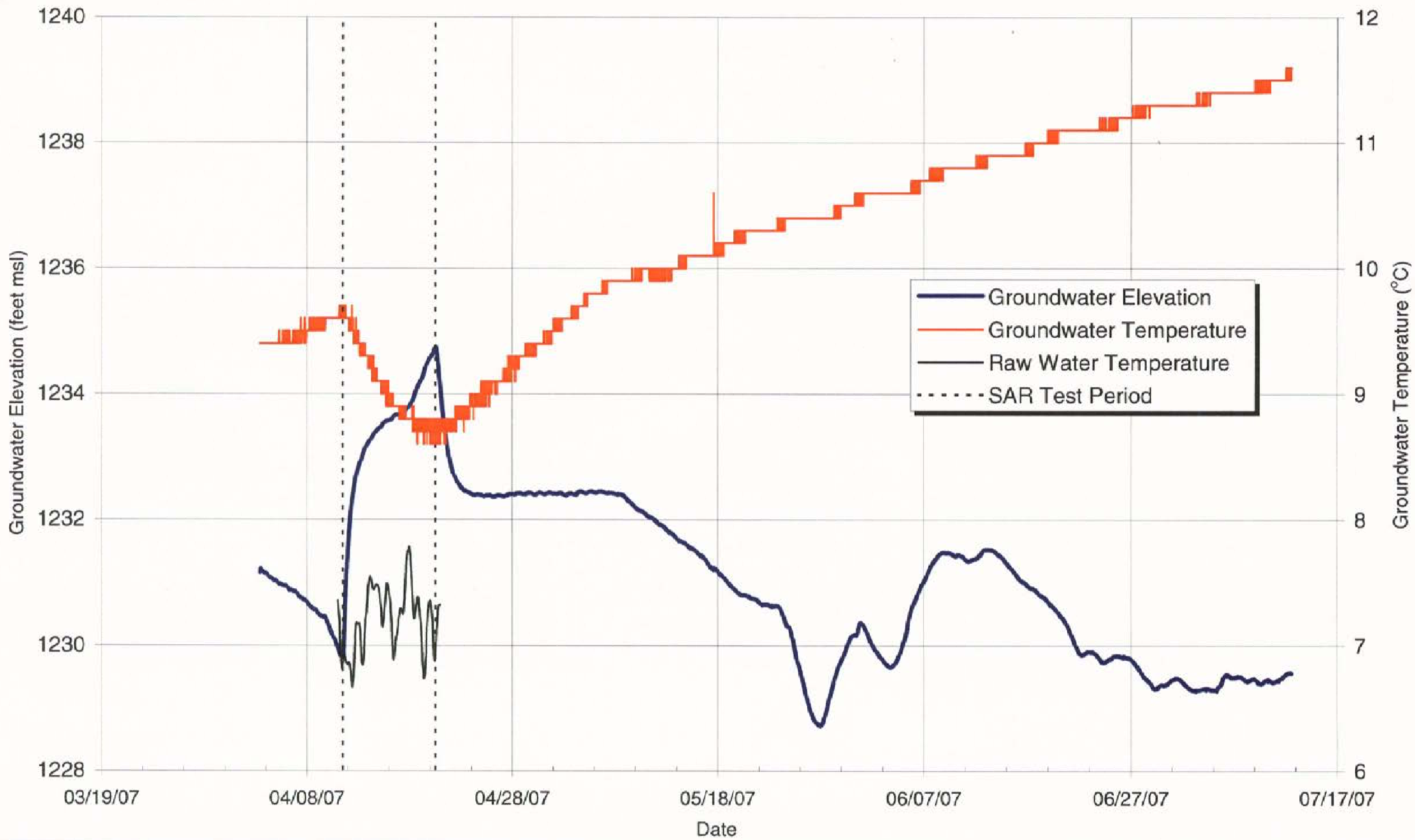
Golder Associates

TITLE

Test Hydrograph - PZ-2

Walla Walla/Shallow Aquifer Recharge

DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003	
CHECKED DH	SCALE na	DWG. NO. na	
REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. 5-7	



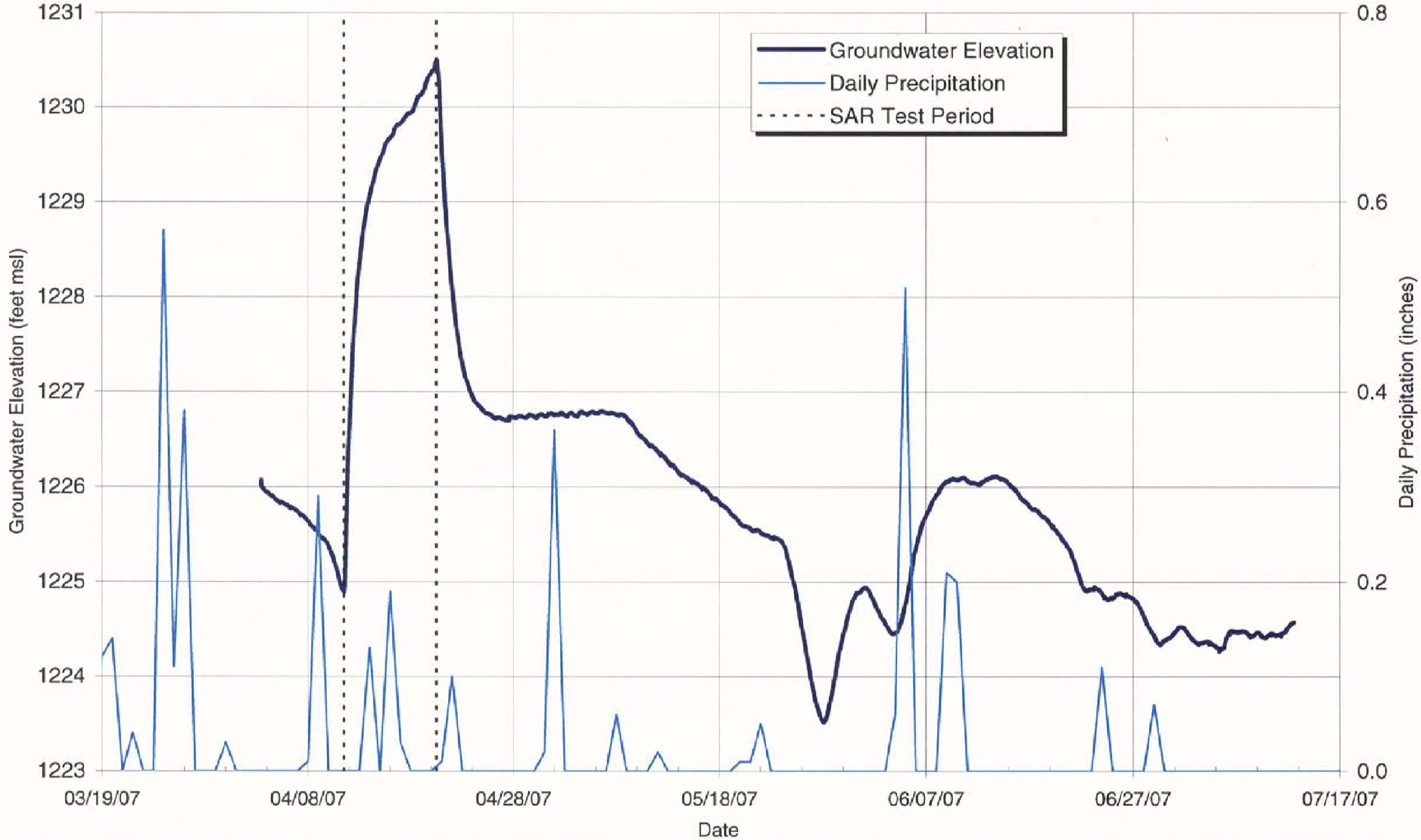
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Groundwater Temperature - PZ-2

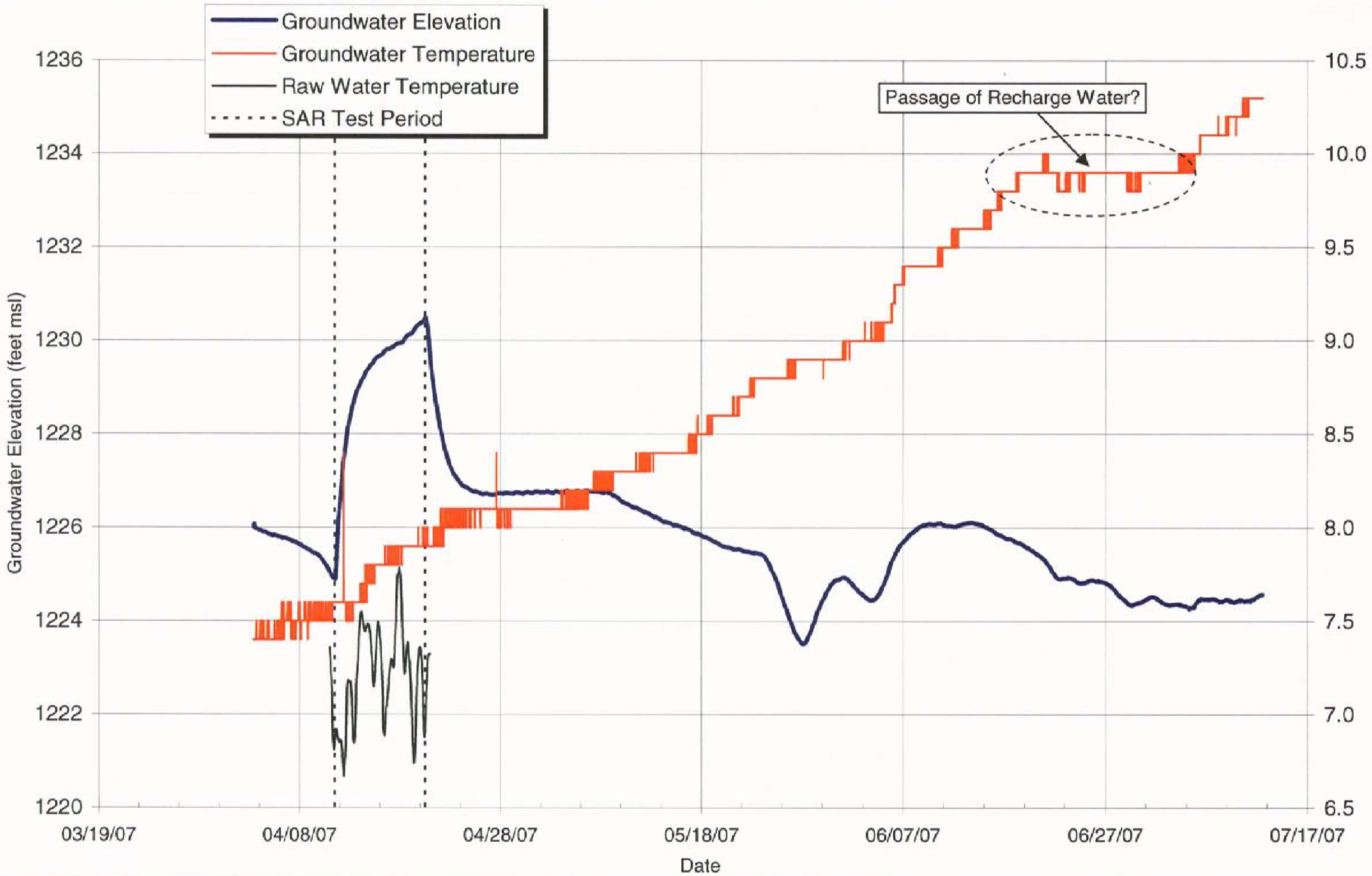
DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	**5-8**



Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE	**Test Hydrograph - PZ-4**		
DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003	
CHECKED DH	SCALE na	DWG. NO. na	
REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. **5-9**	



Golder Associates	TITLE Groundwater Temperature - PZ-4		
Walla Walla/Shallow Aquifer Recharge	DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003
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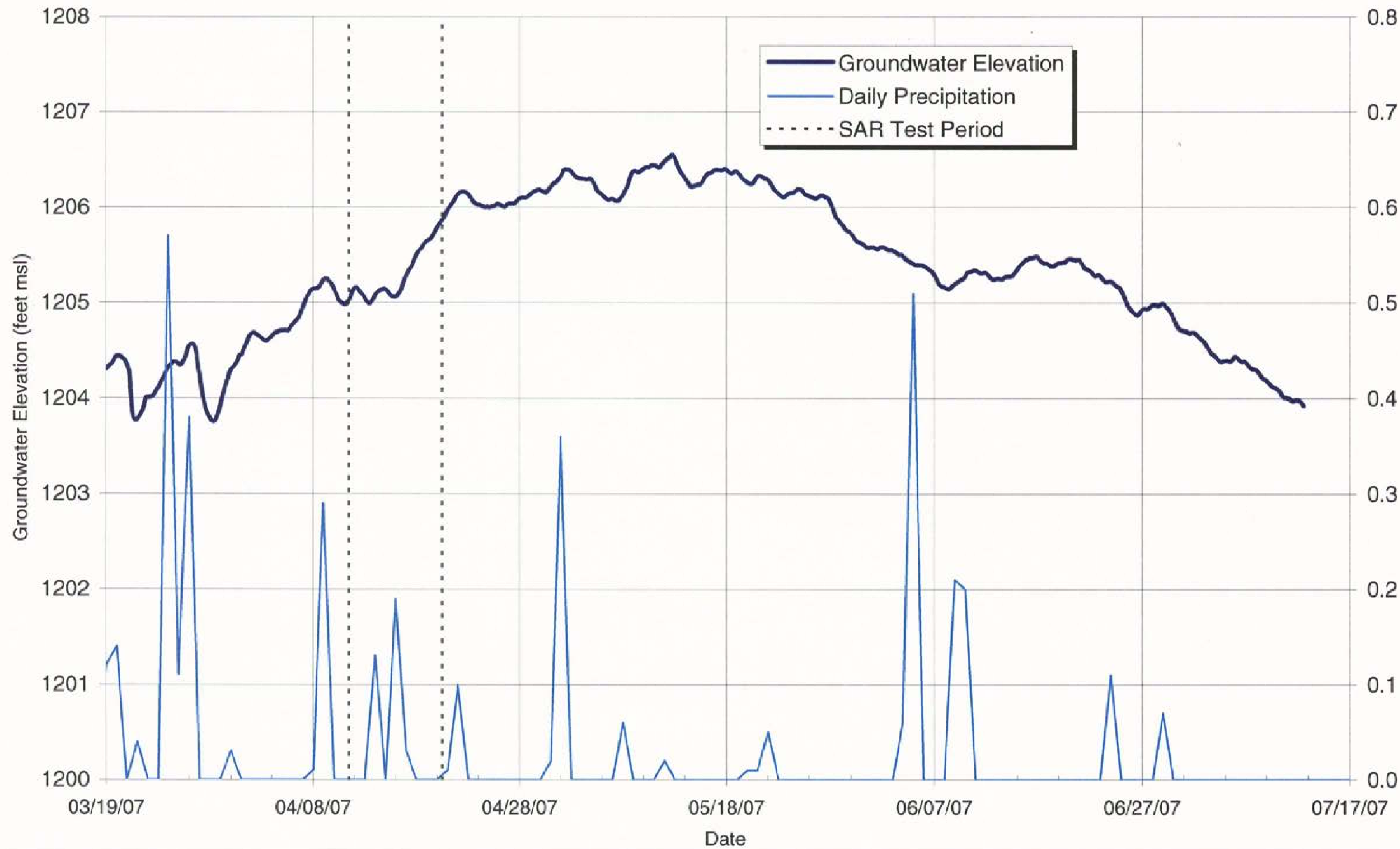
	REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. 5-10



Golder Associates

Walla Walla/Shallow Aquifer Recharge	TITLE Test Hydrograph - MW-1		
	DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003
	CHECKED DH	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. 5-11

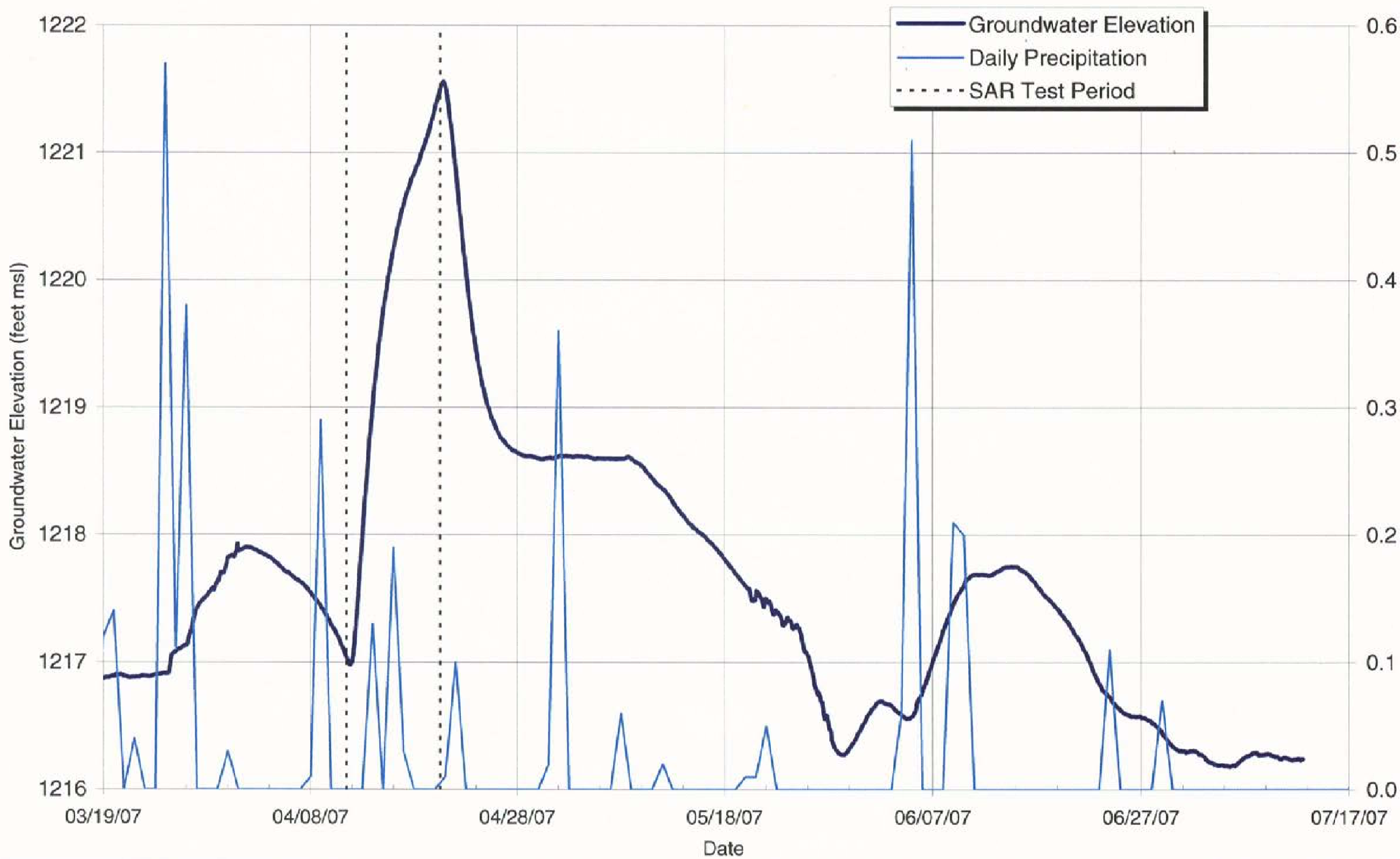
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

