SW WELL 1A REPORT

# THE CITY OF YELM SOUTHWEST WELL 1A DEVELOPMENT REPORT

## Drilling, Well Construction and Testing

**Submitted To:** Stephanie Ray
City of Yelm
PO Box 479
Yelm, WA 98587

**Submitted By:** Golder Associates Inc.
9 Monroe Parkway, Suite 270
Lake Oswego, OR 97035 USA

**Distribution:** 6 Copies (4 electronic) – City of Yelm
1 Copy – Golder Associates, Lake Oswego, OR

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# EXECUTIVE SUMMARY

A new water well (SW Well 1A; Ecology Well Tag No. ALM 113) was constructed and tested in the Tahoma Terra area west of Yelm in Thurston County, Washington to evaluate the area as a potential new source for groundwater development. Testing has shown that Yelm has installed a very successful new water supply well capable of producing high quality water at yields two to three times greater than expected. Formation samples, water quality, and water level response during aquifer testing indicate that SW Well 1A is completed in the deeper portion of the regional aquifer system (the TQu unit), and development of the groundwater appears feasible.

This report describes results from the SW Well 1A drilling, well construction, and testing program. The major conclusions and recommendations are summarized in the sections below.

## Well Construction

The drilling and testing program for SW Well 1A began in April 2010 and was completed in October 2010. The well is located in SE¼, SE¼, Section 23, T17N, R1E W.M. Well construction information is summarized below:

- Well casing diameter and depth: 12-inch to 367.5 feet below ground surface (ft bgs);
- Well depth: 633 ft bgs;
- Well seal diameter and depth: 16-inch to 327.7 ft bgs;
- Well screen assembly: An 8-inch pipe-size screen assembly extends from 349 to 633 ft bgs. The top of the screen assembly consists of 20-ft of 8-inch blank steel riser pipe, which includes a 5-ft pressure relief screen (from 352 to 357 ft bgs) that is positioned within the 12-inch production casing. The screen assembly consists of three screened sections placed in the intervals 369 to 437 ft bgs, 487 to 547 ft bgs, and 611 to 625 ft bgs. The screen sections are separated by 8-inch blank steel pipe. The bottom of the screen assembly includes 8-ft of an 8-inch steel casing tailpipe from 633 to 625 ft bgs;
- Well screen: 8-inch diameter pipe-size, stainless steel, “V-wire” wrap, 35-slot (0.035-inch slot size) Johnson well screen;
- Filter pack: 10-20 Colorado silica sand extending from 353 to 633 ft bgs;
- Screen design capacity: 2,700 gpm;
- Static water level: 102.5 ft bgs; and
- Aquifer source: Confined, unconsolidated and undifferentiated deposits of the TQu unit.

## Aquifer Testing

The aquifer testing program at SW Well 1A included step-rate and constant-rate aquifer tests. A step-rate test was conducted at pumping rates of 750, 1,300 and 1,800 gpm. Total drawdown of approximately 29.1, 49.6, and 68.2 feet were observed, equating to short-term specific capacity values of 25.8, 26.2, and

26.4 gpm/ft, respectively. The slight increases in specific capacity suggest that the well continued to develop during testing.

A constant-rate aquifer test including baseline and recovery monitoring was conducted over a 14 day period from September 29 to October 13, 2010. The pumping portion of the aquifer test was conducted at a constant pumping rate of 2,100 gallons per minute for a period of nearly 73 hours, which resulted in a maximum drawdown of approximately 82.3 feet. The specific capacity at the end of the test was 25.5 gpm/ft. The efficiency of SW Well 1A is estimated at 93 percent.

The water level in SW Well 1A post-pumping was projected to recover to pre-test water levels (i.e., water level recovery trends toward zero residual drawdown at *t/t'* = 1). The recovery response curve indicates that recovery was affected by a linear negative aquifer boundary condition. The presence of the boundary was not apparent on either the specific capacity or pumping response curves and does not appear to have accelerated drawdown in or limited flow to the well during pumping. The aquifer's hydraulic response to pumping indicates a well confined aquifer with no apparent evidence of leakance.

Transmissivity estimates of the TQu in the vicinity of SW Well 1A ranged between 42,400 and 58,900 gpd/ft. The geometric mean transmissivity equated to 47,827 gpd/ft. Storativity was estimated to be 2.0 x $10^{-4}$, consistent with typical confined aquifer coefficients.

An observation well network consisting of 10 private domestic wells, municipal test wells, and piezometers were monitored (in addition to SW Well 1A) as part of the testing program. No hydraulic response to pumping SW Well 1A was apparent in any of the observation wells monitored. Consequently, groundwater development from the SW Well 1A is not expected to result in significant impacts to existing groundwater users or nearby surface water features. Response to planned future pumping is evaluated in Yelm's Mitigation Plan to support water right permitting.

## Water Quality

Groundwater from SW Well 1A was cold, clear, odorless, and was noted to have a slight metallic/mineral taste. Analytical results show that:

- No volatile organic compounds, synthetic organic compounds, herbicides, or hydrogen sulfide were detected;
- The only inorganic constituent having a concentration above its regulatory criteria was manganese. The manganese concentration of 0.15 mg/L is at a level three times the recommended secondary (aesthetic) limit of 0.05 mg/L. Although a manganese concentration at this level is likely to cause staining, it does not pose a risk to human health or the environment;
- The total coliform result of 2 MPN/100 mL suggests the presence of coliform bacteria (other than fecal coliform and *E. coli* because these were not detected). The sample was

collected before the well was disinfected and it is most likely that the result is due to a sampling circumstance or condition and is not representative of source water quality;

- Radon was detected at 234 pCi/L, below the proposed federal drinking water criteria of 300 pCi/L; and
- The chemical signature of groundwater from SW Well 1A is most consistent with groundwater from the deeper, regional TQu flow regime.

## Recommendations

Based on the results of the drilling and testing program at SW Well 1A, Golder recommends the following:

- As part of the finished design, the well should be equipped with the following:
  - Two water level access pipes for long-term water level monitoring; and
  - A filter pack fill tube to allow placement of additional filter pack as it may settle over time.
- Static water levels, pumping rates, and pumping volumes should be monitored on a regular basis to track usage, seasonal water level fluctuations, and well performance;
- Based on a projected pumping water level of 186 ft bgs at a rate of 2,100 gpm, the pump intake should be set to a depth of 266 feet bgs;
- Repeat bacteriological samples should be collected as part of the source approval process to validate the coliform presence result;
- Track radon concentrations once the well is online for production to assess whether they change over time. Additionally, the City may consider integrating (or reserving space for) a radon treatment system as part of planned treatment facilities to avoid the addition of infrastructure after the facility has been constructed;
- Treatment would likely be required for manganese to maintain the delivered water aesthetic quality and prevent scaling in the City's piping and distribution system;
- Complete the conditions outlined in Thurston County Public Health and Social Services Department's Well Site Inspection Application Report (project # 2010100450) as part of the WAC 246-290 requirements for new drinking water source approval;
- Submit water system plans and specifications to the Washington State Department of Health Office of Drinking Water; and
- Complete and submit a SW Well 1A wellhead protection plan.