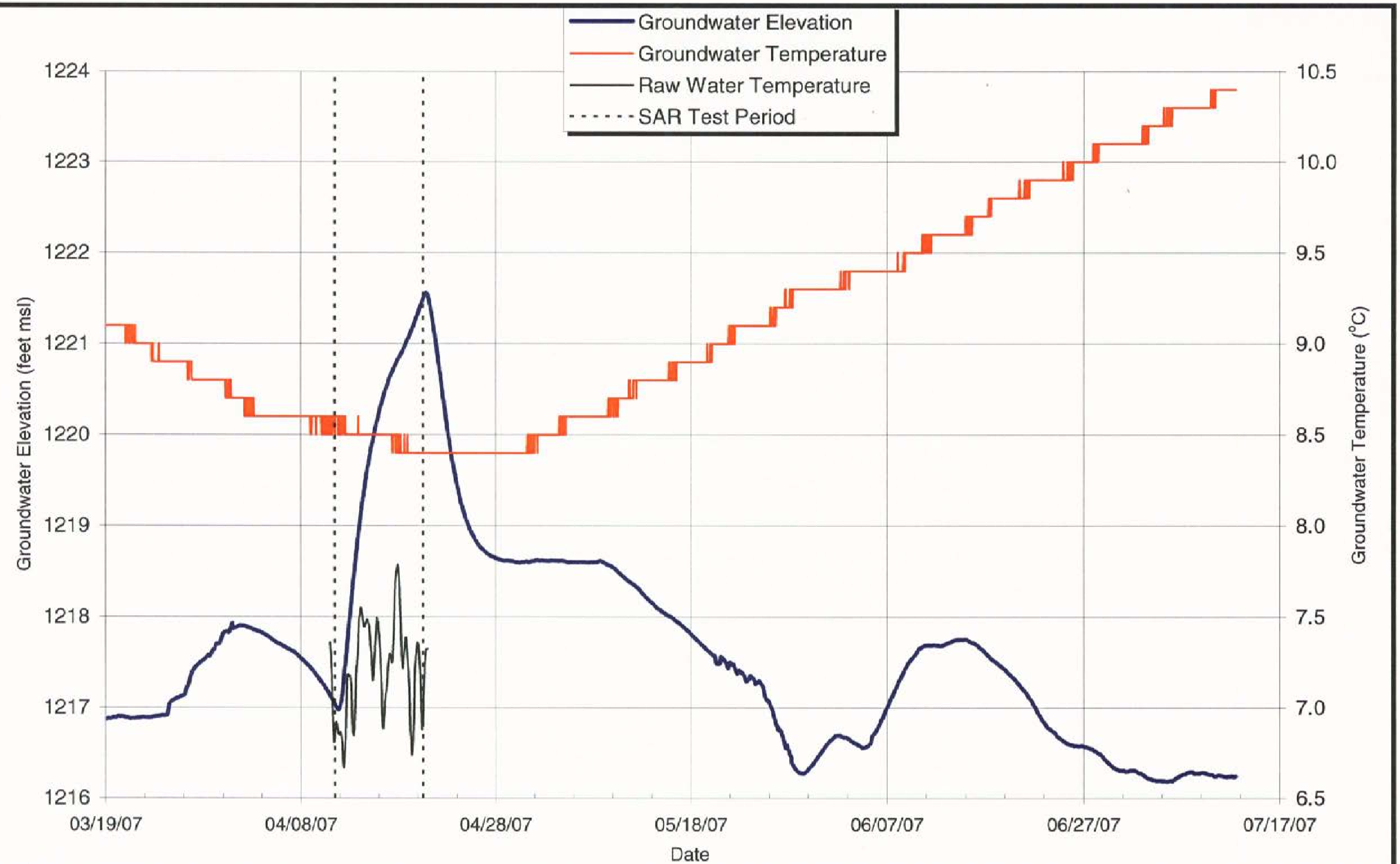
Groundwater Temperature - MW-1

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	5-12

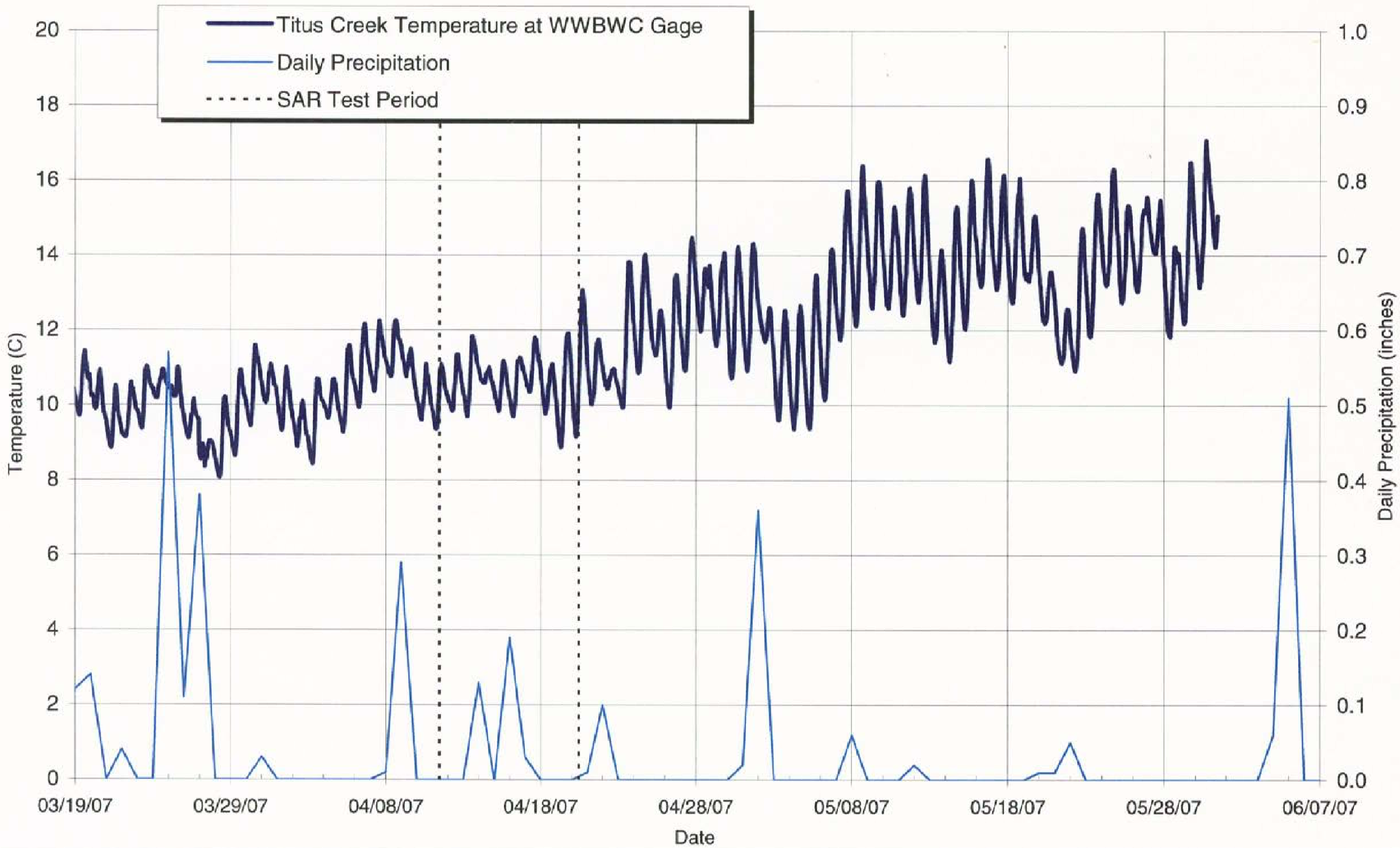


Golder Associates

Walla Walla/Shallow Aquifer Recharge	TITLE **Test Hydrograph - County Well**		
	DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003
	CHECKED DH	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. **5-13**



Golder Associates	TITLE **Groundwater Temperature - County Well**		
Walla Walla/Shallow Aquifer Recharge	DRAWN MPK	DATE Dec-07	JOB NO. 063-1345.003
	CHECKED DH	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. PZ-1 hydrograph	FIGURE NO. **5-14**



Golder Associates

Walla Walla/Shallow Aquifer Recharge

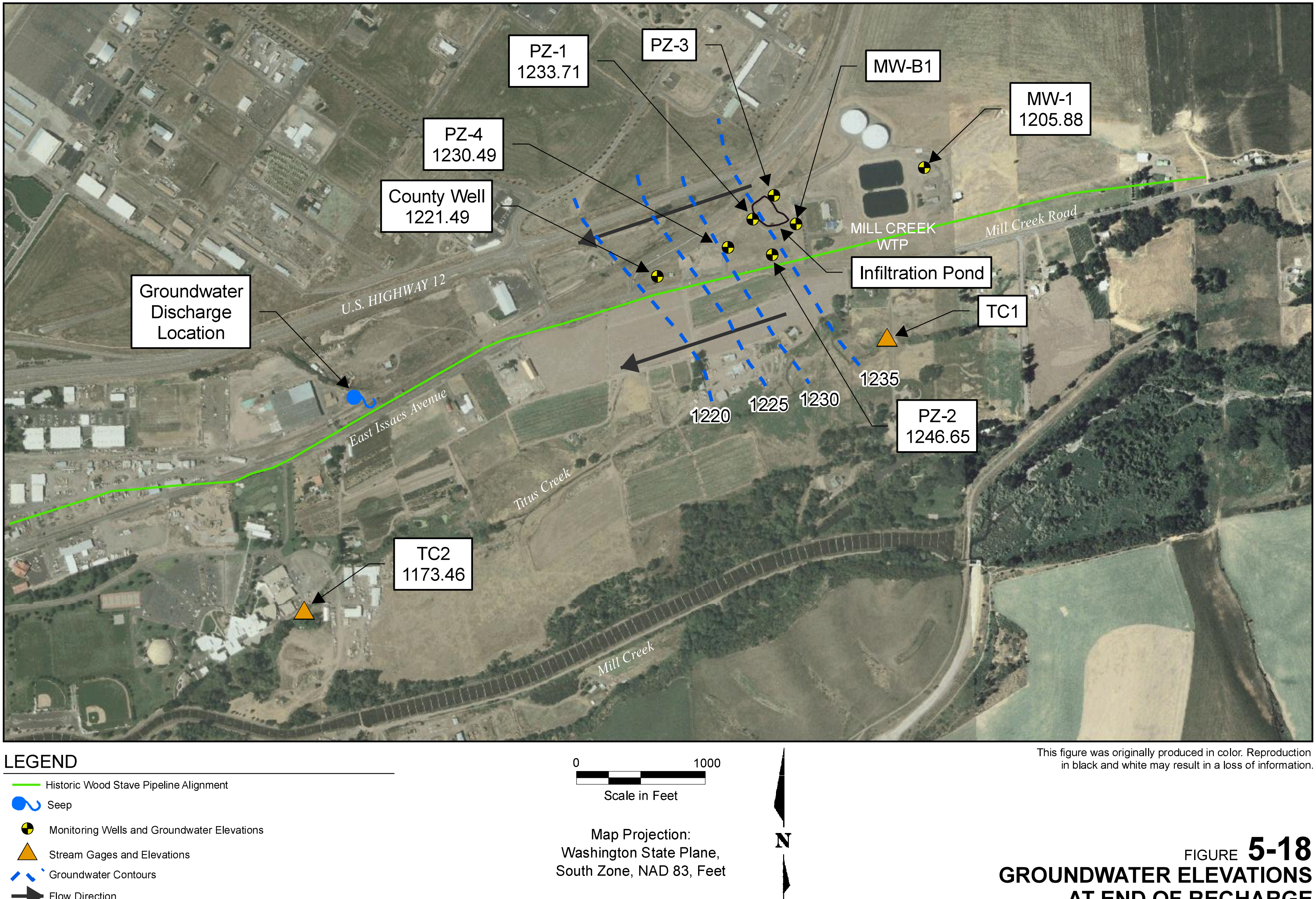
TITLE

Titus Creek Temperture at WWBWC Gage (TC-2) during SAR Test

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	titus creek	FIGURE NO.	5-15

FIGURE 5-16. Overview of Seep Location

FIGURE 5-17. Seepage from Cut Bank



Note: Water Levels Measured April 20, 2007

Map Projection:
Washington State Plane,
South Zone, NAD 83, Feet

Source: NAIP, Golder

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

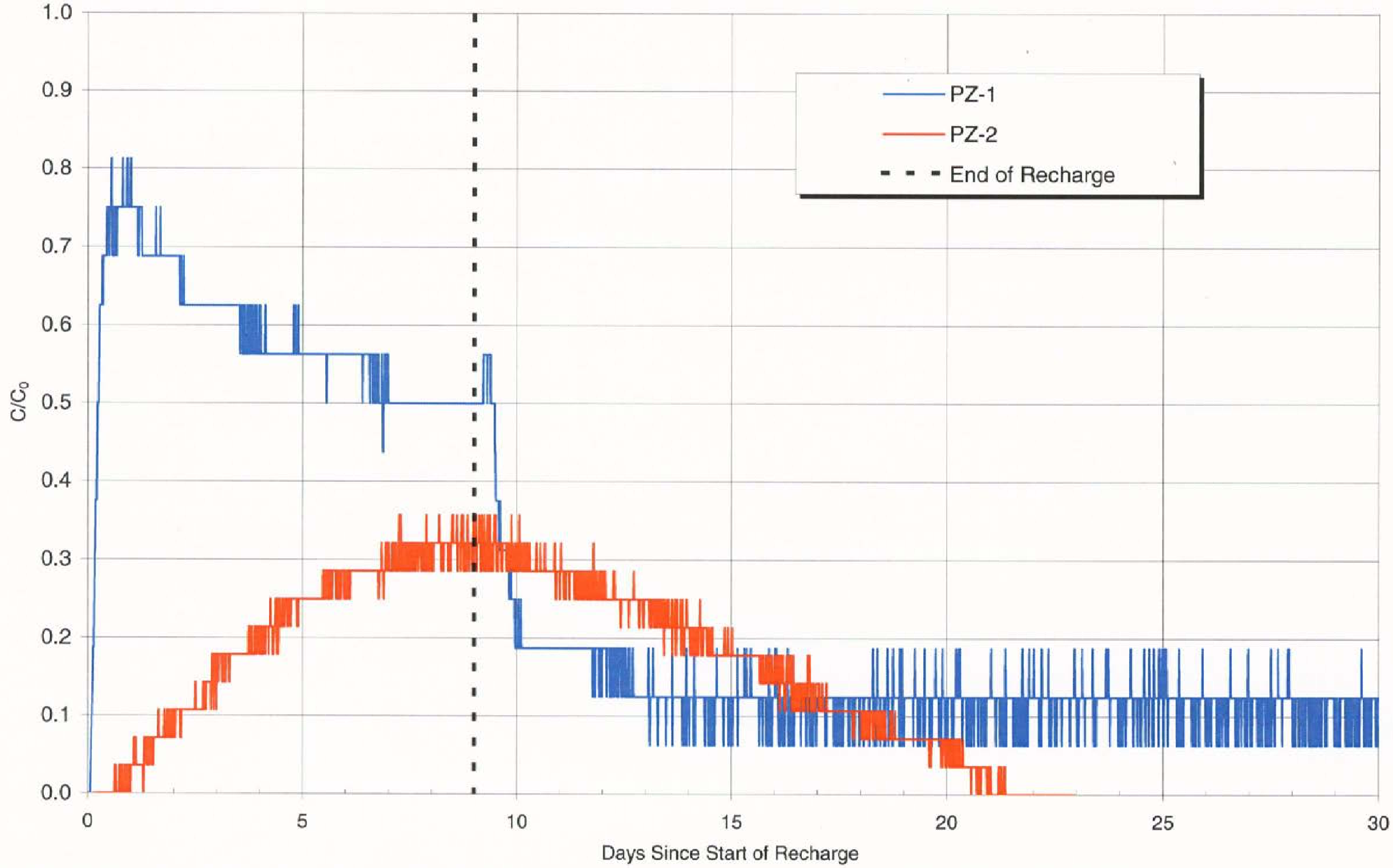
FIGURE **5-18**

GROUNDWATER ELEVATIONS AT END OF RECHARGE

WALLA WALLA/SHALLOW AQUIFER RECHARGE/WA

0631345300F02R04.mxd | 11/15/2007 | KDEROUEN

Golder Associates



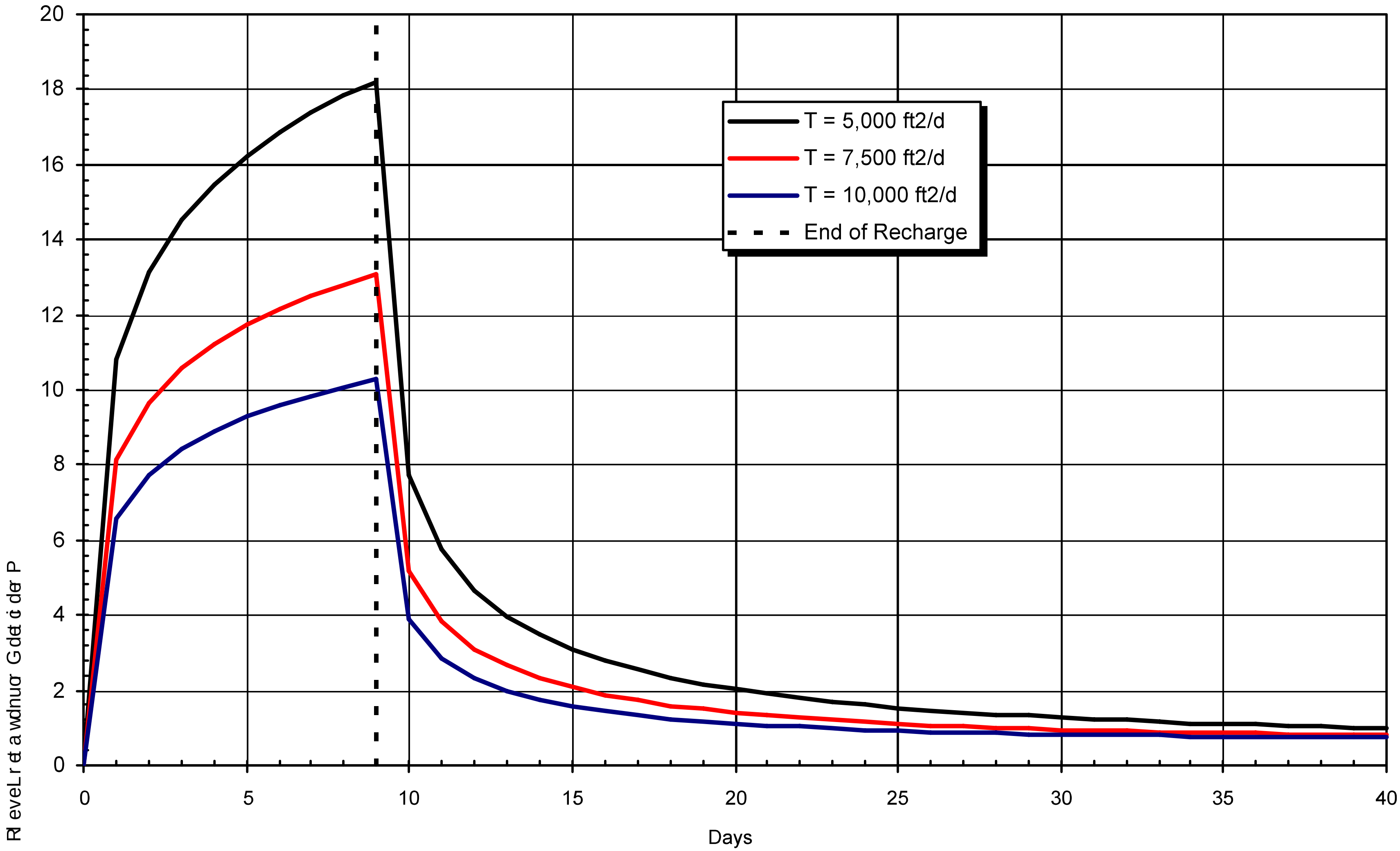
Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Groundwater Temperature Evolution

DRAWN	MPK	DATE	Dec-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	PZ-1 hydrograph	FIGURE NO.	**5-19**



Golder Associates

Walla Walla/Shallow Aquifer Recharge

TITLE

Predicted Recharge Mound Decay

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345.003
CHECKED	DH	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	decay evolution	FIGURE NO.	**5-20**

APPENDIX A

WELL LOGS

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

File Original and First Copy with Department of Ecology
Second Copy—Owner's Copy
Third Copy—Driller's Copy

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. [redacted]

Water Right Permit No. ______

(1) **OWNER:** Name Willis E. Logan   Address 3420 Isaacs; Walla Walla, Wa. 99362

(2) **LOCATION OF WELL:** County Walla Walla   SE ¼ NW ¼ Sec 13 T. 7N N., R 36E W.M.

(2a) **STREET ADDDRESS OF WELL** (or nearest address) 3420 Isaacs; Walla Walla, Wa. 99362

(3) **PROPOSED USE:** [X] Domestic [ ] Irrigation [ ] DeWater Industrial [ ] Test Well [ ] Municipal [ ] Other [ ]

(4) **TYPE OF WORK:** Owner's number of well (if more than one) ______
Abandoned [ ] New well [X] Deepened [ ] Reconditioned [ ]
Method: Dug [ ] Cable [X] Rotary [ ] Bored [ ] Driven [ ] Jetted [ ]

(5) **DIMENSIONS:** Diameter of well 8 inches.
Drilled 182 feet. Depth of completed well 182 ft.

(6) **CONSTRUCTION DETAILS:**
Casing installed: 8 " Diam. from +1.4 ft. to 111 ft.
Welded [X] 6 PUC " Diam. from 102 ft. to 182 ft.
Liner installed [X]
Threaded [ ] ______ " Diam. from ______ ft. to ______ ft.

Perforations: Yes [X] No [ ]
Type of perforator used Saw
SIZE of perforations 3/16 in. by 4 in.
6 per ft. perforations from 112 ft. to 172 ft.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.

Screens: Yes [ ] No [X]
Manufacturer's Name ______
Type ______ Model No. ______
Diam. ______ Slot size ______ from ______ ft. to ______ ft.
Diam. ______ Slot size ______ from ______ ft. to ______ ft.

Gravel packed: Yes [ ] No [X] Size of gravel ______
Gravel placed from ______ ft. to ______ ft.

Surface seal: Yes [X] No [ ] To what depth? 18 ft.
Material used in seal Bentonite
Did any strata contain unusable water? Yes [ ] No [X]
Type of water? ______ Depth of strata ______
Method of sealing strata off ______

(7) **PUMP:** Manufacturer's Name ______
Type: ______ H.P. ______

(8) **WATER LEVELS:** Land-surface elevation above mean sea level 1190 ft.
Static level 16 ft. below top of well Date 1-6-92
Artesian pressure ______ lbs. per square inch Date ______
Artesian water is controlled by ______ (Cap, valve, etc.))

(9) **WELL TESTS:** Drawdown is amount water level is lowered below static level
Was a pump test made? Yes [ ] No [X] If yes, by whom? ______
Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.
" " " "
" " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test ______
Bailer test 40 gal./min. with 10 ft. drawdown after 2 hrs.
Airtest ______ gal./min. with stem set at ______ ft. for ______ hrs.
Artesian flow ______ g.p.m. Date ______
Temperature of water 61 Was a chemical analysis made? Yes [ ] No [X]

(10) **WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION**

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
Gravel & Cobblestones	0	12
Cement Gravel	12	48
Brown Clay & Gravel	48	175
Light-brown Clay	175	182

RECEIVED
JAN 13 1992
DEPARTMENT OF ECOLOGY
SPOKANE REGIONAL OFFICE

Work started 12/2/91, 19. Completed 1/6, 1992

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME Thomas R. Ruther (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address 1421 Circle Dr; Walla Walla, Wa. 99362

(Signed) Thomas R Ruther (WELL DRILLER) License No. 0428

Contractor's Registration No. Rutheth 1260A Date Jan. 6, 19 92

(USE ADDITIONAL SHEETS IF NECESSARY)

Second Copy — Owner's Copy
Third Copy — Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Application No. ______
Permit No. G3-23639P

(1) OWNER: Name Klicker Bros. & Sons Address Route # 4 Box 236 Walla Walla Was

(2) LOCATION OF WELL: County Walla Walla NW ¼ NW ¼ SW ¼ Sec. 13 T. 7 N., R. 36E W.M.

Bearing and distance from section or subdivision corner

(3) PROPOSED USE: Domestic ☐ Industrial ☒ Municipal ☐ Irrigation ☐ Test Well ☐ Other ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) none
New well ☒ Deepened ☐ Reconditioned ☐
Method: Dug ☐ Bored ☐ Cable ☒ Driven ☐ Rotary ☐ Jetted ☐

(5) DIMENSIONS: Diameter of well 8 inches.
Drilled 119 ft. Depth of completed well 119 ft.

(6) CONSTRUCTION DETAILS: Unknown
Casing installed: ___" Diam. from ___ ft. to ___ ft.
Threaded ☐ ___" Diam. from ___ ft. to ___ ft.
Welded ☐ ___" Diam. from ___ ft. to ___ ft.

Perforations: Yes ☐ No ☒
Type of perforator used
SIZE of perforations ___ in. by ___ in.
___ perforations from ___ ft. to ___ ft.
___ perforations from ___ ft. to ___ ft.
___ perforations from ___ ft. to ___ ft.

Screens: Yes ☐ No ☒
Manufacturer's Name
Type ___ Model No. ___
Diam. ___ Slot size ___ from ___ ft. to ___ ft.
Diam. ___ Slot size ___ from ___ ft. to ___ ft.

Gravel packed: Yes ☐ No ☒ Size of gravel:
Gravel placed from ___ ft. to ___ ft.

Surface seal: Yes ☐ No ☐ To what depth? ___ ft. unknown
Material used in seal
Did any strata contain unusable water? Yes ☐ No ☐
Type of water? ___ Depth of strata ___
Method of sealing strata off

(7) PUMP: Manufacturer's Name Little Cheif
Type: Turbine H.P. 3

(8) WATER LEVELS: Land-surface elevation above mean sea level ~~1200~~ 850 ft.
Static level unknown ft. below top of well Date
Artesian pressure ___ lbs. per square inch Date
Artesian water is controlled by ___ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes ☐ No ☒ If yes, by whom?
Yield: ___ gal./min. with ___ ft. drawdown after ___ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
unknown					

Date of test
Bailer test ___ gal./min. with ___ ft. drawdown after ___ hrs.
Artesian flow ___ g.p.m. Date
Temperature of water ___ Was a chemical analysis made? Yes ☐ No ☒

(10) WELL LOG:

Formation: *Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.*

MATERIAL	FROM	TO
unknown		
~~To the best of my knowledge this well was constructed during the period 1947 to 1949. As I have worked on the pump, I have this much information about the well. In 1967 during the month of March, after repairing the pump, I checked the flow pumping in the open discharge and the measured flow was in excess of forty gallons per minute.~~		
I did not drill this well but am sending along the information aquired by working on the pump.		
W. E. Ruther		
Unknown		

COO 30 AF/yr
30
27
5

RECEIVED
JUL 18 1977
DEPARTMENT OF ECOLOGY
SPOKANE REGIONAL OFFICE

Work started ___, 19__. Completed ___, 19__.

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME W. E. Ruther & Son
(Person, firm, or corporation) (Type or print)
Address Route # 4 Walla Walla Wn 99362

[Signed] William E Ruther
(Well Driller)

License No. 0430 Date 7/15, 1977

7/18/77

(USE ADDITIONAL SHEETS IF NECESSARY)

Please print sign and return to the Department of Ecology

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

Water Well Report

Original – Ecology 1st copy – owner 2nd copy – driller

ECOLOGY

Construction/Decommission 129182

☑ Construction

☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

Current Notice of Intent No W05730

Unique Ecology Well ID Tag No AAN 999

Water Right Permit No ______

Property Owner Name Mark & Lisa Klicker

Well Street Address Looking Glass Rd

City Walla Walla County Walla Walla

Location NE 1/4 1/4 SW 1/4 Sec 13 Twn 7N R 36 EWM ☑ or WWM ☐ circle one

Lat/Long (s t r still REQUIRED) Lat Deg 46 Lat Min/Sec 05/09 Long Deg 118 Long Min/Sec 15'/19"

Tax Parcel No ______

PROPOSED USE ☑ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other ______

TYPE OF WORK Owner s number of well (if more than one) ______

☑ New well ☐ Reconditioned *Method* ☐ Dug ☐ Bored ☐ Driven

☐ Deepened ☑ Cable ☐ Rotary ☐ Jetted

DIMENSIONS Diameter of well 6 inches drilled ______ ft

Depth of completed well 152 ft

CONSTRUCTION DETAILS

Casing Installed ☑ Welded 6 Diam from +1.5 ft to 97 ft

☑ Liner installed 4.5" Diam from 92 ft to 152 ft

☐ Threaded ______ Diam from ______ ft to ______ ft

Perforations ☑ Yes ☐ No

Type of perforator used saw cut

SIZE of perfs 1/4 in by 6 in and no of perfs 4/ft from 97 ft to 150 ft

Screens ☐ Yes ☑ No ☐ K Pac Location ______

Manufacturer s Name ______

Type ______ Model No ______

Diam ______ Slot size ______ from ______ ft to ______ ft

Diam ______ Slot size ______ from ______ ft to ______ ft

Gravel/Filter packed ☐ Yes ☑ No ☐ Size of gravel/sand ______

Materials placed from ______ ft to ______ ft

Surface Seal ☑ Yes ☐ No To what depth? 27 ft

Material used in seal bentonite

Did any strata contain unusable water? ☐ Yes ☑ No

Type of water? ______ Depth of strata ______

Method of sealing strata off ______

PUMP Manufacturer s Name ______

Type ______ H P ______

WATER LEVELS Land surface elevation above mean sea level ______ ft

Static level 51 ft. below top of well Date 3/18/03

Artesian pressure ______ lbs per square inch Date ______

Artesian water is controlled by ______ (cap valve etc)

WELL TESTS Drawdown is amount water level is lowered below static level

Was a pump test made? ☑ Yes ☐ No If yes by whom? driller

Yield 75 gal /min with 23 ft drawdown after 8 hrs

Yield ______ gal /min with ______ ft drawdown after ______ hrs

Yield ______ gal /min with ______ ft drawdown after ______ hrs

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test ______

Bailer test ______ gal /min with ______ ft drawdown after ______ hrs

Airtest ______ gal /min with stem set at ______ ft for ______ hrs

Artesian flow ______ g.p m. Date ______

Temperature of water 52 Was a chemical analysis made? ☑ Yes ☐ No

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation Describe by color character size of material and structure and the kind and nature of the material in each stratum penetrated with at least one entry for each change of information indicate all water encountered (USE ADDITIONAL SHEETS IF NECESSARY)

MATERIAL	FROM	TO
Topsoil	0	5
Brown Clay & Gravel	5	14
Gravel	14	25
Brown Clay & Gravel	25	38
Cemented Gravel	38	75
Brown Clay & Gravel	75	96
Gravel (WB)	96	142
Blue Basalt	142	152

RECEIVED MAR 20 2003

Start Date 2/23/2003 Completed Date 3/19/2003

WELL CONSTRUCTION CERTIFICATION I constructed and/or accept responsibility for construction of this well and its compliance with all Washington well construction standards Materials used and the information reported above are true to my best knowledge and belief

Driller/Engineer/Trainee Name (Print) Thomas R Ruther Jr

Driller/Engineer/Trainee Signature Thomas R Ruther

Driller or trainee License No 0429

If TRAINEE,
Driller s Licensed No ______
Driller s Signature ______

Drilling Company T.R Ruther Well Drilling

Address 1714 Circle Drive

City State Zip Walla Walla,WA 99362

Contractor s Registration No TRRUTWD990CW Date 3/19/2003

180510

WATER WELL REPORT

Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Construction/Decommission (*"x" in circle*)

[x] Construction

[ ] Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

CURRENT Notice of Intent No. R62686

Unique Ecology Well ID Tag No. AKT 213

Water Right Permit No. ______

Property Owner Name City of Walla Walla

Well Street Address Mill Creek Water Treatment Plant

City Walla Walla County Walla Walla

Location NE1/4-1/4 SW1/4 Sec 13 Twn 7 R 36 EWM [x] or WWM [ ] circle one

Lat/Long (s, t, r Still **REQUIRED**) Lat Deg ______ Lat Min/Sec ______ Long Deg ______ Long Min/Sec ______

Tax Parcel No. N/A

PROPOSED USE: [ ] Domestic [ ] Industrial [ ] Municipal [ ] DeWater [ ] Irrigation [x] Test Well [ ] Other ______

TYPE OF WORK: Owner's number of well (if more than one) MW-3

[x] New well [ ] Reconditioned [ ] Deepened

Method: [ ] Dug [ ] Bored [ ] Driven [ ] Cable [x] Rotary [ ] Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 87 ft.

Depth of completed well 83.2 ft B.G.S.\85.7 T.O.C.

CONSTRUCTION DETAILS

Casing Installed: [x] Welded 6" Diam. from +2.5 ft. to 83.2 ft.
[ ] Liner installed ___" Diam. from ___ ft. to ___ ft.
[ ] Threaded ___" Diam. from ___ ft. to ___ ft.

Perforations: [ ] Yes [x] No

Type of perforator used ______

SIZE of perfs ___ in. by ___ in. and no. of perfs ___ from ___ ft. to ___ ft.

Screens: [x] Yes [ ] No [x] K-Pac Location 69.7 B.G.S.

Manufacturer's Name Johnson

Type S.S. Model No. ______

Diam. 5 Slot size .025 from 75 ft. to 80 ft.

Diam. 5 Slot size sump from 80 ft. to 83.2 ft.

Gravel/Filter packed: [ ] Yes [x] No [ ] Size of gravel/sand ______

Materials placed from ___ ft. to ___ ft.

Surface Seal: [x] Yes [ ] No To what depth? 18 ft.

Material used in seal Bentonite Chips

Did any strata contain unusable water? [ ] Yes [x] No

Type of water? ______ Depth of strata ______

Method of sealing strata off ______

PUMP: Manufacturer's Name ______

Type: ______ H.P. ______

WATER LEVELS: Land-surface elevation above mean sea level ___ ft.

Static level 47.2 ft. below top of well Date 9/13/05

Artesian pressure ___ lbs. per square inch Date ___

Artesian water is controlled by ______ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? [ ] Yes [x] No If yes, by whom? ______

Yield: ___ gal./min. with ___ ft. drawdown after ___ hrs.

Yield: ___ gal./min. with ___ ft. drawdown after ___ hrs.

Yield: ___ gal./min. with ___ ft. drawdown after ___ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test ______

Bailer test ___ gal./min. with ___ ft. drawdown after ___ hrs.

Airtest 2 gal./min. with stem set at 80 ft. for 1 hrs.

Artesian flow ___ g.p.m. Date ___

Temperature of water ___ Was a chemical analysis made? [ ] Yes [x] No

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Brown silty topsoil with cobbles with medium gravel.	0	18
Wet silty brown angular basalt, medium.	18	20
Reddish brown dense sandy silt/weathered rock.	20	75
Brown silty medium sand with gravel/water.	75	87

RECEIVED SEP 30 2005 DEPARTMENT OF ECOLOGY

05-1465-08

Start Date 9/13/05 Completed Date 9/13/05

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

[ ] Driller [ ] Engineer [ ] Trainee Name (Print) Matthew Call

Driller/Engineer/Trainee Signature [signature]

Driller or trainee License No. 2571 & 2467

If TRAINEE, Driller's Licensed No. ______

Driller's Signature ______

Drilling Company Tacoma Pump & Drilling Co., Inc.

Address 30316 Mountain Highway

City, State, Zip Graham, WA 98338

Contractor's Registration No. TACOMPD203PF Date 9/22/05

10730

RESOURCE PROTECTION WELL REPORT

START CARD NO 17859

PROJECT NAME: City of Walla walla Dept. of Public Works

COUNTY: Walla walla

WELL IDENTIFICATION NO. B-2 / ABT-563

LOCATION SW 1/4 NW 1/4 Sec 13 Twn 7N R 36E

DRILLING METHOD: Tubex XL

STREET ADDRESS OF WELL: Twin Reservoirs site

DRILLER: Robert A. Sheldon

FIRM: Environmental West Explor.

WATER LEVEL ELEVATION: 15' B.G.L.

SIGNATURE: [signature]

GROUND SURFACE ELEVATION: NA.