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# 1.0 INTRODUCTION

The City of Yelm (City) has constructed and tested a new water supply well (SW Well 1A; Well Tag No. ALM 113) to explore the potential of developing new groundwater sources from a portion of the aquifer system that would lessen the effects of pumping on local surface water features. Currently, the City's municipal water is supplied by two relatively shallow wells in downtown Yelm. Developing a groundwater supply from deeper portions of the aquifer system would allow the City to meet increasing demands for water while minimizing impacts of the withdrawals.

The City has drilled at tested three test wells in 1994 (North, South, and West Test Wells) and one test well in 2005 (SW Well 1). These wells identified a deep, permeable aquifer that appeared to be more regional in nature than the aquifer supporting the downtown wells. The City decided to drill and install a new test/production well to assess this deep aquifer supply closer to the City's existing infrastructure.

Well construction began in April 2010 and testing was completed in October 2010. The drilling and testing program described in this report was conducted in accordance with the Washington State Department of Ecology's preliminary drilling and testing permit and was designed to:

- Explore the potential for withdrawing water from a deeper supply source near Yelm;
- Characterize aquifer properties in the immediate vicinity of the test/production well;
- Evaluate potential production capacity;
- Assess potential impacts to existing groundwater users and surface water bodies; and
- Characterize water quality of the targeted supply source.

## 1.1 Site Location

SW Well 1A is located in the Tahoma Terra area west of downtown Yelm in Thurston County, Washington. The site is located in SE¼, SE¼, Section 23, T17N, R1E W.M. (Figure 1). The ground surface elevation is approximately 381 ft above the National Geodetic Vertical Datum of 1929 (ft NGVD29). The well is located near Thompson Creek, which is tributary to the Nisqually River.

## 2.0 HYDROGEOLOGIC SETTING

The Yelm area is situated in the south-central portion of the Puget Sound Lowland. The Puget Sound Lowland is a north-south-oriented basin that has experienced repeated deposition, erosion and reworking of geologic sediments during glacial and interglacial periods. The repeated glacial advances and retreats covered the area with layered, unconsolidated glacial and non-glacial deposits. The most recent glacial advance into the Yelm area took place approximately 13,500 to 15,000 years ago and is known as the Vashon Stade of the Fraser Glaciation.

Extensive geologic studies of Thurston County and the Yelm area were conducted by Mundorff et al. (1955), Wallace and Molenaar (1961) and Noble and Wallace (1966), with more recent investigations conducted by Drost et al. (1998), Drost et al. (1999), and Robinson and Noble (2001). The glacial geohydrologic units known to exist within this area of Thurston County from the surface downward include:

- Recessional Outwash (Qvr);
- Till (Qvt);
- Advance Outwash (Qva);
- Kitsap Formation (Qf);
- Salmon Springs(?) Drift (Qc);
- Unconsolidated and undifferentiated deposits (TQu); and
- Bedrock (Tb).

The primary water-bearing units include the Qva, Qc, and TQu. The till (Qvt) and Kitsap Formation (Qf) units are typically composed of low-permeability, fine-grained sediments and act as confining layers for deeper groundwater flow systems. The TQu unit contains both aquifers and confining layers (Drost et al., 1999). A table summarizing the lithologic and hydrologic characteristics of each unit is presented in Table 1 (adapted from Drost et al., 1999). The hydrostratigraphic units (as interpreted from area well logs) are illustrated on geologic cross-sections shown on Figures 2 and 3 (cross-section locations, well locations, and area well logs are included in Appendix A; adapted from Golder, 2009). A brief description of each unit is provided in the subsections below.

### 2.1 Recessional Outwash (Qvr)

The recessional outwash deposits (Qvr) blanket most of Yelm east of the Thurston Highlands. The sediments were deposited by meltwater streams discharging from the glacier as it retreated from the Yelm area. With the exception of alluvial sands and gravels found along many of the local streams, the recessional outwash is the youngest geologic deposit in the study area. The Qvr sediments are composed primarily of sand and gravel. Area well logs indicate the thickness to range between 10 and 50 feet (Appendix A). The Qvr unit is generally too thin to support groundwater supply wells along the western margin of Yelm Prairie; most wells in the area are completed in the deeper, more transmissive Qva aquifer.

## 2.2 Till (Qvt)

An unsorted mixture of rock debris known as glacial till (Qvt) underlies the Qvr unit and confines groundwater in the deeper Qva. The till was picked up and transported by the glacier as it advanced into the area and was deposited over the Qva. The Qvt deposits are generally composed of a mixture of sands, gravels, cobbles, and boulders within a compacted matrix of silt and clay. Drillers commonly refer to these deposits as "hardpan", "cemented", or "clay boulder". The Qvt unit is found at depth throughout the Yelm area and is exposed at the surface west of Yelm forming the eastern portion of the Thurston Highlands. The thickness generally ranges between 35 and 80 feet (Appendix A), and is known to exceed 100 feet in areas west and southwest of Yelm (Drost et al., 1999). The Qvt unit is considered a confining bed (i.e., aquitard) and its cemented conditions limit its water transmitting capacity.

## 2.3 Advance Outwash (Qva)

The advance outwash deposits (Qva) lie beneath and are confined by the overlying Qvt till. The Qva sediments were carried and deposited by meltwater streams discharging from the glacier as it advanced into the Yelm area. The Qva is a relatively permeable aquifer unit in the area consisting generally of gravel in a matrix of sand with some sand lenses. The Qva is widespread throughout the subsurface ranging in thickness between 15 and 85 ft (Appendix A), and is the primary source for domestic and municipal water supplies in the Yelm area.

## 2.4 Kitsap Formation (Qf)

The Kitsap Formation is a low-permeability, fine-grained confining layer that separates the overlying Qva unit from the deeper Qc and TQu units. The Qf unit is composed predominately of clay and silt, with some layers of sand and gravel, and may include some till or till-like deposits and minor amounts of peat and wood. The Qf unit is extensive throughout the Yelm area and its thickness generally ranges between approximately 25 and 80 feet (Appendix A).