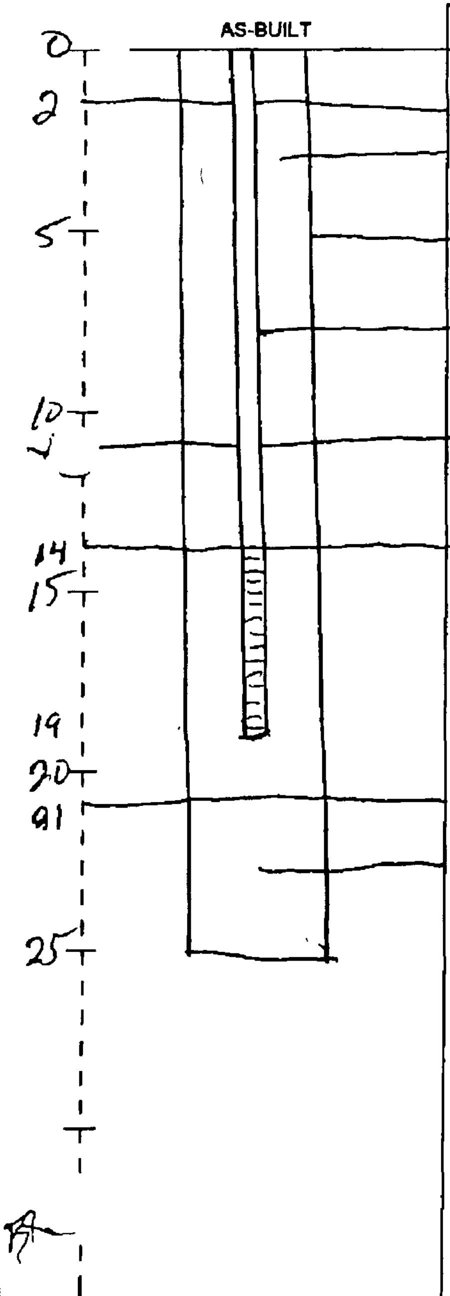
CONSULTING FIRM: CH2M Hill

INSTALLED: 10-17-96

REPRESENTATIVE: Tod Cotton

DEVELOPED: NA.

AS-BUILT	WELL DATA	FORMATION DESCRIPTION
0	Flush monument & concrete	
2	3/8" Hole plug seal	
5	6" Borehole	silty gravel + cobbles
	2" P.V.C. Blank	
11	Top of 8/12 silica sand Filter pack	
14	Top of 2" .020 slot P.V.C. screen	OCT 2 1996
19		
21	3/8" Hole plug seal	
25		25

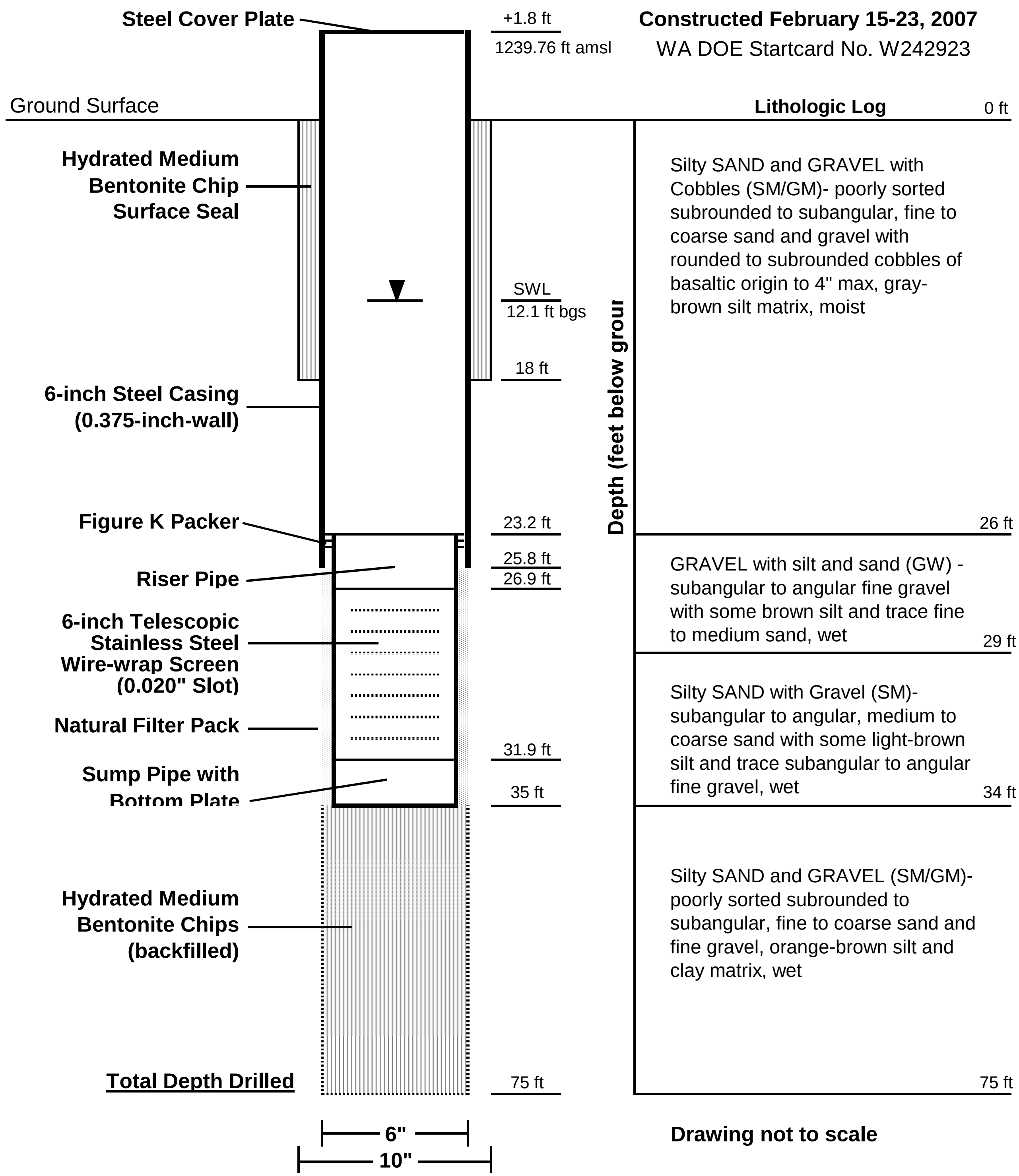


SCALE: 1" = 5'

PAGE 1 OF 1

ECY 050-12 (Rev. 11/89)

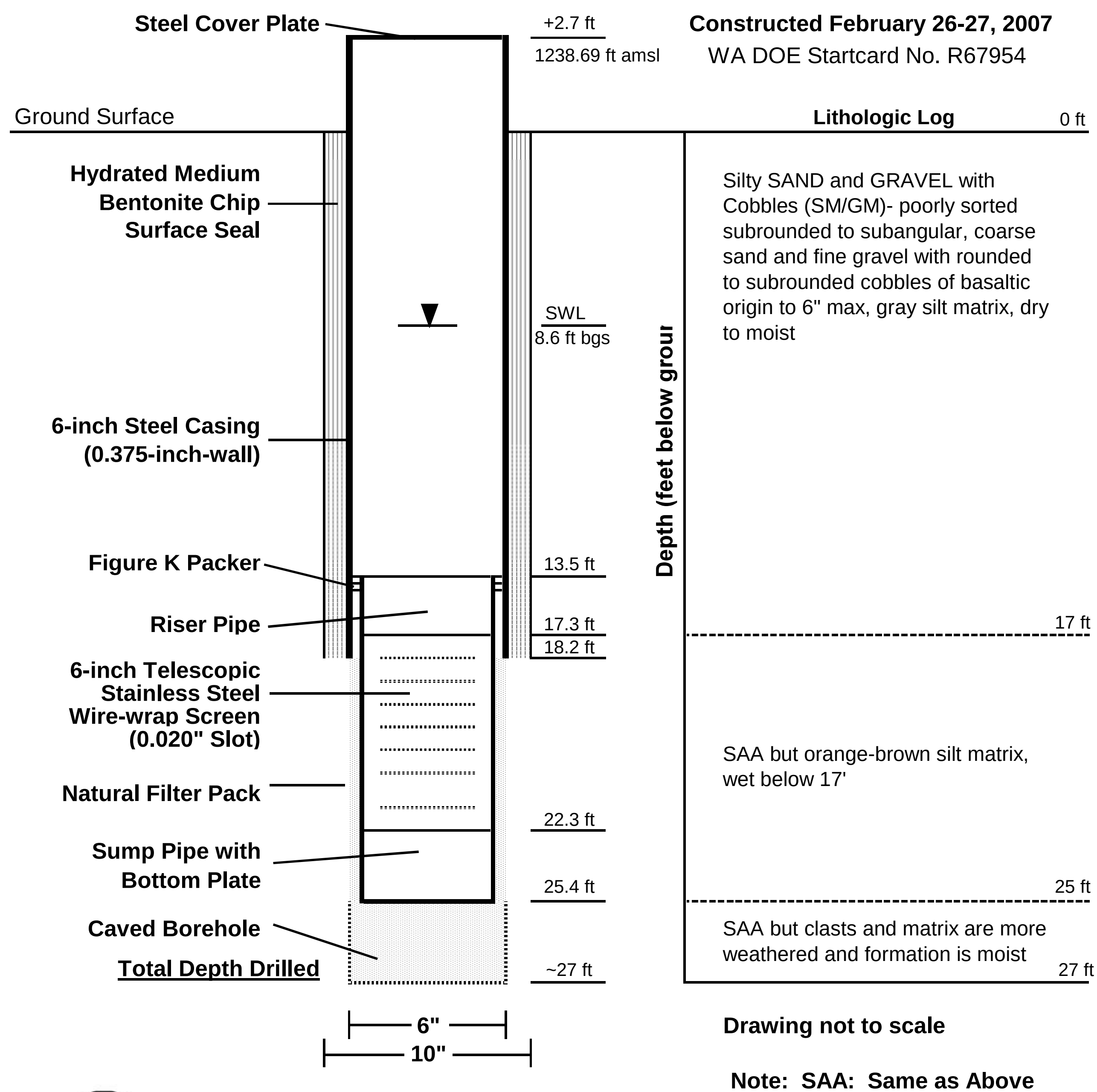
The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.



Golder Associates

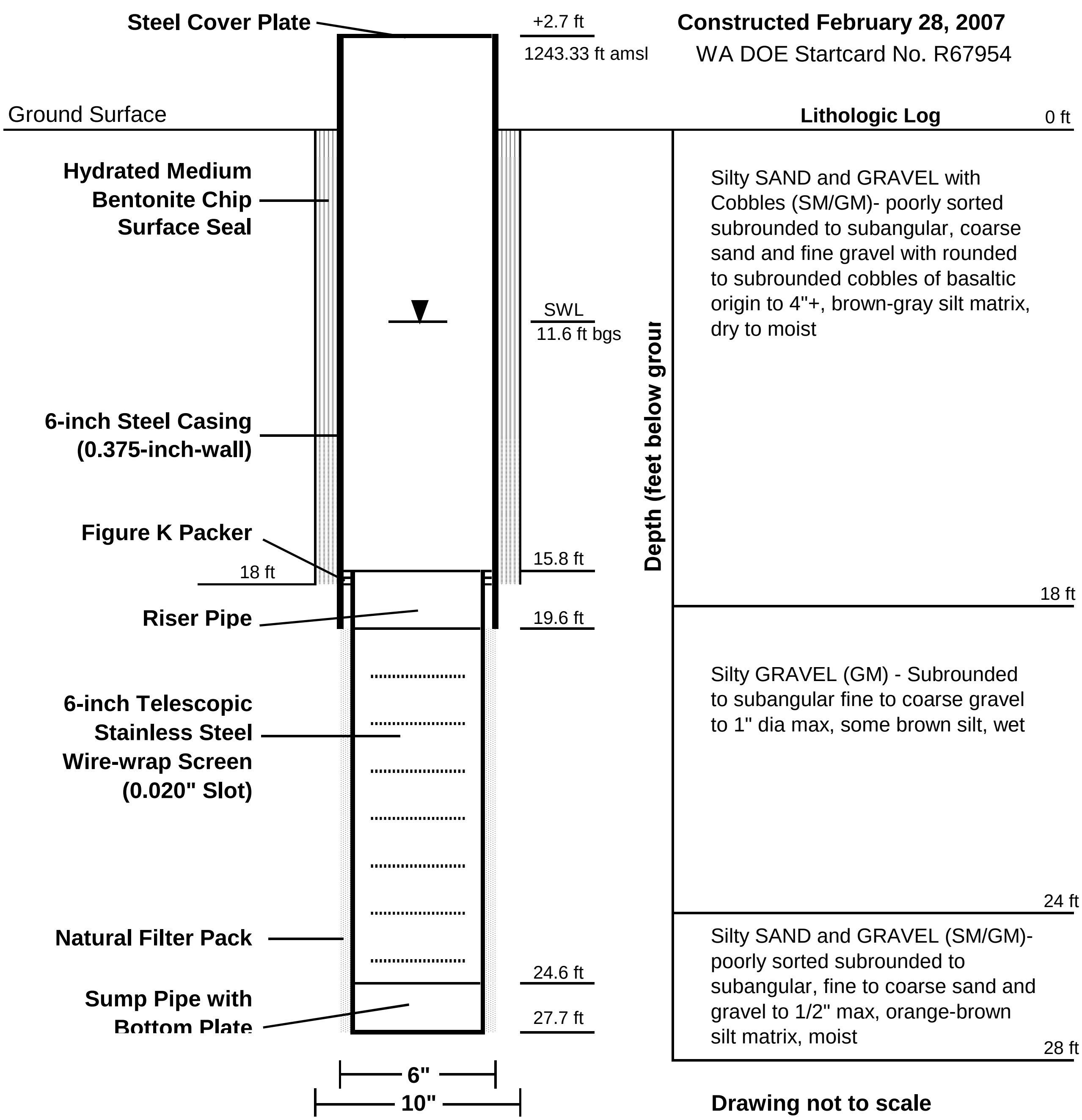
Walla Walla SAR Piezometer 1
As-built Construction and Lithologic Log
Mill Creek WTP, Walla Walla, WA

Logged: JI	**Figure A-1**
Check: RB	



Walla Walla SAR Piezometer 2
As-built Construction and Lithologic Log
Mill Creek WTP, Walla Walla, WA

Logged: JI	**Figure A-2**
Check: RB	

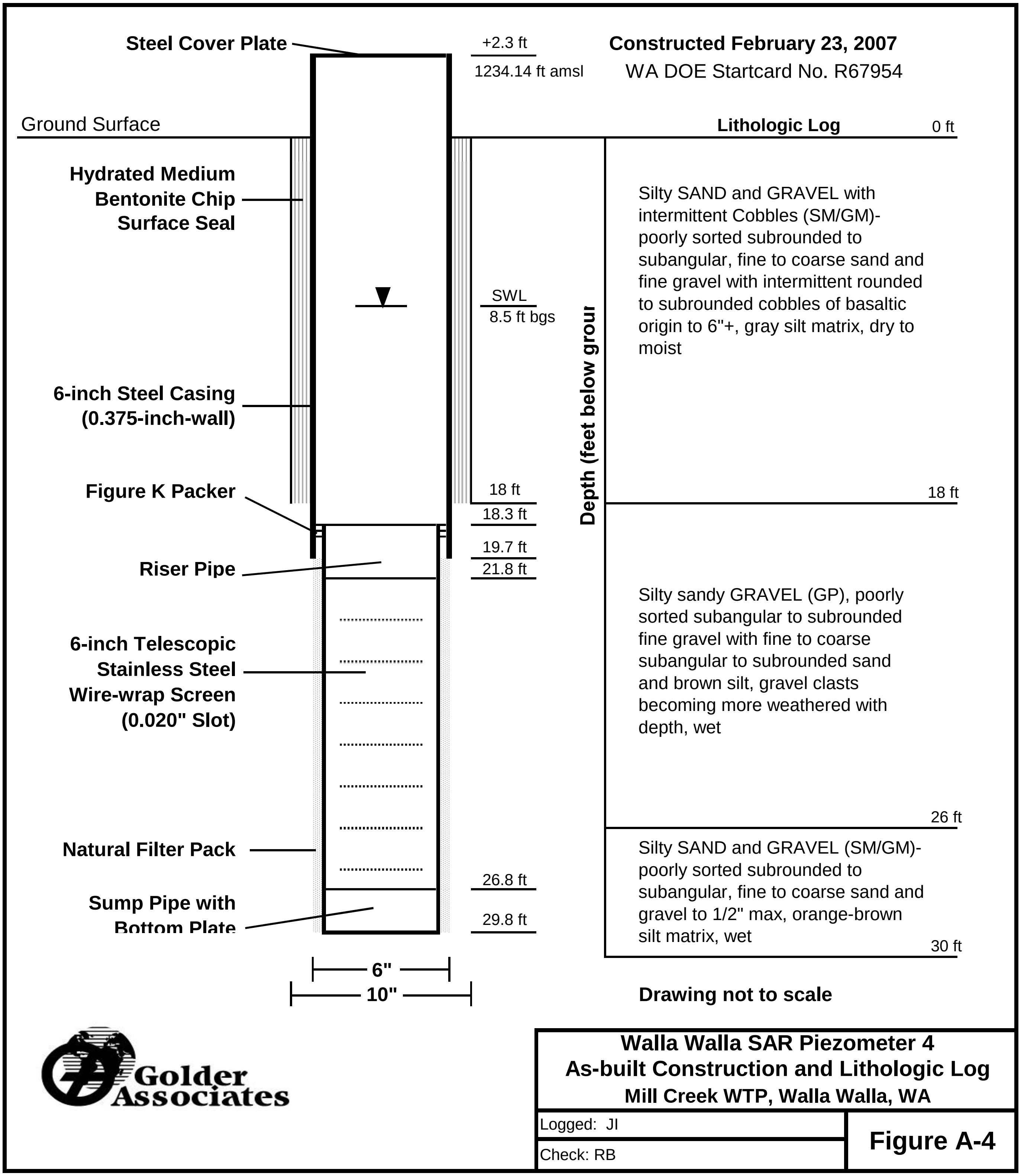


Drawing not to scale

Golder Associates

Walla Walla SAR Piezometer 3
As-built Construction and Lithologic Log
Mill Creek WTP, Walla Walla, WA

Logged: JI	**Figure A-3**
Check: RB	


Steel Cover Plate
+2.3 ft
1234.14 ft amsl
Constructed February 23, 2007
WA DOE Startcard No. R67954
Ground Surface
Lithologic Log
0 ft
Hydrated Medium Bentonite Chip Surface Seal
Silty SAND and GRAVEL with intermittent Cobbles (SM/GM)- poorly sorted subrounded to subangular, fine to coarse sand and fine gravel with intermittent rounded to subrounded cobbles of basaltic origin to 6"+, gray silt matrix, dry to moist
SWL
8.5 ft bgs
Depth (feet below grour
6-inch Steel Casing (0.375-inch-wall)
Figure K Packer
18 ft
18.3 ft
18 ft
19.7 ft
21.8 ft
Riser Pipe
Silty sandy GRAVEL (GP), poorly sorted subangular to subrounded fine gravel with fine to coarse subangular to subrounded sand and brown silt, gravel clasts becoming more weathered with depth, wet
6-inch Telescopic Stainless Steel Wire-wrap Screen (0.020" Slot)
26 ft
Natural Filter Pack
Silty SAND and GRAVEL (SM/GM)- poorly sorted subrounded to subangular, fine to coarse sand and gravel to 1/2" max, orange-brown silt matrix, wet
26.8 ft
Sump Pipe with Bottom Plate
29.8 ft
30 ft
6"
10"
Drawing not to scale
Golder Associates
Walla Walla SAR Piezometer 4
As-built Construction and Lithologic Log
Mill Creek WTP, Walla Walla, WA
Logged: JI
Check: RB
Figure A-4

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

well #1

WELL LOG

No. Decla. #1127
Cert. #1063-D

Date May 15, 1942
Record by Paul H. Meyer
Source G. W. Decla. Claim

Location: State of WASHINGTON
County Walla Walla
Area
Map
SE¼ NW¼ sec. 13 T. 7 N., R. 36 E.