## 2.5 Salmon Springs(?) Drift

Below the Qf is the Salmon Springs(?) Drift unit (Qc). The Qc unit consists mainly of coarse-grained sand and gravel is characterized by its oxidized red or brown staining (i.e., iron-oxides). This unit is referred to as the Salmon Springs(?) Drift by Noble and Wallace (1966) because its stratigraphic relationships mapped in Thurston County are similar to the Salmon Springs Drift type-section mapped in Pierce County and north of Tacoma, WA. The Qc unit is extensive throughout the Yelm area and its thickness typically ranges between 15 and 50 feet (Appendix A). Groundwater in the Qc is confined by the overlying Qf unit and is a supply source for some wells.

## 2.6 Unconsolidated and Undifferentiated Deposits (TQu)

Unconsolidated and undifferentiated deposits of the TQu underlie the Qc unit. The TQu consists of glacial and non-glacial sediments of clay, silt, sand, and gravel, and is known to consist of layers of fine-grained confining beds and coarse-grained aquifer units (Drost et al., 1999). The TQu is widespread throughout the region, but its thickness and groundwater development capacity is not well known. The TQu is the target aquifer for SW Well 1A

## 2.7 Bedrock (Tb)

The deepest geohydrologic unit in the Yelm area is the consolidated bedrock (Tb). The bedrock unit consists of sedimentary claystone, siltstone and sandstone and igneous bodies of andesite and basalt. The Tb unit is known to contain some water in fractures and joints, but is considered an unreliable source due to low yields and poor water quality (Drost et al., 1998).

## 2.8 Groundwater

Groundwater in the Yelm area is derived from two different flow systems: shallow and deep. The shallow groundwater system consists primarily of the advance outwash (Qva) deposits, whereas the deeper, regional groundwater system consists of the older glacial deposits identified as the Salmon Springs(?) Drift (Qc) and unconsolidated and undifferentiated deposits of the TQu. Studies conducted by Robinson and Noble (1995 and 2001) indicate that the groundwater elevation and flow direction of the deeper system are different from those in the shallow system beneath Yelm. Groundwater within the shallow system generally flows in a northerly direction across Yelm Prairie toward the Nisqually River, whereas groundwater in the deeper system moves northwest away from the Nisqually River toward Olympia, WA. The TQu unit was the target aquifer source for the SW Well 1A due to its depth, confined nature, and reduced potential for interference with shallow groundwater resources in the area.

## 3.0 WELL DRILLING, CONSTRUCTION AND COMPLETION

SW Well 1A was drilled and tested between April and October 2010 by the E&I Rotary group of Boart Longyear (Boart) of Sherwood, Oregon. Drill cuttings characterization and construction oversight was provided by Golder Associates Inc. (Golder). This section provides information on well construction and design.

### 3.1 Well Drilling

SW Well 1A was drilled to a depth of 800 feet below ground surface (ft bgs) using dual-rotary (air) drilling methods. The deepest production zone target by this well occurred at 629 ft bgs, so the lower section of the borehole was backfilled with neat cement in accordance with WAC 173-160 from 800 to 650 ft bgs. Pea gravel was placed from 650 to 633 ft bgs to form a base for the screen assembly. The final depth of the completed well is 633 ft.

The SW Well 1A borehole advanced through the glacial geohydrologic units described above. The hydrostratigraphy, hydrogeologic characteristics, and thicknesses observed at SW Well 1A are summarized below. The geologic log for SW Well 1A is provided in Appendix B:

- **Recessional Outwash (Qvr)** – The Qvr unit is present between the depths of 0 and 25 ft bgs and consisted mainly of sand and silt;
- **Till (Qvt)** – The Qvt unit consisted predominately of cemented, fine-to-coarse sand and gravel with silt and cobbles, and is approximately 145 ft thick (25 to 170 ft bgs);
- **Advance Outwash (Qva)** – The Qva unit is roughly 49 ft thick (170 to 219 ft bgs) and consisted mainly of sand with gravel and silt;
- **Kitsap Formation (Qf)** – The Qf unit consisted of both silt and clay with organics and fine-to-coarse sand with silt, gravel and cobbles, and is approximately 21 ft thick (219 and 240 ft bgs);
- **Salmon Springs(?) Drift (Qc)** – The Qc unit is roughly 60 ft thick (240 and 300 ft bgs) and consisted predominately of sand with gravel (stained reddish brown) and silt; and
- **Unconsolidated and undifferentiated deposits (TQu)** – SW Well 1A is completed within the coarse-grained, water-bearing layers of the TQu. The coarse-grained layers consisted predominately of fine-to-coarse sand with some gravel, while the fine-grained layers generally consist of silt and clay with some fine sand. The SW Well 1A borehole encountered relatively thick zones of heaving sand within the TQu. The TQu unit at SW Well 1A is at least 500 ft thick (from 300 ft bgs to the total explored drilling depth of 800 ft bgs). The total thickness however, remains unknown because bedrock was not encountered within the exploratory drilling depth.

### 3.2 Well Design

The well is completed with a 16-inch neat cement surface seal to a depth of 327.7 ft bgs, which extends approximately 27.7 ft into the TQu unit. Approximately 4.3 ft of 20-40 filter pack sand was placed below the seal to prevent downward migration of cement as it was placed. The well is cased with 12-inch steel production casing that extends from approximately 2 feet above ground surface (ft ags) to a depth of

367.5 ft bgs. Three water bearing zones were identified based on formation samples and air-lift tests conducted during drilling (a fourth water bearing zone was encountered below 650 ft bgs, but was not screened due to the presence of a strong hydrogen sulfide odor). Grain size distributions of the samples were used to design the appropriate filter pack gradation and well screen slot size. The geologic log, as-built diagram, and water well report for SW Well 1A are included in Appendix B.

An 8-inch pipe-size screen assembly extends from 349 to 633 ft bgs. The top of the screen assembly consists of 20-ft of 8-inch blank steel riser pipe, which includes a 5-ft pressure relief screen (from 352 to 357 ft bgs) that is positioned within the 12-inch production casing. The screen assembly consists of three screened sections. The screen sections were placed in the intervals 369 to 437 ft bgs, 487 to 547 ft bgs, and 611 to 625 ft bgs. Each screen section consists of 8-inch pipe-size stainless steel, "V-wire" wrap 35-slot (0.035-inch slot size) well screen. The screen sections are separated by 8-inch blank steel pipe. The bottom of the screen assembly includes 8-ft of an 8-inch steel casing tailpipe from 633 to 625 ft bgs. Steel bands were used as casing guides to centralize the screen assembly in the borehole. The centralizers were welded to the solid casing (blank) sections of the assembly at 120-degree spacing. The annular space between the screen assembly and production casing and borehole is filled with 10-20 Colorado silica sand filter pack. The filter pack extends from 353 to 633 ft bgs.