DIAGRAM OF SECTION

13

Drilling Co.
Address
Method of Drilling drilled Date Apr. 5 1942
Owner City of Walla Walla
Address Walla Walla, Wash.
Land surface, datum ft. above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)		
	See attached sheet		
Pump	Test:		
	Dim: 810' x 16"		
	SWL: 90'		
	Dd: 22'		
	Yield: 1900 g.p.m.		
	Casing: 16" dia. st'd well casing		
	from 0' to 145½'		
	16" shoe @ 145½'.		
	Pump: Deep well turbine, 10"		
	Motor: 100 hp, electric		

Turn up

Sheet ___ of ___ sheets

Well #1 - 502

WELL #1

Sand, gravel and boulders	32	32
Cement gravel	8	40
Fine gravel, brown clay	11	51
Gravel, clay and large boulders	8	59
Brown clay and gravel	31	90
Cement gravel	15	105
Brown clay and gravel	23	128
Large boulders (top of bedrock)	9	137
Black basalt	53	190
Black basalt interspersed with seams of clay	57	247
Hard gray basalt w/last 14' softer indicating change of formation	53	300
Black, honeycomb basalt	64	364
Hard, black basalt	4	368
Black basalt	79	447
Gray basalt	57	504
Black basalt	51	555
Brown basalt	4	560
Black basalt	155	725
Basalt crevice, very bad	45	750
Gray and brown basalt	12	762
Black basalt, broken	15	777
Gray basalt, hard	4	781
Black basalt, broken	21	802
Gray basalt, hard	8	810

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

Well #1

WELL LOG

No. Decla. #1127
Cert. #1063-D

Date May 15, 1942

Record by Paul H. Meyer

Source J. W. Decla. Claim

Location: State of WASHINGTON

County Walla Walla

Area

Map

SE¼ NW¼ sec. 13 T. 7 N., R. 36 E.W.

13

DIAGRAM OF SECTION

Drilling Co.

Address

Method of Drilling drilled Date Apr. 5, 1922

Owner City of Walla Walla

Address Walla Walla, Wash.

Land surface, datum ft. above below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses. If material water bearing, so state and record static level if reported. Give depths in feet below land surface datum unless otherwise indicated. Correlate with stratigraphic column if feasible. Follow log log of materials, list all casings, perforations, screens, etc.)		
	See attached sheet		
Pump	Test:		
	Dim: 810' x 16"		
	SWL: 90'		
	Dd: 22'		
	Yield: 1900 g.p.m.		
	Casing: 16" dia. st'd well casing		
	from 0' to 145½'		
	16" shoe @ 145½'.		
	Pump: Deep well turbine, 10"		
	Motor: 100 hp. electric		

Turn up Sheet of sheets

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Well Tagging Form

Unique Well Tag No: AGG 274 (502)

RECORD VERIFICATION (check ✓ one)

- [x] Well Report available *(please attach this form to the well report and submit it to the Ecology Regional Office near you)*
- [ ] Verification inconclusive
- [ ] Well Report not available

WELL OWNERSHIP, IF DIFFERENT FROM WELL REPORT

First Name: CITY OF WALLA WALLA Last Name:

Street Address: 55 MOORE PO BOX 478

City: WALLA WALLA State: WA

LOCATION OF WELL, IF DIFFERENT FROM WELL REPORT

Well Address: ON-SITE @ MILL CREEK TREATMENT PLANT

City: WALLA WALLA County: WALLA WALLA

T. 7 N. R. 36 E W.M. Sec. 13 SE 1/4 of the NW 1/4

FOR AGENCY USE ONLY

Latitude ______ ______ ' ______ ______ "

Longitude ______ ______ ' ______ ______ "

- [ ] GPS
- [ ] Topographic Map
- [ ] Survey
- [ ] Computer generated

Elevation at land surface ______ feet/meters *(circle one)*

- [ ] Digital Altimeter
- [ ] Topographic Map
- [ ] Other ______

Additional information, if available:

- [ ] Location marked on topographic map *(please attach)*
- [ ] Location marked on air photo *(please attach)*

RECEIVED
APR 0 2 2002
DEPARTMENT OF ECOLOGY
WELL DRILLING UNIT

FOR AGENCY USE ONLY

WELL CHARACTERISTICS

Physical Description of well (size of casing, type of well, housing, etc.)

16" STEEL CASING

Location of Well identification Tag:

ON CASING

Was supplemental tag needed for ease of identifying well? ☐ Yes ☐ No

If yes, where was tag placed? ______

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Scale 1:24,000 (1"=2,000')

Indicate the location of the well within the Section by drawing a dot at that point.

SECTION ______

COMMENTS: Brent R. Stamm R.S.

WWCHD

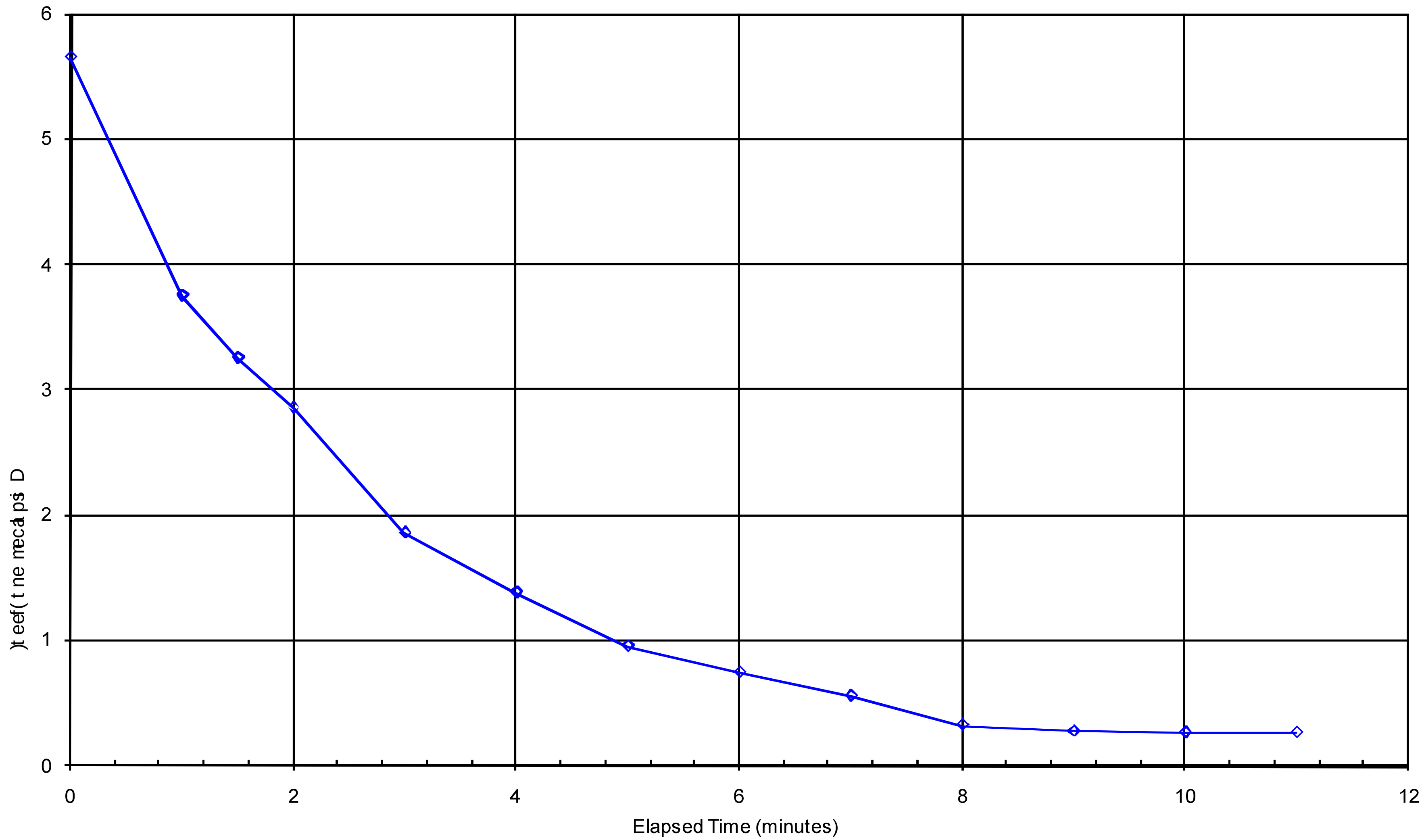
FOR ECOLOGY WATER RESOURCES PROGRAM ONLY

Water Right # ______ Date Issued ______

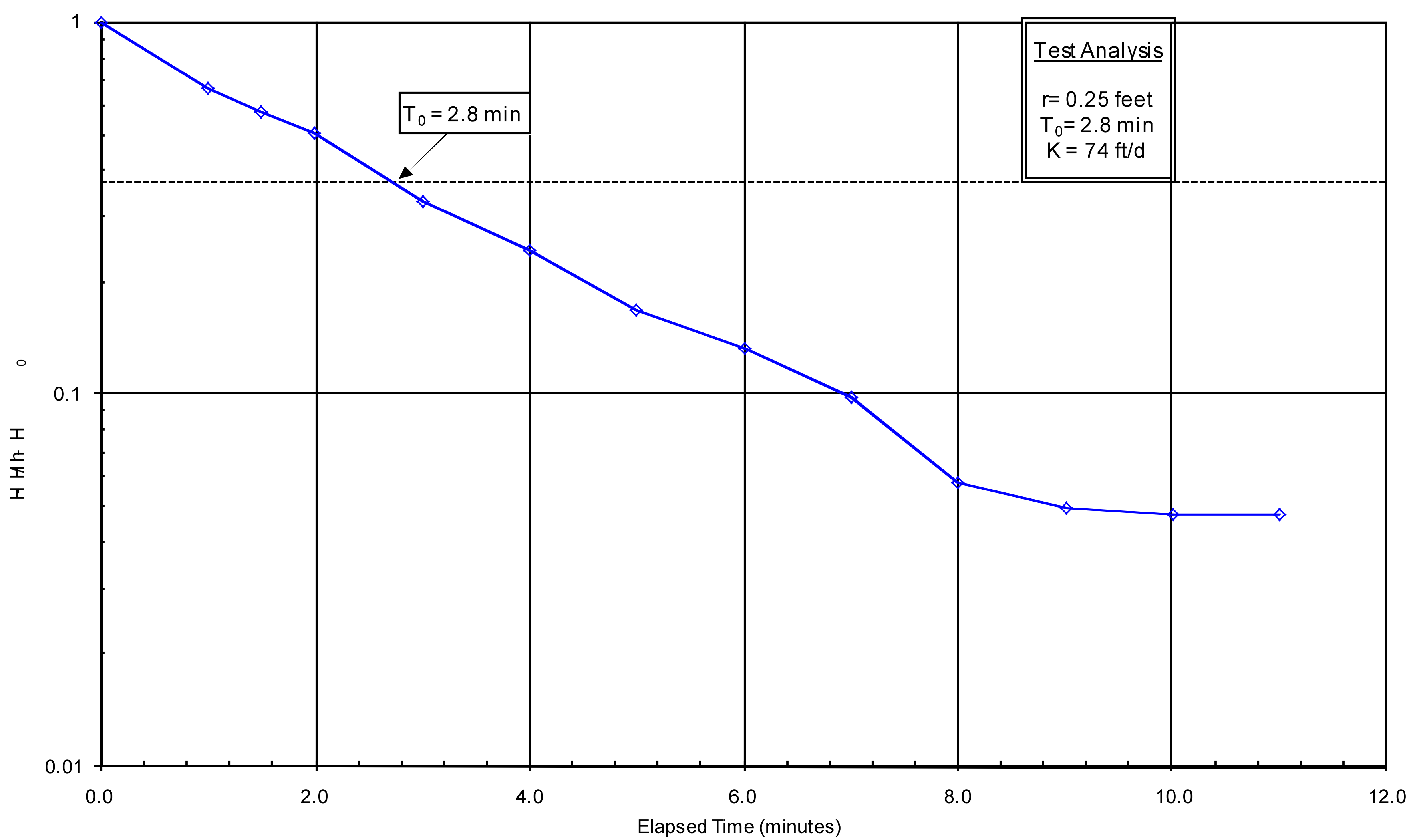
Circle One: Application Permit Certificate Claim Exempt

APPENDIX B

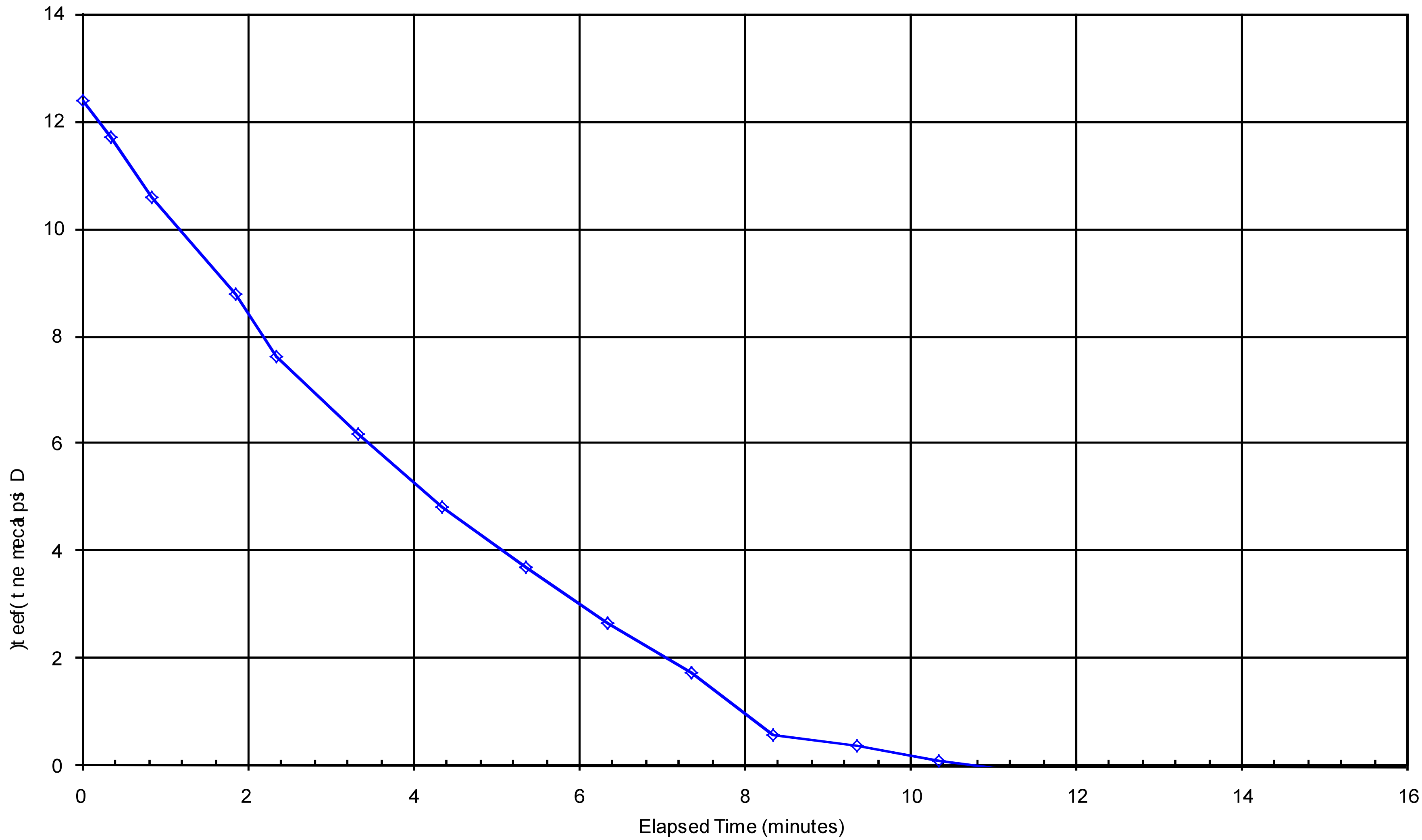
FALLING HEAD TESTS



Golder Associates	TITLE **PZ-1 Test Hydrograph - 21 Feet**		
Walla Walla Shallow Aquifer Recharge	DRAWN MPK	DATE Nov-07	JOB NO. 063-1345
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. SASR piezos.xlx	FIGURE NO. **B-1**



Golder Associates	TITLE **PZ-1 Test Analysis - 21 Feet**		
Walla Walla Shallow Aquifer Recharge	DRAWN MPK	DATE Nov-07	JOB NO. 063-1345
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. SASR piezos.xlx	FIGURE NO. **B-2**



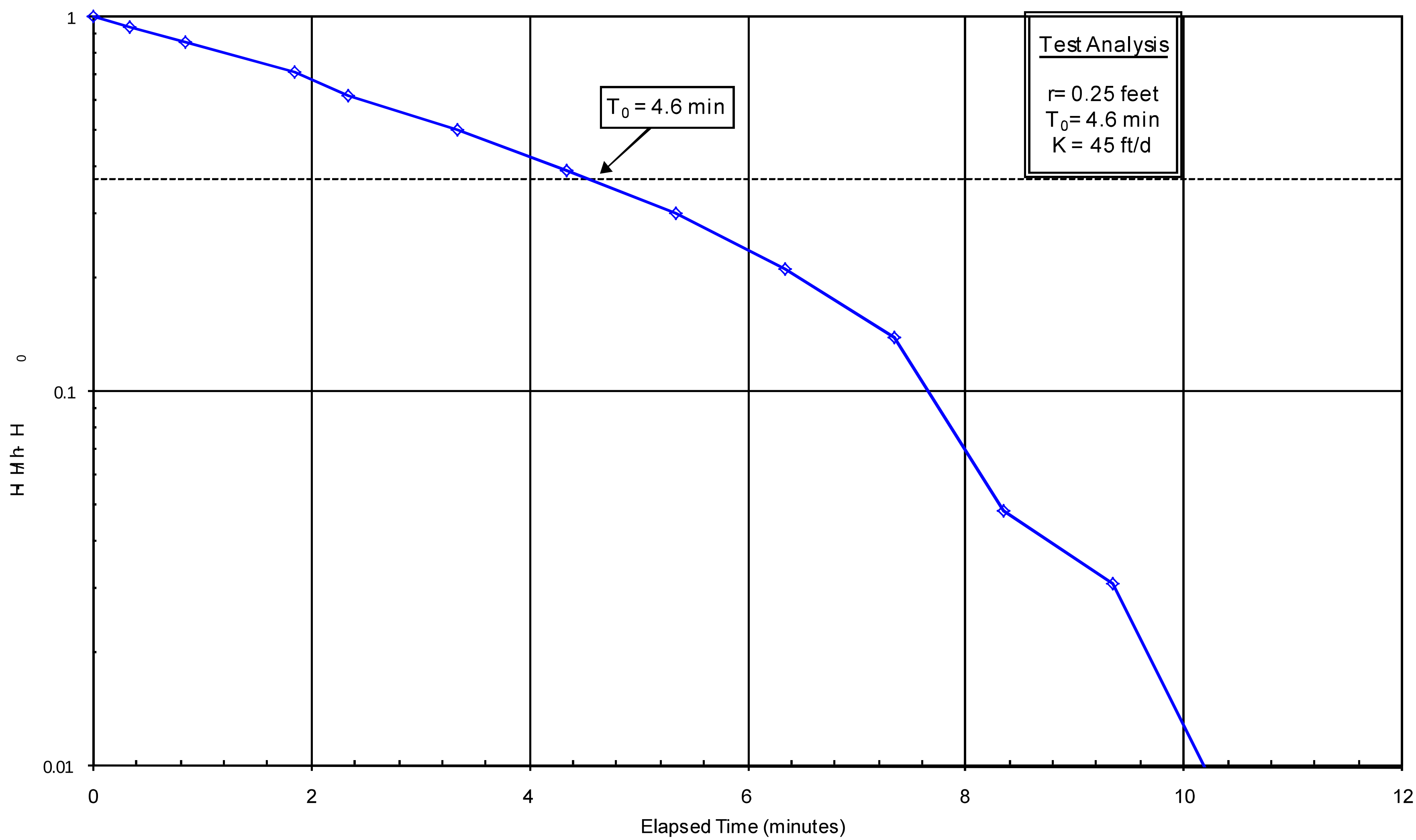
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Hydrograph - 23 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-3**



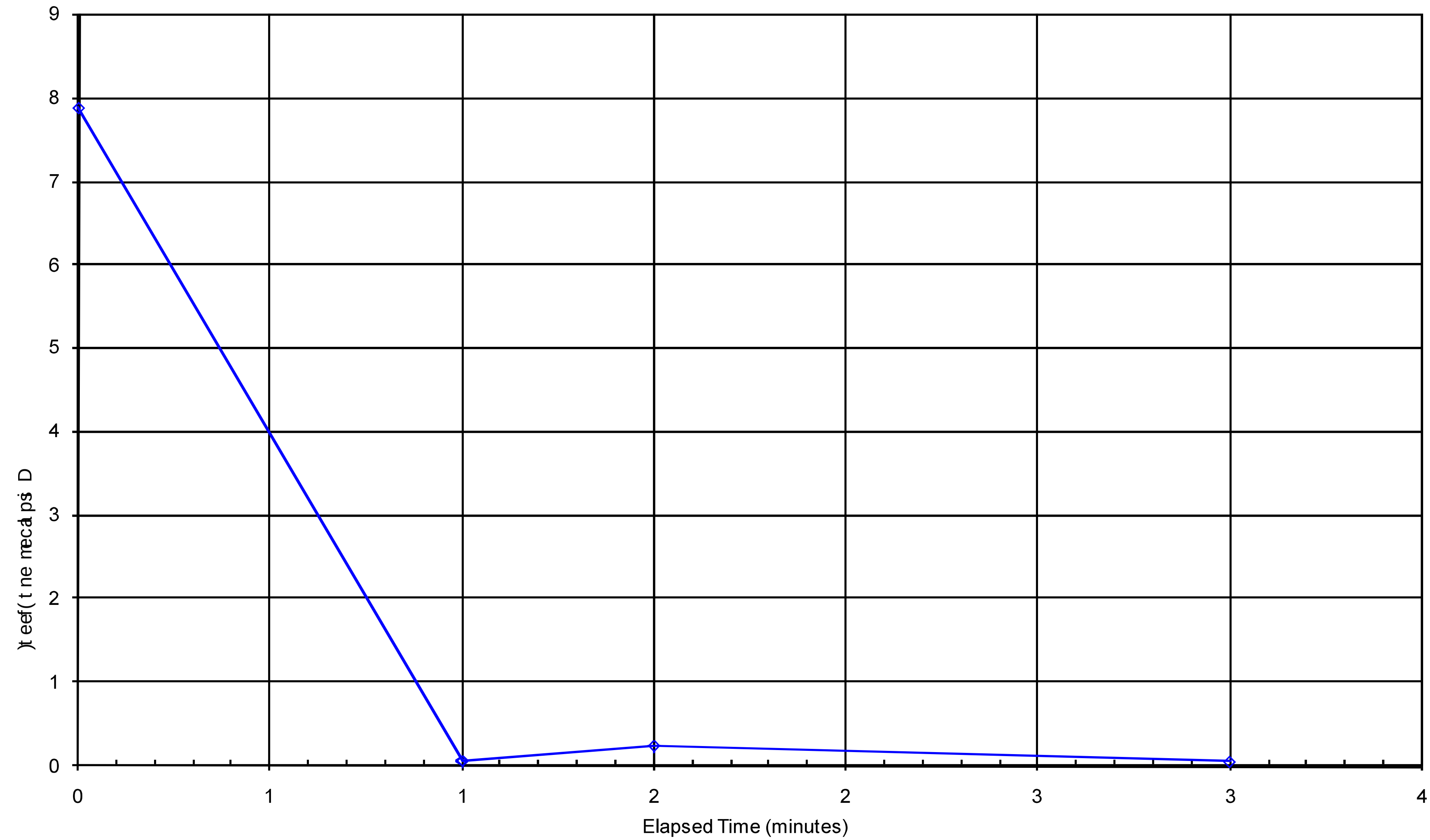
Golder Associates

Walla Walla Shallow Aquifer Recharge

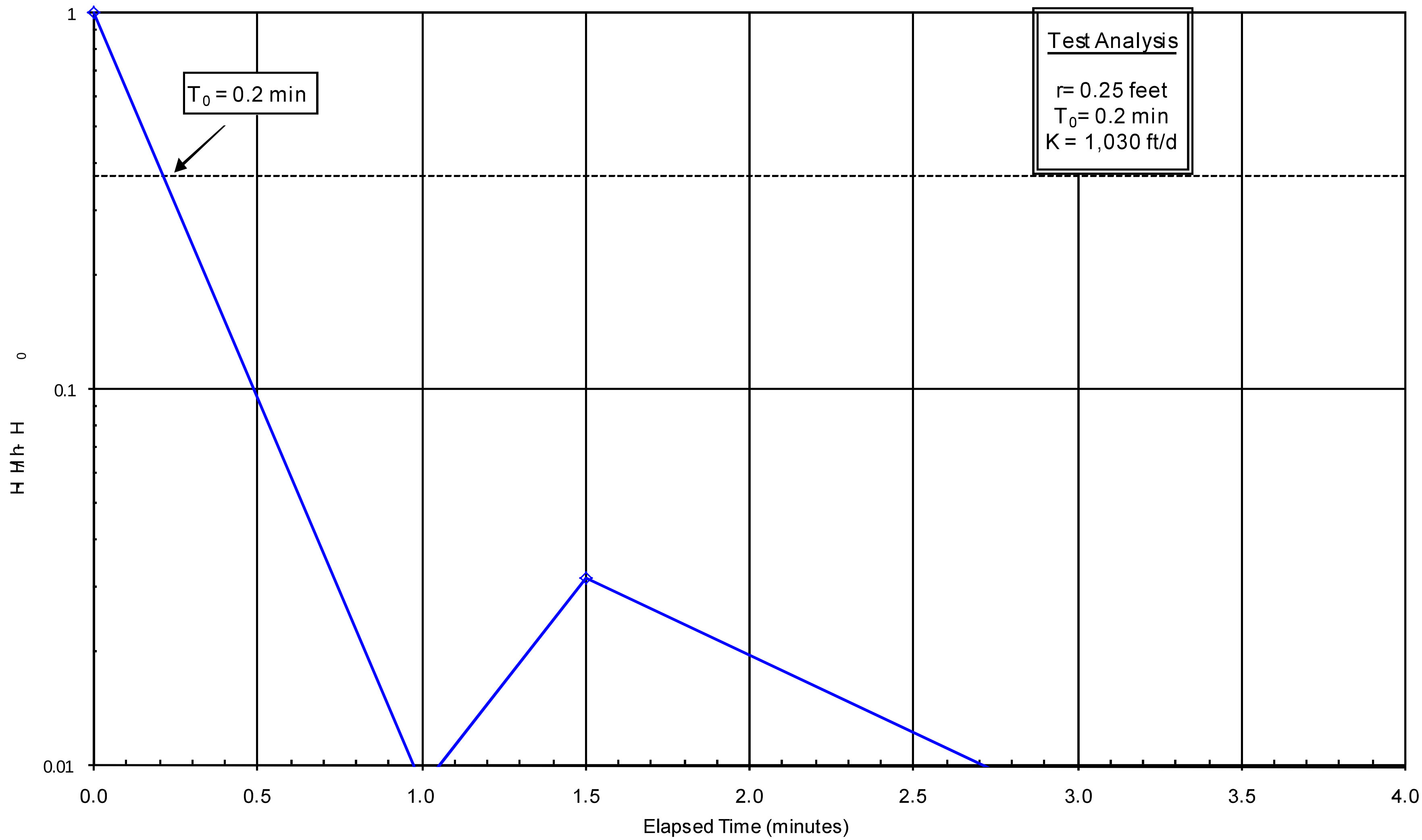
TITLE

PZ-1 Test Analysis - 23 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-4**



Golder Associates	TITLE **PZ-1 Test Hydrograph - 36 Feet**		
Walla Walla Shallow Aquifer Recharge	DRAWN MPK	DATE Nov-07	JOB NO. 063-1345
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. SASR piezos.xlx	FIGURE NO. **B-5**



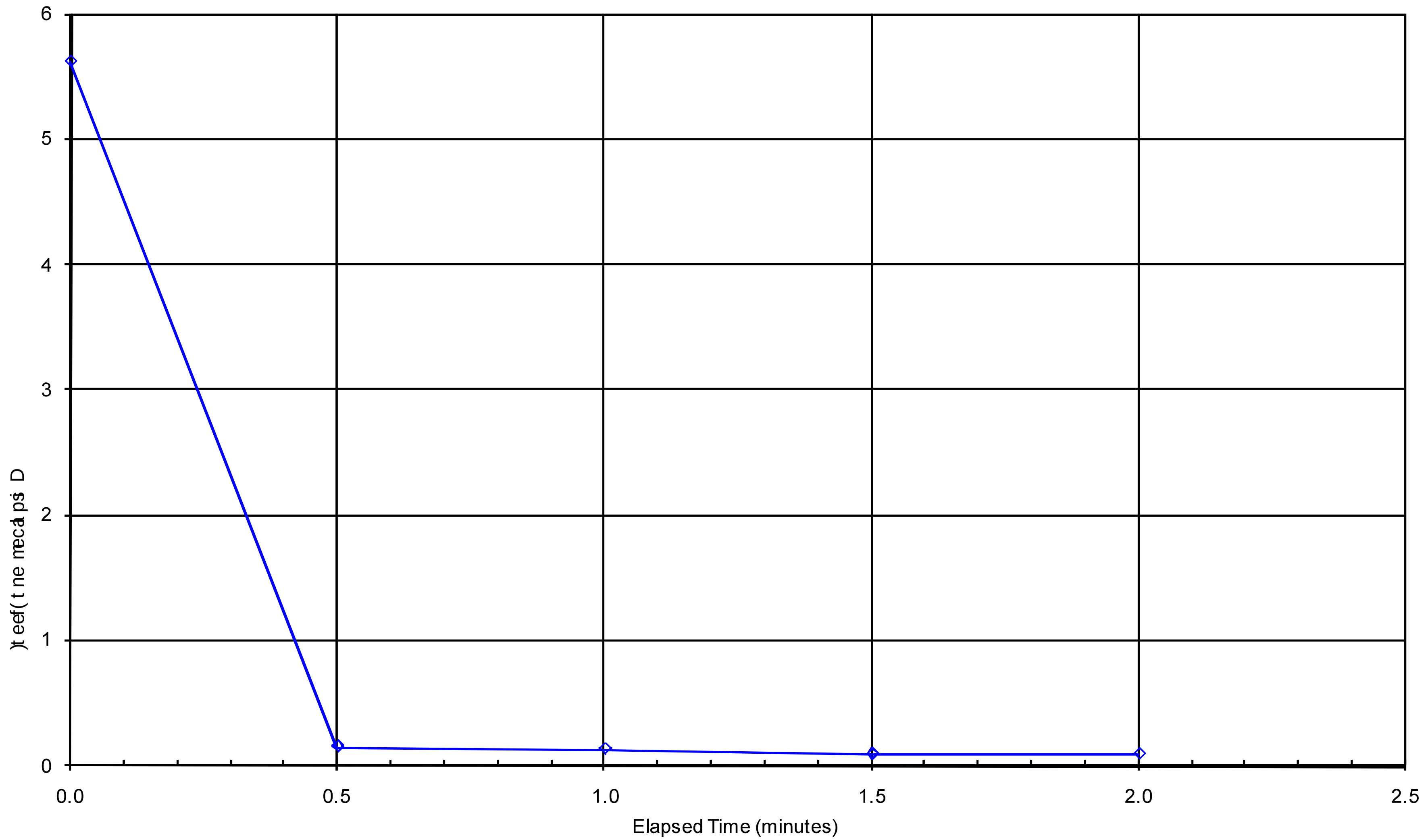
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Analysis - 36 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-6**



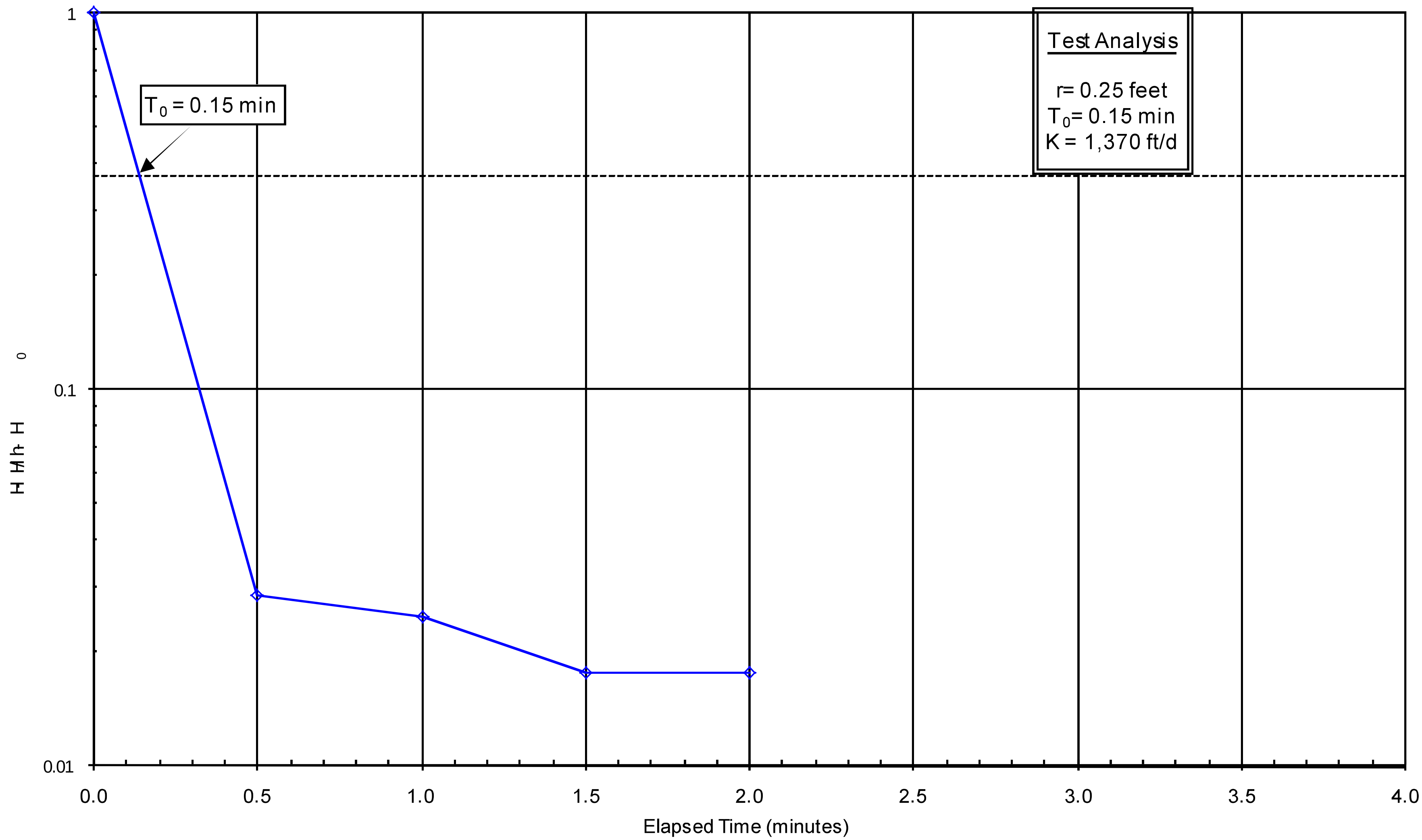
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Hydrograph - 49 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-7**