The design capacity of the well screen based on manufacturer specifications (transmitting capacity of 19 gpm/ft of screen at a recommended entrance velocity of 0.1 ft/sec) is approximately 2,700 gpm.

### 3.3 Well Development

Well development techniques included isolation surging with simultaneous air-lift pumping and application of a liquid polymer dispersant. Surging and airlifting were conducted initially to stabilize the filter pack as the sand was placed and the screen sections exposed. The surge tool was equipped with two, 7.5-inch rubber discs at each end (7-ft separation) to isolate separate screen sections during development. Sand production during development was monitored using an Imhoff cone and each screened interval was developed until the sand content was <5 mL sand per L water and turbidity values were <5 NTU.

After the initial development was complete and filter pack stabilized, a phosphate-free dispersant (Aqua-Clear®) was added to the well to break up fine-grained material from the producing formation and filter pack that may have been emplaced during drilling or construction. The dispersant was jetted into each screen section, allowed to sit overnight and removed using airlift pumping. After the dispersant was removed, the well was further developed using the isolation surge tool and simultaneous airlift pumping until the sand content was < 5 mL sand per L water, turbidity was <5 NTU and field water quality parameters stabilized.

## 3.4 Well Video

A video survey of SW Well 1A was conducted by Water Well Developing and Surveys of Umatilla, Oregon on September 17, 2010. The video was completed to ensure proper construction and completion of the well after it was installed and developed. Results of the survey confirmed that the:

- Production casing, casing welds, and well screen assembly were intact with no apparent defects in construction; and
- The well and screen assembly were constructed and positioned as designed.

## 3.5 Alignment and Plumbness Testing

Alignment and plumbness testing was conducted to assess whether the well was straight and plumb. An alignment test was conducted prior to screen installation by running a 40-ft cylindrical dummy (two well casing lengths) with 11.5-inch rings attached at each end throughout the entire length of the borehole. The dummy freely passed the entire length of the 633-ft borehole indicating the well was in alignment.

A plumbness test was conducted after installation of the screen assembly. The plumbness test was completed by deploying a 3 ft plummet with two 11.75-in outer diameter plates attached to each end. The plummet was positioned in the center of the casing and lowered at 10-ft intervals recording the displacement of the plummet from the center of the casing. The total displacement to the top of the screen assembly was 0.39 inches indicating the well is plumb and straight and within acceptable tolerance limits as specified by AWWA A100-06 standards (i.e., two-thirds the well's inside diameter per 100 feet). Results of the plumbness test are provided in Appendix B.

## 3.6 Well Disinfection

After aquifer testing was completed and the test pump removed, the well was disinfected in accordance with the requirements of WAC 173-160-331 and ANSI/AWWA C654 using Multi-Chlor (12.5% sodium hypochlorite). The well was disinfected by pumping a concentrated disinfection solution through a 3-inch pipe into the water bearing zones to provide a chlorine residual of approximately 50 mg/L. The sodium hypochlorite solution was agitated using airlift pumping to circulate the chlorinated water in the well. The chlorinated water was then pumped from the well until no residual chlorine was detected. The chlorinated water was neutralized with sodium sulfate prior to discharge to the onsite pond.

# 4.0 AQUIFER TESTING

The aquifer testing program at SW Well 1A included step-rate and constant-rate aquifer tests. A step-rate test was performed to evaluate well production and assess potential pumping rates for the constant-rate test. The constant-rate test was conducted to characterize local hydraulic properties of the TQu and assess potential hydraulic response at nearby wells and surface water features. This section describes the aquifer testing approach and results, including (1) test design and monitoring approach, (2) estimates of TQu hydraulic properties, (3) evaluations of well performance, production capacity, and well efficiency, and (4) observed hydraulic response in observation wells.

## 4.1 Approach

The aquifer testing program was conducted according to Ecology's superseding preliminary permit requirements to drill and test SW Well 1A and followed the recommended procedures outlined in Appendix E of the Washington State Department of Health (DOH) Water System Design Manual (DOH #331-123, 2001). Descriptions of the pumping system, discharge location, monitoring procedures, and observation well network are provided in the subsections below.

### *4.1.1 Pumping System*

Boart installed a 7-stage Goulds 12FRHC turbine pump to conduct the aquifer tests. The test pump was powered by a 950 horsepower Cummins QSK23 engine. The engine was equipped with a variable speed drive, which controlled the rotational speed of the engine and the pumping rate from the well. The pumping rate from the well was also controlled by a gate valve at the wellhead.

The test pump was installed on an 8-inch pump column, and the intake was set at approximately 350 ft bgs. The outside diameter of the 7-stage bowl assembly was 11 inches. The remaining annular space between the bowl assembly and the 12-inch production casing was too small to accommodate a foot-valve and prevented its installation. Ecology was notified and waived the foot-valve requirement (Golder, 2010; Gallagher, M., Washington State Department of Ecology, personal communication, September 27, 2010). A check-valve was installed at the surface near the wellhead to prevent backflow from discharge piping.

The discharge rate for the pumping test was measured using a newly calibrated McCrometer flow meter with instantaneous flow rate indicator and volumetric totalizer. Meter calibration was verified in the field and adjusted to match flow rates measured simultaneously using an orifice weir.

Two PVC drop tubes were installed in the well to allow for the installation of a pressure transducer and to obtain manual water-level measurements.

### 4.1.2 Conveyance of Pumped Water

Water generated during aquifer testing was conveyed from the well through a 10-inch pipe to a natural, dry depression located approximately 4,200 feet southwest of the well (Figure 4). Because the well is sealed with neat cement to a depth of 327.7 ft bgs and completed in a confined aquifer, water discharged to the depression at this distance had little potential to recharge the production zone and hydraulically affect the results of the test, and no evidence of artificial recharge to the aquifer was observed in the test data (Section 4.3).

### 4.1.3 Water Level Monitoring

Water levels in each well were recorded using newly calibrated pressure transducers or manually using electronic water-level indicators. Manual water-level measurements were collected regularly at all wells to supplement and validate the high-frequency transducer data. Manual water level measurements were recorded to the nearest hundredth of a foot (0.01 ft).