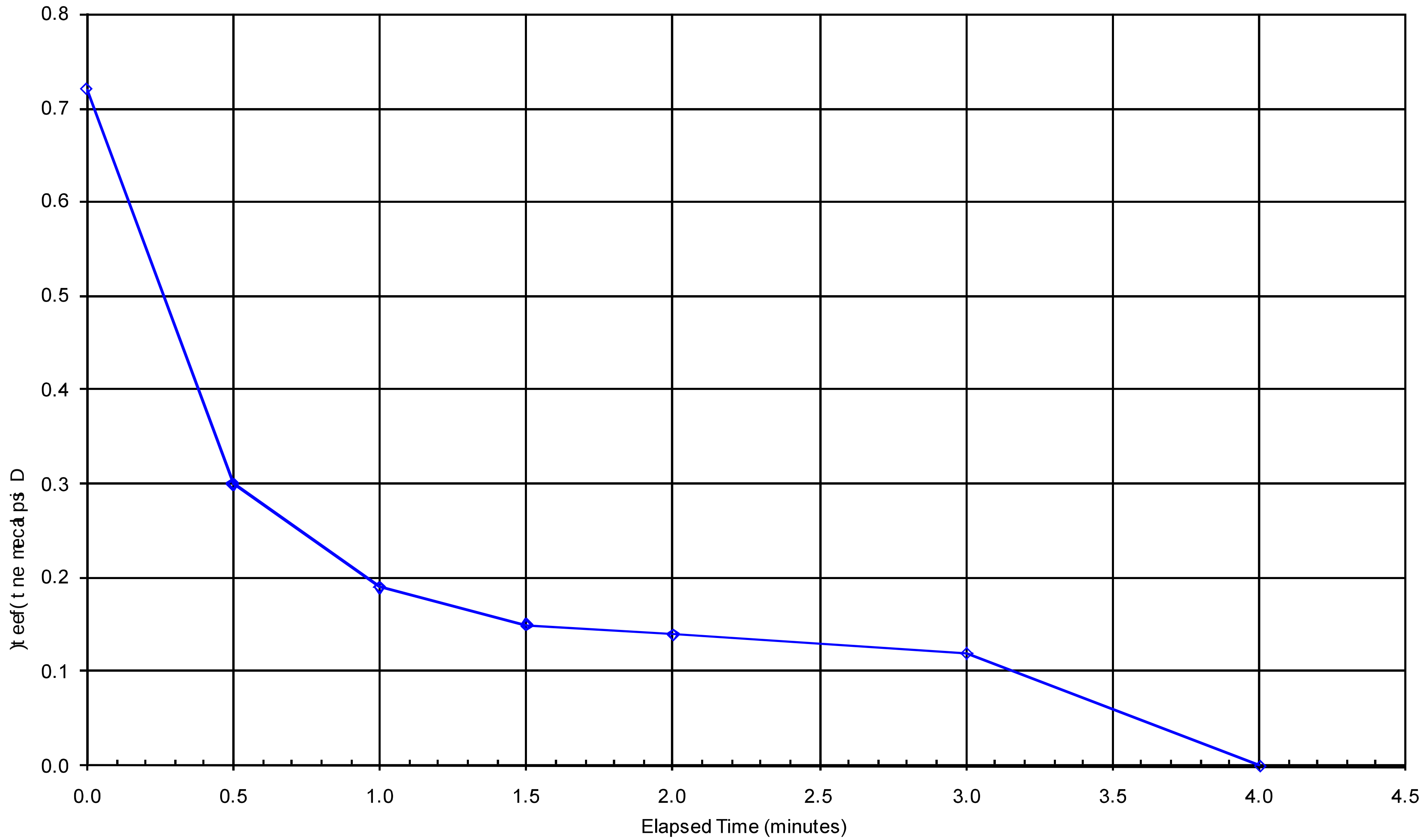
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Analysis - 49 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-8**



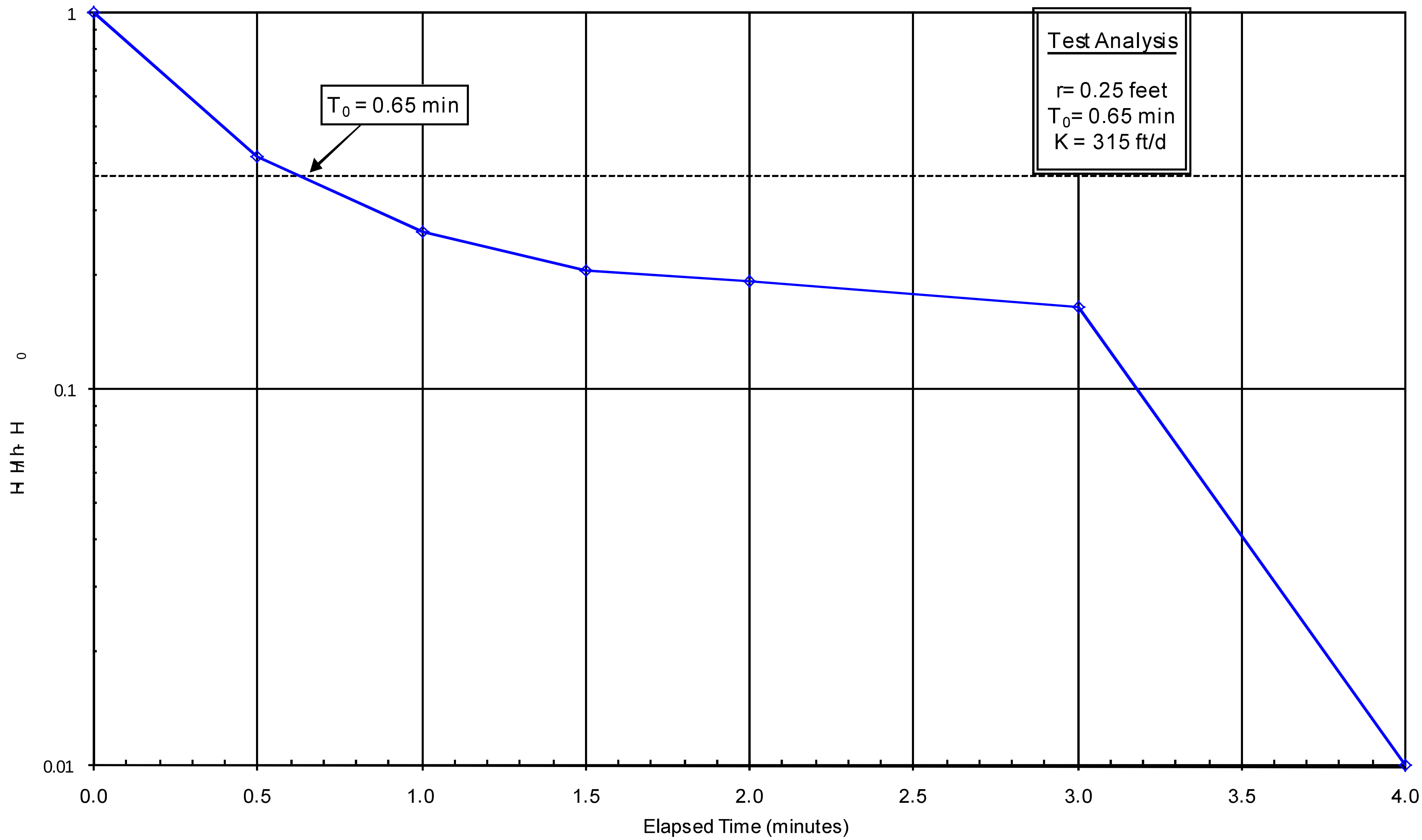
Golder Associates

Walla Walla Shallow Aquifer Recharge

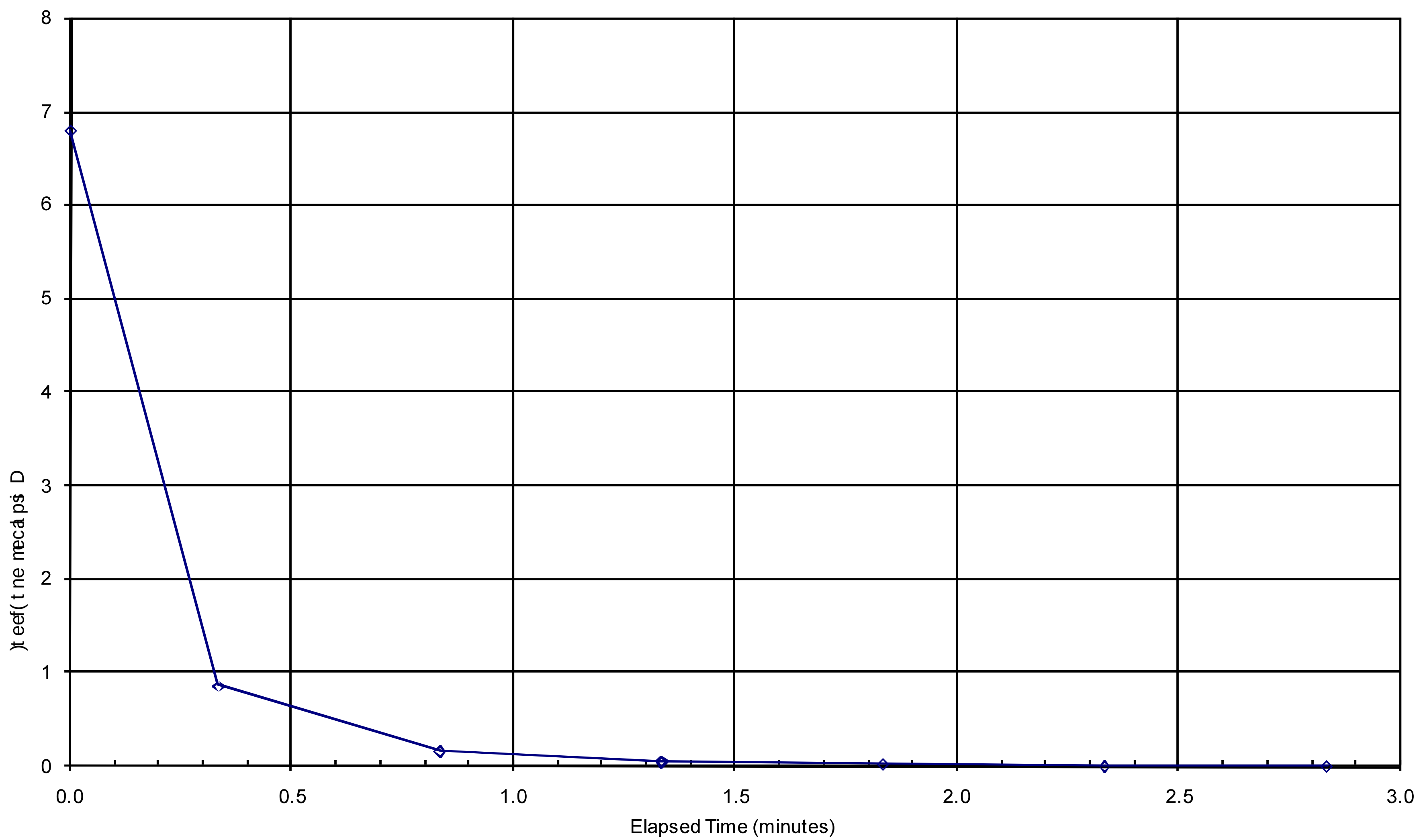
TITLE

PZ-1 Test Hydrograph - 57 Feet

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-9**



Walla Walla Shallow Aquifer Recharge	TITLE: PZ-1 Test Analysis - 57 Feet		
	DRAWN: MPK	DATE: Nov-07	JOB NO.: 063-1345
	CHECKED: DB	SCALE: na	DWG. NO.: na
	REVIEWED: DB	FILE NO.: SASR piezos.xlx	FIGURE NO.: **B-10**



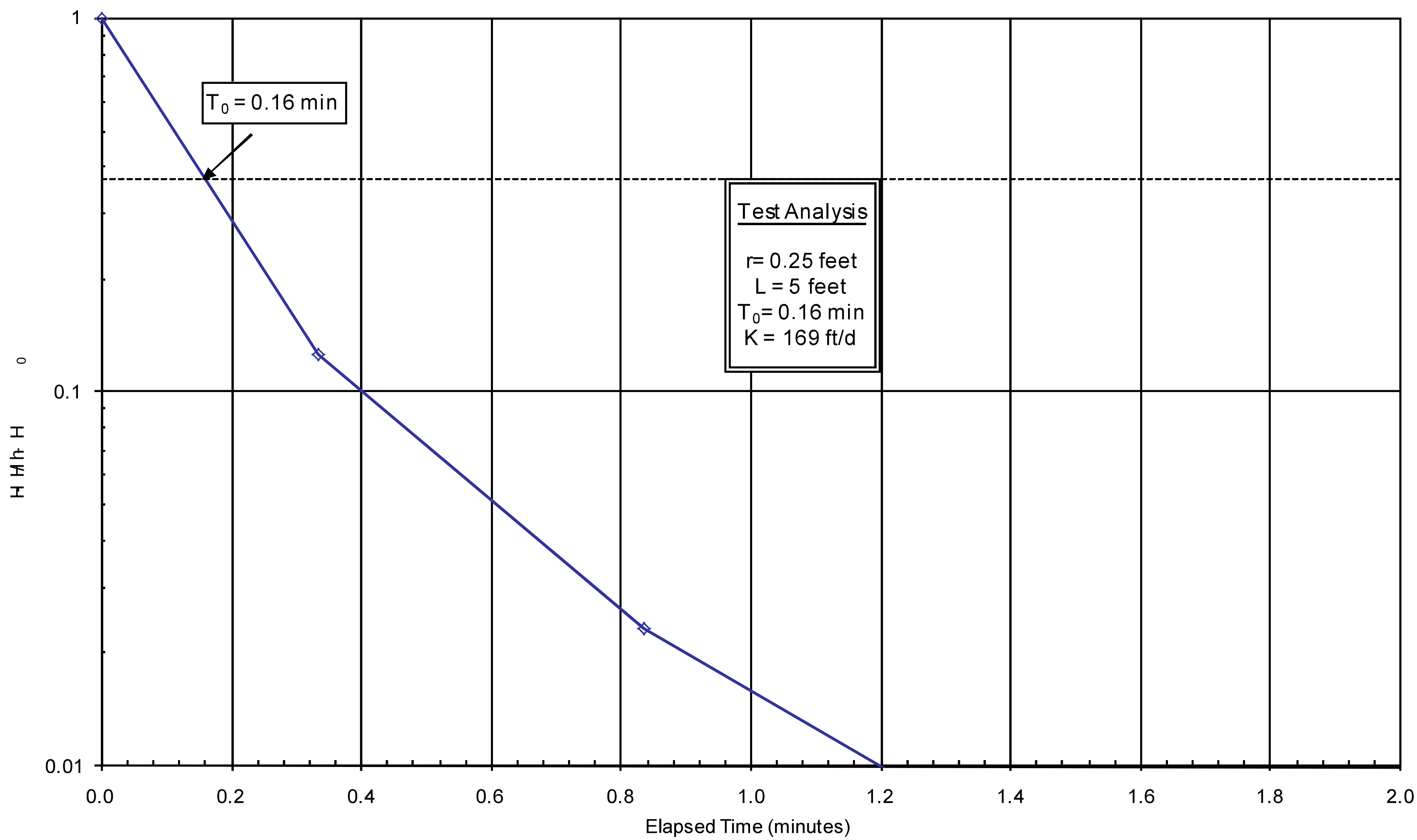
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Hydrograph - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-11**



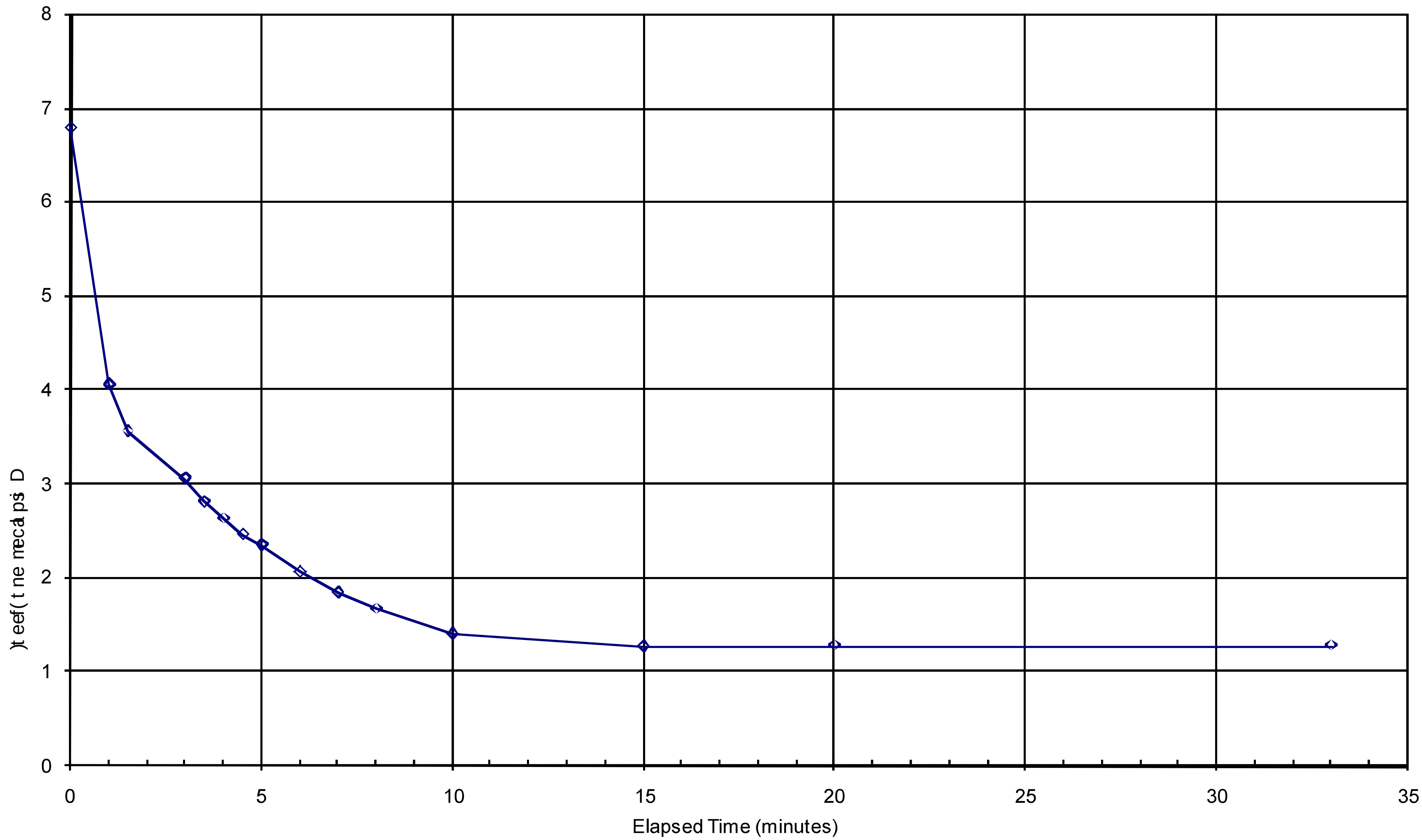
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-1 Test Analysis - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-12**