### 4.1.4 Barometric Pressure and Precipitation Monitoring

A sensor was dedicated for barometric pressure monitoring to correct the transducer data, if needed. Transducer data from the pumping and observation wells were corrected for barometric pressure effects using barometric pressure and the barometric efficiency of each well. The barometric efficiencies were estimated by evaluating the change in water level in the well compared to the change in barometric pressure over the same period using baseline data collected prior to conducting the aquifer tests. The estimated barometric efficiencies for each well are provided in Table 2.

Daily precipitation totals were obtained from a local weather station (Weather Underground Station ID: KWALACEY1) maintained approximately one mile southeast of SW Well 1A (Lat: 46.936° N; Long: -122.614° W; elev: 345 ft).

### 4.1.5 Observation Well Network

A total of 11 wells (including SW Well 1A) were monitored as part of the aquifer testing program. The network of wells consisted of piezometers, private domestic wells, and municipal test wells. Information for each well is provided in Table 2 and their locations shown on Figure 4. Available boring logs and construction diagrams are included in Appendix C. A brief summary of each observation well is provided below:

- **SW Well 1A** – Municipal water-supply test well completed in the TQu to a depth of 633 ft bgs (see Section 3.0 for details on well construction and completion).
- **Thompson Creek Monitoring Well** – Shallow monitoring well drilled to a depth of 17 ft bgs (315.8 ft NGVD29). The well is located adjacent to Thompson Creek approximately 1,855 ft east of SW Well 1A, and is screened in the Qvr just above the base of the Qvt from 11 to 16 ft bgs (321.8 to 316.8 ft NGVD29). The well was used as a monitoring

location during the constant-rate pump test to evaluate the potential for hydraulic response in the shallow aquifer in connection with the creek;

- **P18** – Piezometer drilled to a depth of 56 ft bgs (322.7 ft NGVD29). The piezometer is located approximately 1,978 ft northwest of SW Well 1A and is screened in the Qva from 45 to 56 ft bgs (333.4 to 322.9 ft NGVD29);
- **Baker Well** – Domestic well drilled to a depth of 85 ft bgs (260 ft NGVD29). The well is located approximately 2,174 ft northeast of SW Well 1A, and is completed in the Qva at a depth of 84 ft bgs (261 ft NGVD29). The well was completed without a well screen or casing perforations;
- **P2** – Piezometer drilled to a depth of 59 ft bgs (315.4 ft NGVD29). The piezometer is located approximately 2,441 ft southwest of SW Well 1A and is believed to be screened in the Qvt from 49 to 59.5 ft bgs (325.4 to 314.9 ft NGVD29);
- **Purvis Well** – Domestic well drilled to a depth of 155 ft bgs (227 ft NGVD29). The well is located approximately 2,733 ft northeast of SW Well 1A, and is completed in the Qc at a depth of 155 ft bgs (227 ft NGVD29). The well was completed without a well screen or casing perforations;
- **P3** – Piezometer drilled to a depth of 61.2 ft bgs (341.2 ft NGVD29). The piezometer is located approximately 3,887 ft southwest of SW Well 1A and is screened in the Qvr from 50.6 to 61.2 ft bgs (351.8 to 341.2 ft NGVD29);
- **North Test Well (NTW)** – Exploratory water-supply test well drilled to a depth of 240 ft bgs (453.9 ft NGVD29). The test well is located approximately 6,309 ft southwest of SW Well 1A, and is perforated in the TQu from 195 to 225 ft bgs (258.9 to 228.9 ft NGVD29);
- **South Test Well (STW)** – Exploratory water-supply test well drilled to a depth of 260 ft bgs (194.5 ft NGVD29). The test well is located approximately 8,393 ft southwest of SW Well 1A, and is perforated in the TQu from 195 to 237 ft bgs (259.5 to 217.5 ft NGVD29) and 247 to 254 ft bgs (207.5 to 200.5 ft NGVD29);
- **West Test Well (WTW)** – Exploratory water-supply test well drilled to a depth of 290 ft bgs (152.2 ft NGVD29). The test well is located approximately 10,326 ft southwest of SW Well 1A, and is perforated in the TQu from 230 to 245 ft bgs (212.2 to 197.2 ft NGVD29) and 247 to 254 ft bgs (177.2 to 157.2 ft NGVD29); and
- **SW Well 1** – Exploratory water-supply test well drilled to a depth of 410 ft bgs (32.1 ft NGVD29). The test well is located approximately 10,394 ft southwest of SW Well 1A, and is screened in the TQu from 337 to 352 ft bgs (105.1 to 90.1 ft NGVD29), 359 to 375 ft bgs (83.1 to 67.1 ft NGVD29) and 390 to 399 ft bgs (52.1 to 43.1 ft NGVD29).

## 4.2 Step-Rate Test

The step-rate test was conducted on September 23, 2010 to evaluate well production and select the pumping rate for the constant-rate pumping test. A hydrograph showing the pumping water level is provided in Figure 5. The well was pumped for three steps at respective rates of 750, 1,300 and 1,800 gpm. Each step rate was maintained for a minimum of 90 minutes as pumping water levels stabilized before increasing the production rate. Small rate adjustments were necessary during the early portions of the first step to maintain a constant pumping rate. The depth to water prior to testing was 88.5 ft bgs. Field data sheets are provided in Appendix D. Electronic data files and tables are provided in Attachment A.

The test results showed specific capacity to be very similar amongst steps and that it increased slightly at each step in pumping rate. Total drawdown of approximately 29.1, 49.6, and 68.2 feet were observed in the pumping well for each of the respective pumping rates equating to short-term specific capacity values of 25.8, 26.2, and 26.4 gpm/ft, respectively. The observed trend is opposite of what is expected because turbulent well losses increase as a function of pumping rate causing well performance and specific capacity to decrease. The slightly increasing trend is an indication that the well was continuing to develop as it was pumped at rates far exceeding those used during the initial development. The amount of specific capacity increase lessened with each step, indicating that specific capacity was stabilizing.

The pre-testing static water level was likely not representative of the actual water level in the aquifer due to water added to the system during drilling to control heaving sands encountered in the production zones, incomplete hydraulic connection with the aquifer due to partial development, and water added to lubricate bearings immediately prior to pumping. This was confirmed by full projected recovery in response to the constant rate test. Over 0.8 million gallons (MG) was added to the borehole (Ray, S., City of Yelm, personal communication, November 2010), which likely resulted in some localized pressure increases in poorly connected aquifer layers. Approximately 0.4 MG of water was discharged during the step-rate test.

Well production and aquifer parameters were estimated from the step-rate test results using the Birsoy and Summers (1980) and Eden and Hazel (1973) analytical solutions available in the Aquifer$^{Win32}$ software package (ESI, 2003). Results of the analyses are shown in Figures 6 and 7 and summarized in Table 3.

Aquifer transmissivity and storativity were estimated using the Birsoy and Summers (1980) analytical solution. Figure 6A shows the pattern of drawdown in terms of $s/Q$ versus log-adjusted pumpage time ($\beta$) for each of the three steps. The test results for each step conform to ideal conditions and plot along the same straight line of slope $\Delta(s/Q)$. This indicates that factors such as continued well development and the presence of hydrologic boundaries did not affect conformity with ideal conditions and the test results are valid for estimating transmissivity and storativity. Results of the analysis indicate that the TQu in the vicinity of SW Well 1A has a transmissivity of approximately 48,000 gpd/ft and a storativity of $2.0 \times 10^{-4}$ (Table 3). The storativity value is consistent with values for confined aquifers (generally range from $1 \times 10^{-3}$ to $1 \times 10^{-5}$).

Figure 6B compares drawdown observed during the step-rate test with drawdown predicted by the Birsoy and Summers (1980) solution. The predicted values are consistent with those observed indicating the validity of the analytical solution.

Aquifer transmissivity was estimated using the Eden and Hazel (1973) analytical solution. Figure 7A shows drawdown versus the product of yield and log-adjusted pumpage time (*H*) for each of the three steps. Using the slope of linear regression lines optimized to best-fit the test results equates to a TQu transmissivity in the vicinity of SW Well 1A of approximately 58,900 gpd/ft.

Figure 7B also compares predicted drawdown versus pumping rate to drawdown assuming a 100 percent efficient borehole. The comparable values indicate that turbulent well losses are low and the well is highly efficient. The well is estimated to be 93 percent efficient (as presented in Section 4.4).

Figure 7C compares drawdown observed during the step-rate test with drawdown predicted by the Eden and Hazel (1973) solution. The predicted values are consistent with those observed indicating the validity of the analytical solution.

The Eden and Hazel (1973) analytical solution was also used to estimate well production. Drawdown predicted by the solution for various pumping rates is shown in Figure 7B. Results of the analysis show that drawdown is predicted to be approximately 100 feet at a pumping rate equivalent to the design capacity of the well screen (2,700 gpm). This rate could likely be sustained for the constant-rate pumping test assuming no flow-limiting boundary conditions are encountered during the test that would cause the pumping water level to exceed available drawdown. The total drawdown available was 219 feet (based on a pump intake depth of 350 feet bgs, static water level of 88.5 feet bgs, and 40 feet of pump submergence). Although it appears that the well is capable of producing higher pumping rates, rates exceeding the design capacity of the well will result in entrance velocities that exceed the recommended well design criteria of 0.1 ft/sec and could increase the likelihood for incrustation or corrosion of the well screen (Driscoll, 1986).

## 4.3 Constant-Rate Test

A three-day, constant-rate pumping test was performed at SW Well 1A beginning on October 6, 2010. The test was composed of three phases spanning approximately 14 days: baseline water-level monitoring, pumping, and recovery water-level monitoring. Results from each testing phase are presented and discussed in the subsections below. Field data sheets are provided in Appendix D. Electronic data files and tables are provided in Attachment A.

### *4.3.1 Barometric Pressure and Precipitation*

Precipitation and barometric pressure observed during the testing period are presented in Figure 8. Barometric pressure ranged between approximately 33.0 and 33.9 ft of water (ft H2O). The overall general barometric pressure trend was gradually increasing throughout most of the testing period. Transient periods of decline were observed on the overall trend during the latter portion of baseline and early pumping phases and during the latter portion of recovery.



Golder Associates

Little to no precipitation events occurred during the eight days leading up to the pumping period. Minor precipitation events took place during the pumping and recovery phases. Each event totaled 0.4 inches or less. A total of 0.85 inches were recorded during the testing period.

### 4.3.2 Baseline Monitoring

Baseline monitoring began a minimum of seven days prior to pumping to assess background hydrogeologic conditions and pre-existing groundwater-level trends. The baseline water-level trends for SW Well 1A and the observation wells are presented in Figures 9 through 16. The following pre-test groundwater level trends were observed:

- Relatively stable trends were observed in SW Well 1A, SW Well 1, WTW, NTW, and STW (Figures 9 and 14 through 16). As a result, no antecedent trend corrections were necessary to evaluate the potential hydraulic response to pumping or to characterize aquifer properties;
- Decreasing trends were observed at the Thompson Creek, P2, and P3 monitoring wells (Figures 10 and 12). The water level in the Thompson Creek monitoring well was flashy, rising and falling in response to intermittent precipitation events, but the overall trend was decreasing throughout the testing period. The water level in P2 decreased at a relatively faster rate than P3. P3 is completed in the recessional outwash unit (Qvr) while P2 is completed in the underlying low-permeability till (Qvt). The slower rate of water-level decline in P3 is likely related to the underlying till layer impeding the downward migration of groundwater within the overlying Qvr and becoming perched atop the Qvt;
- A decreasing water level trend was observed in P18 during baseline monitoring. A measurement collected on 10/6/2010 8:45 AM before pumping began indicated that the well was dry. This well continued to be monitored as part of the aquifer testing program and all subsequent observations indicated a dry well; and
- Water level trends in the Baker and Purvis domestic wells (Figures 11 and 13) appear moderately stable, but no trends or response can be discerned. During non-pumping periods, the apparent static water levels vary by approximately four feet in the Baker Well (49 to 53 ft bgs) and approximately three feet in the Purvis Well (83 to 86 ft bgs) depending upon frequency of use. Pumping water levels approached depths of 70 ft bgs in the Baker Well and 110 ft bgs in the Purvis Well. Baseline data show several periods when pumping in these wells is frequent enough that water levels do not fully recover from the previous pumping event before pumping begins again causing periods of progressive drawdown.

### 4.3.3 Pumping Phase

Pumping began at 2:35 PM on October 6, 2010, and continued until 3:05 PM on October 9, 2010 for a total pumping time of approximately 73 hours. Totalizer volume measurements were consistent with instantaneous flow readings, and indicated that the average discharge rate was approximately 2,100 gpm throughout the test. Small flow adjustments were necessary during early portions of the pumping period to maintain a constant pumping rate as water was conveyed to the Thurston Highlands discharge site and pipe flows were adjusted. A total of approximately 9 MG of water was discharged during the test. Hydrographs of SW Well 1A and the observation wells during the pumping phase of the constant-rate test are shown in Figures 9 through 16.