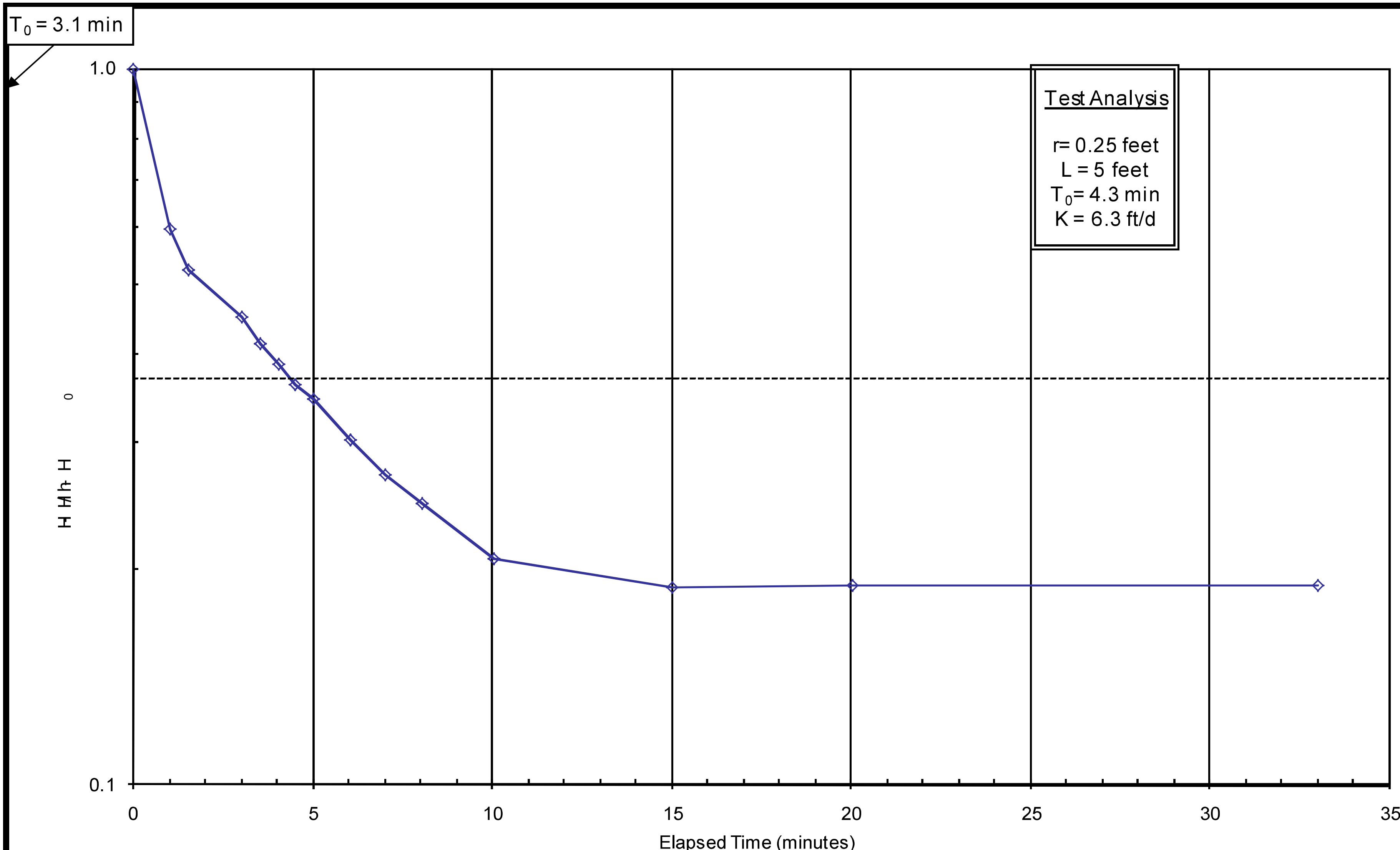
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-2 Test Hydrograph - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-13**



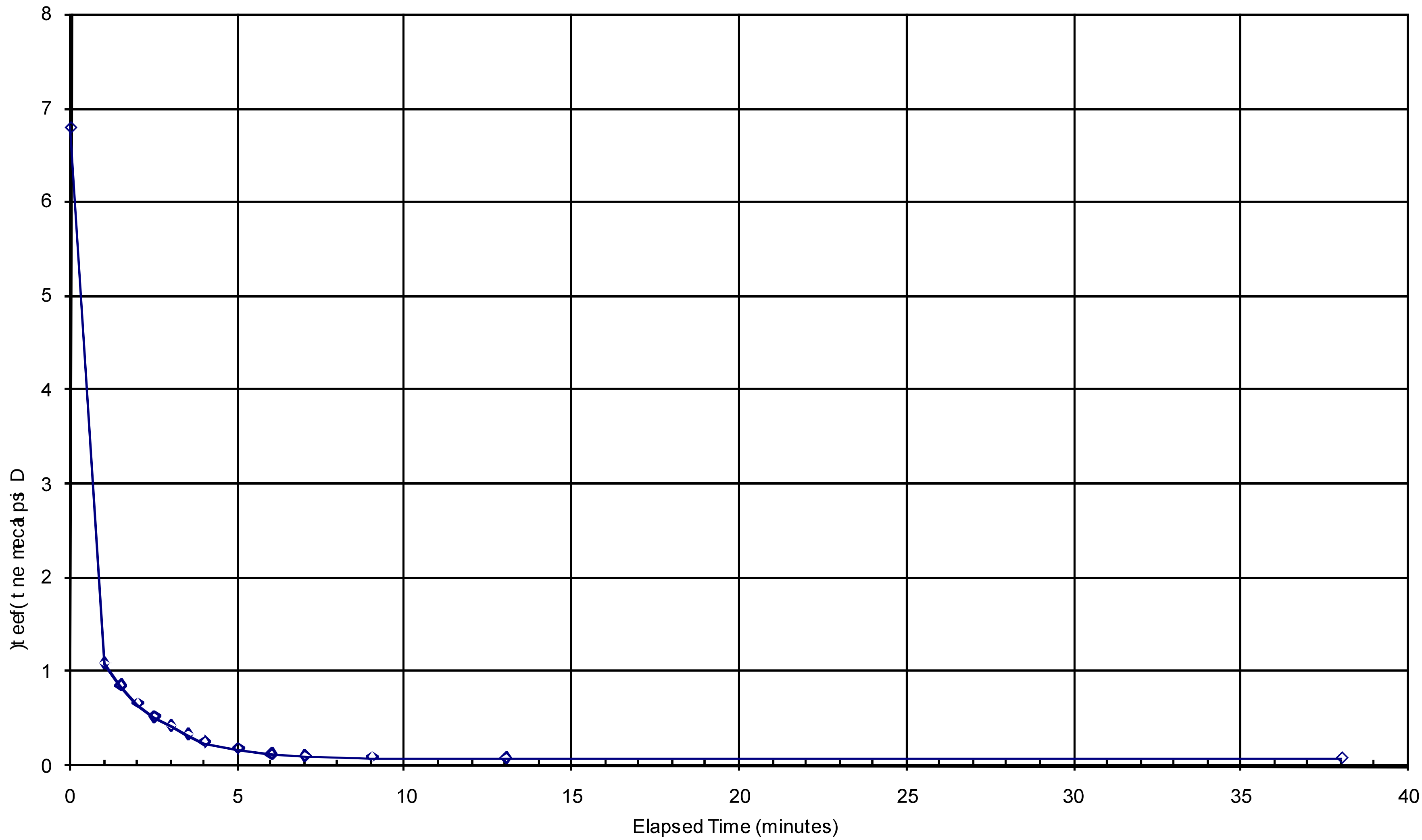
Golder Associates

Walla Walla Shallow Aquifer Recharge

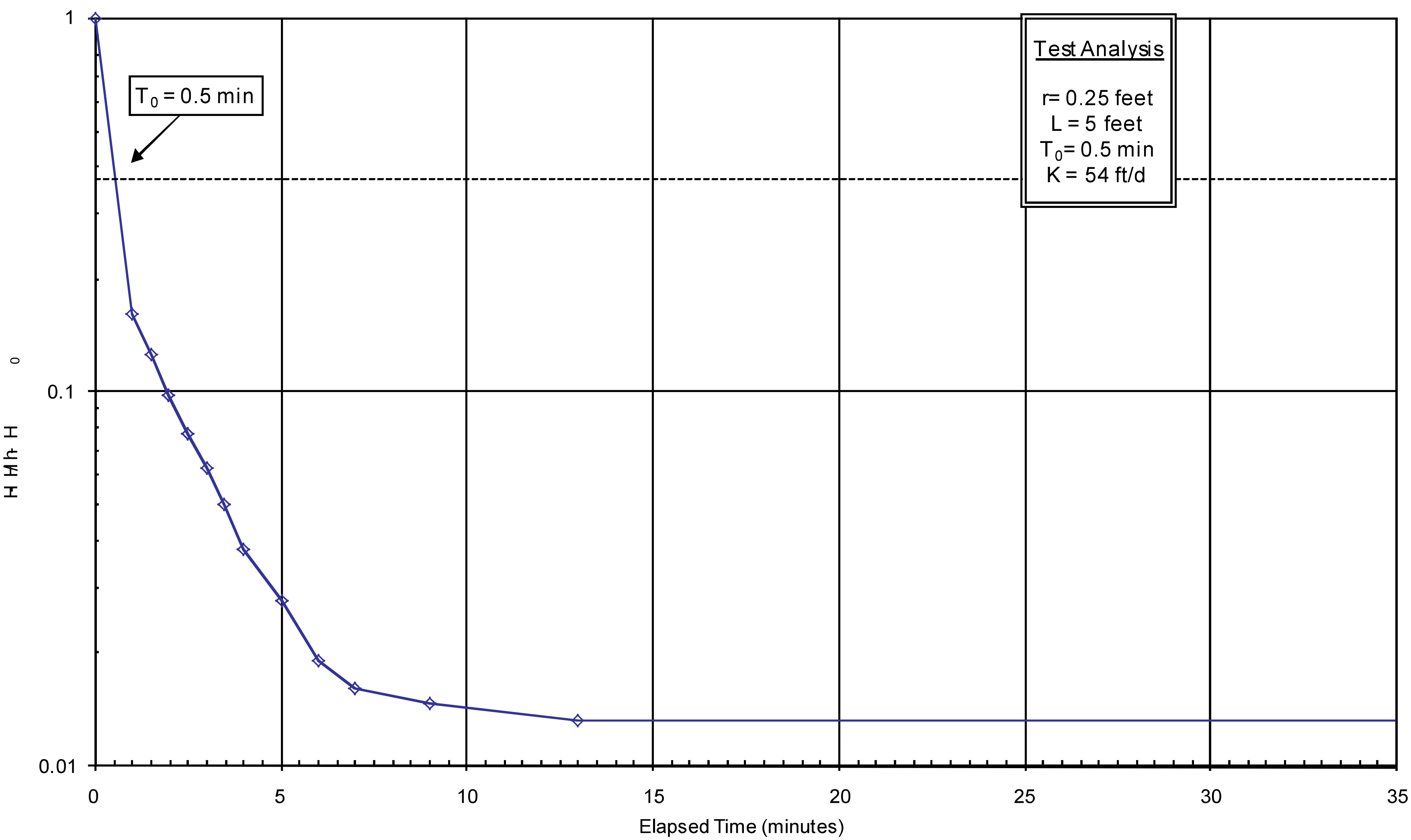
TITLE

PZ-2 Test Analysis - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-14**



Golder Associates	TITLE PZ-3 Test Hydrograph - Completed Piezometer		
Walla Walla Shallow Aquifer Recharge	DRAWN MPK	DATE Nov-07	JOB NO. 063-1345
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. SASR piezos.xlx	FIGURE NO. **B-15**



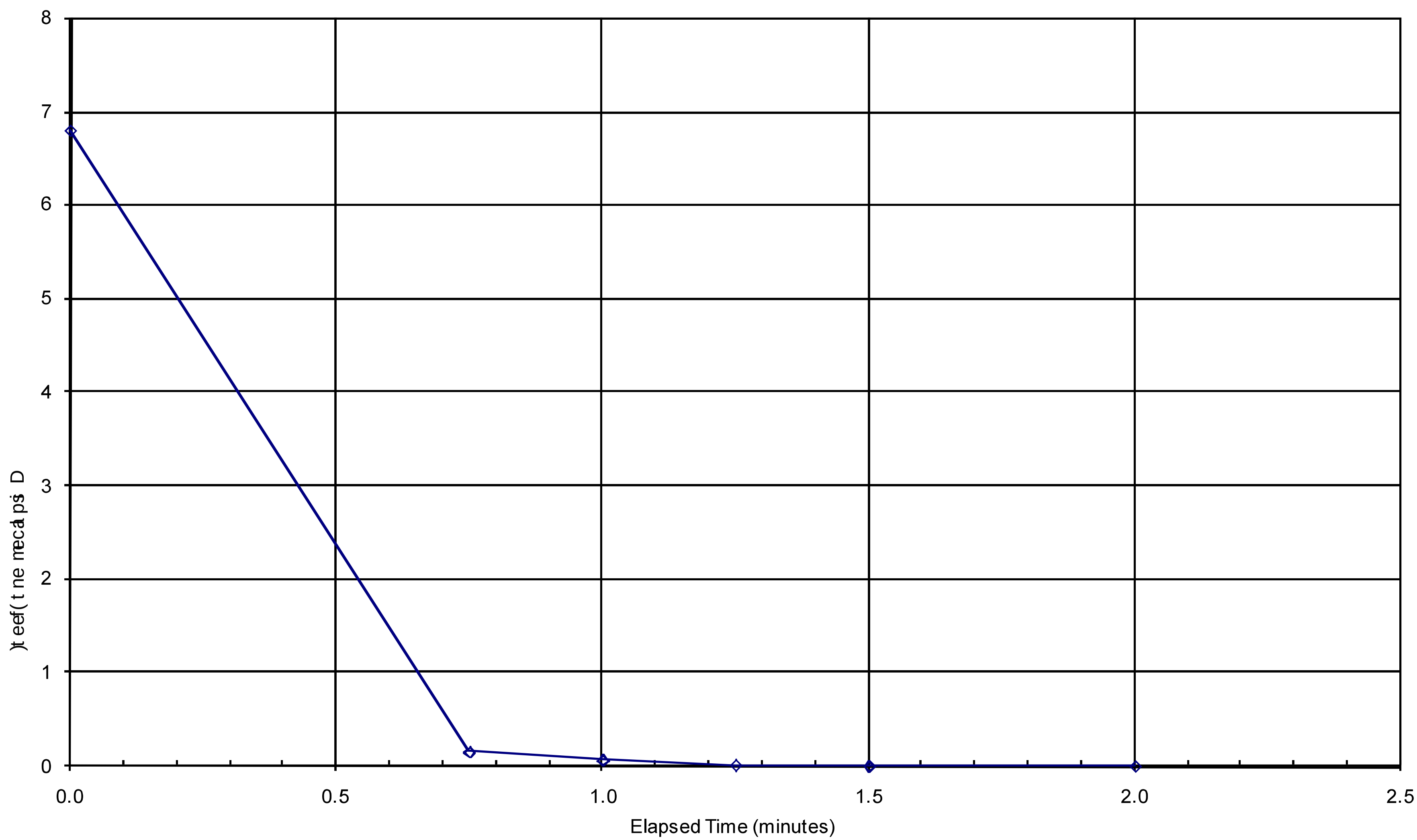
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-3 Test Analysis - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-16**



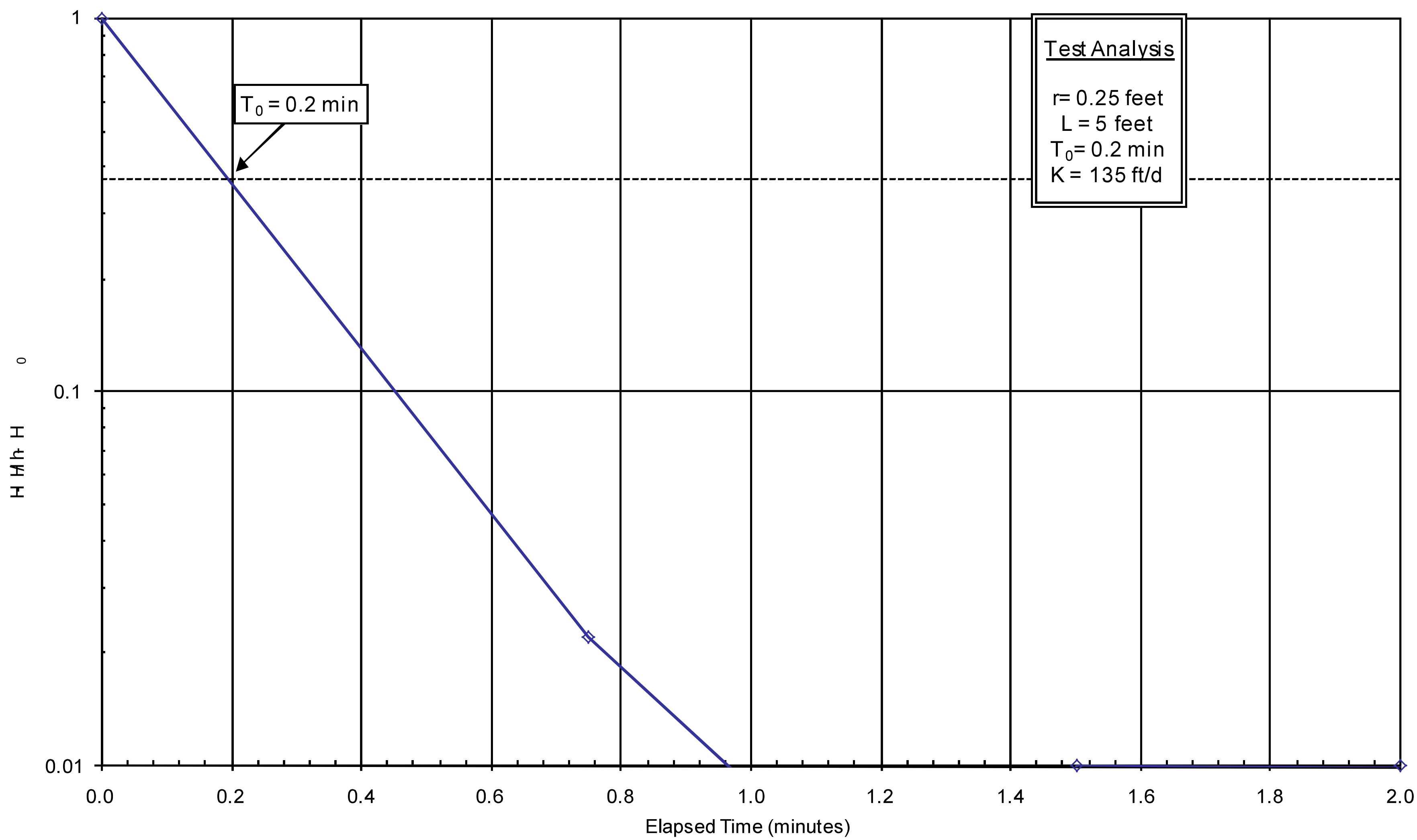
Golder Associates

Walla Walla Shallow Aquifer Recharge

TITLE

PZ-4 Test Hydrograph - Completed Piezometer

DRAWN	MPK	DATE	Nov-07	JOB NO.	063-1345
CHECKED	DB	SCALE	na	DWG. NO.	na
REVIEWED	DB	FILE NO.	SASR piezos.xlx	FIGURE NO.	**B-17**



Golder Associates	TITLE **PZ-4 Test Analysis - Completed Piezometer**		
Walla Walla Shallow Aquifer Recharge	DRAWN MPK	DATE Nov-07	JOB NO. 063-1345
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. SASR piezos.xlx	FIGURE NO. **B-18**