#### 4.3.3.1 SW Well 1A

Figure 9 shows the hydrograph for SW Well 1A during the pumping phase of the constant-rate test. The static water level immediately prior to pumping was 102.5 feet bgs. After pumping began, the water level dropped rapidly and began to stabilize toward a depth of approximately 180 feet bgs. During the last five hours of pumping, the absolute change in water level ranged between 0.03 and 0.09 ft and was below Ecology's stability target of 0.1 ft/hr for at least four hours (Figure 17). A maximum drawdown of approximately 82.2 feet (water level of 184.7 feet bgs) was observed by the end of the pumping period, indicating a specific capacity of 25.5 gpm/ft after approximately 73 hours of pumping at 2,100 gpm (Figure 18). After the constant-rate test was complete, Boart began the mechanical process of shutting down the pumping system, which included opening a series of vacuum relief valves along the discharge pipeline to prevent pipe collapse and ramping down the pump motor before shutoff.

Small rate adjustments were necessary during the first 150 minutes pumping to maintain a constant rate as test water was conveyed to the Thurston Highlands discharge location. To assist in the evaluation of the aquifer's hydraulic response to pumping SW Well 1A during this period, a plot of specific capacity versus elapsed pumping time was constructed to normalize drawdown with respect to pumping rate (Figure 18). The plot shows no apparent aquifer boundary conditions.

Aquifer transmissivity was estimated using the Theis (1935) analytical solution available in the Aquifer$^{win32}$ software package (ESI, 2003). Figure 19A presents a log-log plot of drawdown versus elapsed pumping time at SW Well 1A superimposed on the non-equilibrium Theis type-curve for a fully confined aquifer. The observed response is an excellent match of the type-curve indicating a confined aquifer response with no apparent evidence of leakance or hydraulic boundary conditions. Results of the analysis indicate that the TQu in the vicinity of SW Well 1A has a transmissivity of approximately 42,400 gpd/ft (Table 3). Drawdown predicted by the Theis (1935) solution is consistent with the observed response indicating the validity of the analytical solution (Figure 19B).

The hydraulic response to pumping and aquifer transmissivity of the TQu in the vicinity of SW Well 1A was also estimated using the Cooper-Jacob (Cooper and Jacob, 1946; Jacob, 1950) straight-line method. A semi-log plot of drawdown versus elapsed pumping time (Figure 20) shows the rate of drawdown to be relatively consistent throughout the test with the exception of some small rate adjustments within the early portion of the test. No hydraulic boundary effects were apparent during the test. Results of the analysis indicate a transmissivity of 43,650 gpd/ft (Table 3) and is consistent with TQu transmissivity estimated using the Theis (1935) solution.

#### 4.3.3.2 Observation Network Wells

No apparent hydraulic response to pumping SW Well 1A was observed in the observation well network:

- **Thompson Creek Monitoring Well** – The water level exhibited fluctuations in response to precipitation events, but continued a declining trend consistent with the baseline period. No evidence of decline due to pumping is apparent (Figure 10);
- **P18** – This well was dry before pumping began and remained dry during the pumping and recovery periods;
- **Baker Well and Purvis Wells** – There was no apparent response to pumping SW Well 1A at these two domestic wells (Figures 11 and 13). The water levels observed in these wells during the pumping and recovery periods behaved similarly as those observed during baseline monitoring, including response to barometric pressure changes. In addition to response to barometric pressure variability, the Purvis well exhibits increased pumping frequency and duration relative to the baseline monitoring period. No response to pumping SW Well 1A are apparent;
- **P2 and P3** – The water level trends in these wells were declining throughout baseline monitoring and continued to decline at similar rates throughout the pumping and recovery periods (Figure 12). No response to pumping was apparent at these wells; and
- **SW Well 1 and the North, South and West Test Wells –** The stable water level trends observed in these wells during baseline monitoring continued on similar trends throughout the pumping and recovery periods and no evidence of decline due to pumping SW Well 1A is apparent (Figures 14 through 16).

### *4.3.4 Recovery Phase*

Recovery monitoring began at the termination of the pumping period and continued until 1:00 PM on October 13, 2010. Figure 9 shows recovery phase in context of the entire constant-rate test, and Figure 20 shows a more detailed analysis. SW Well 1A recovered to within 75 percent of the pre-test water level after approximately 40 minutes. At the end of the recovery phase, the water level had risen to 107.8 ft bgs, approximately 5.3 ft below its pre-test level of 102.5 ft bgs. The recovery trend shown on the hydrograph indicates that the water level is projected to continue to rise after monitoring stopped.

Assuming theoretical idealized aquifer conditions (no leakance, no boundaries, and homogeneity), the water level in a well will recover to the pre-test static level following the termination of pumping. If other hydrogeologic conditions influence the aquifer's hydraulic response (e.g., recharge to the aquifer, variations in aquifer permeability, pumping of other wells, and/or the presence of aquifer boundaries within the radius of influence of the well), a different (though diagnostic) recovery response will occur. Figure 21 presents the recovery analysis for SW Well 1A using the Theis (1946) method. This recovery analysis is performed by plotting residual drawdown (drawdown remaining in the well after pumping has stopped) against the logarithm of the ratio of time since pumping started (*t*) and time since pumping stopped (*t'*). This ratio of time is dimensionless, and is referred to as *t/t'*. Under ideal aquifer conditions (uniform confined aquifer of infinite extent), the recovery data should trend toward zero residual drawdown at *t/t'* = 1.

The plot shows three recovery segments representing: (1) an early recovery response during the first four minutes after pumping stopped (*t/t'* > 1,000), (2) a transition period between four and 230 minutes after pumping stopped (*t/t'* between 1,000 and 20), and (3) a late recovery response for the remaining 5,445 minutes of recovery (*t/t'* less than 20). If residual drawdown is still apparent at *t/t'* = 1, then water was removed from storage within the aquifer because the aquifer has a limited extent, thus indicating that the aquifer was de-watered or depressurized (the volume of water pumped was significant relative to the volume available from storage and natural recharge). This response did not occur at SW Well 1A indicating that the recharge to the aquifer appears capable of sustaining the withdrawal represented by this test.

The early recovery response resulted from pump column storage (relatively small volume of water contained in the pump column added to the system after pumping stopped) and the mechanical process of shutting down the pumping system. The large pump diameter required to achieve the target test rate precluded installation of a check-valve to prevent water in the pump column (above the pumping water level) from re-entering the well casing. After the early recovery response stabilized, the water level begins recovering at a relatively constant rate until approximately *t/t'* = 10. During the latter portion of the transition period, the rate of recovery begins to increase and trending toward zero residual drawdown at *t/t'*= 1. The shape of the late recovery response curve is concave upward indicating that recovery was affected by a linear barrier boundary (Hargis, 1979). The presence of the barrier boundary was not apparent on either the specific capacity or pumping response curves and could have been masked by the small changes in pumping rate necessary during the early portion of the test to maintain a constant pumping rate. The presence of the barrier boundary does not appear to have accelerated drawdown in or limited flow to the well and likely represents a change in transmissivity at distance.

Since the recovery response was influenced by pump column storage and barrier boundary effects, aquifer transmissivity was not estimated with the recovery data. The TQu transmissivity estimates derived from step-rate and constant-rate pumping analyses are considered most representative of actual conditions in the vicinity of SW Well 1A (Table 3).

## 4.4 Well Efficiency

The efficiency of SW Well 1A was estimated using an empirical relationship between transmissivity and specific capacity. This empirical relationship is described in Driscoll (1986), and can be used to estimate well efficiency through the ratio of the actual specific capacity to the theoretical specific capacity. The theoretical specific capacity (defined as the estimated transmissivity divided by 2,000) is 23.9 gpm/ft when using a transmissivity of 47,827 gpd/ft. The actual specific capacity calculated after the three-day pumping period was 25.5 gpm/ft. The ratio of the actual to theoretical specific capacity indicates that the SW Well 1A has an efficiency of approximately 93 percent.

## 4.5 Well Yield

The City intends to operate SW Well 1A at a maximum instantaneous pumping rate of 2,100 gpm. The constant-rate test results were used to estimate pumping water levels and pump intake depth settings under the expected operating conditions, using the following values and assumptions:

- Specific capacity of 25.5 gpm/ft;
- Expected operating production capacity of 2,100 gpm;
- Static water level = 103 ft bgs;
- Assumed allowance for pump submergence = 40 ft;
- Assumed allowance for seasonal groundwater fluctuations = 20 ft; and
- Buffer of 20 ft to accommodate uncertainty.

Based on the above values and assumptions, the estimated pumping water level will be approximately 186 ft bgs, representing 83 feet of drawdown (compared to fall 2010 static water levels). Actual available drawdown is approximately 167 ft.

Factoring in allowances for pump submergence, seasonal groundwater level fluctuations, and accommodations for uncertainty, the estimated pump intake depth setting should be 266 ft bgs. These estimates assume that aquifer characteristics will be stable over time/distance during long-term pumping and no significant boundary conditions exist that may reduce available drawdown.

## 4.6 Groundwater Development Impact Assessment

Because the well withdraws water from a deep well-confined portion of the aquifer system, and results from the aquifer test conducted to assess this system did not result in observable response in nearby wells, pumping at SW Well 1A is not expected to result in significant impact to existing groundwater users or nearby surface water features. Most, if not all, of the groundwater users in the Yelm area utilize the Qva and Qc aquifer units as a groundwater supply source since these are shallower and therefore more accessible than the TQu. The only wells known to be completed within the TQu unit in the Yelm area are the City's test wells (NTW, STW, WTW, and SW Well 1) shown on Figure 4. The nearest TQu well is the NTW located approximately 1.2 miles southwest of SW Well 1A, and no response to pumping was observed at that location.

Based on the confined nature of the TQu and the 327.7-ft seal depth, no significant hydraulic response in the overlying units is expected. It is possible that measurable response could eventually be observed, though the upward propagation of hydraulic effects from pumping will clearly be limited by the overlying low-permeability confining Qf and Qvt units, and the magnitude of any future response is expected to be small. Since no response was observed, future response cannot be extrapolated from these results. As no response was observed in overlying aquifer units or at the Thompson Creek observation well, impacts to nearby surface water features are expected to be minor as well.

## 5.0 WATER QUALITY

Water quality monitoring was included as part of the SW Well 1A testing program. Groundwater quality samples were collected from SW Well 1 and SW Well 1A and submitted to Washington State certified drinking water laboratories for analysis. Field water quality measurements for pH, temperature, specific conductance, turbidity, oxidation-reduction potential (ORP), and dissolved oxygen (DO) were also obtained as part of the testing program. Field water quality data sheets and laboratory test results for the sample suites are included in Appendices D and E.

### 5.1 SW Well 1

Ecology's superseding preliminary permit to drill and test SW Well 1A included a requirement that at least one TQu observation well be monitored for water quality during aquifer testing. However, pumping an observation well during the test (to ensure the sample was representative) would cause unwanted hydraulic interference, possibly invalidating test interpretation. Consequently, the well was not pumped, and a sample was collected from the well using a small disposable bailer during the pumping portion of the aquifer test. This sample was measured for field characteristics only because it is unlikely to be representative of actual water quality conditions in the aquifer. Those compliance-driven measurements are included below:

- pH: 9.2
- Temperature: n/a
- Specific conductance: 209 µS/cm
- Dissolved oxygen: 3.9 mg/L
- ORP: -75.4 mV

To provide Ecology with a comparable (though not in time) sample from the deeper portion of the aquifer system at a second well, a sample was collected from SW Well 1 and analyzed for a suite of general chemistry and field parameters to characterize water quality during the drilling phase of the project. The samples were collected on May 19, 2010 after approximately 7,800 gallons (~5 well volumes) had been pumped from the well.

Test America was contracted to perform the water quality analyses. Summary reports, which include the results, analytical methods used and their associated method detection limits, and quality control results provided by the laboratory, are included in Appendix E-1. The final field parameter values measured at the end of the sampling event are summarized below:

- pH: 6.2
- Temperature: 9.8 $^{o}$C (49.6 $^{o}$F)
- Specific conductance: 110 µS/cm

- Dissolved oxygen: 3.0 mg/L
- ORP: 183 mV

These results are considered representative of TQu water quality, though over a mile from SW Well 1A.

Laboratory test results show that water quality from SW Well 1 meets all Primary Maximum Contaminant Levels (MCLs) for the drinking water analytes tested. The groundwater is moderately hard with a hardness of 67 mg/L as $CaCO_3$. Aesthetically, groundwater from SW Well 1 was cold, clear, odorless, and had a slight metallic/mineral taste.

Laboratory test results also show that iron, manganese, and pH exceed their respective Secondary MCLs (SMCL), and that iron and manganese are mostly in insoluble form. Total iron and manganese concentrations were 1.2 and 0.14 mg/L, respectively. For comparison, dissolved iron and manganese concentrations were 0.05 and 0.02 mg/L. The secondary MCLs for iron and manganese are 0.3 and 0.05 mg/L. Manganese and iron levels above the SMCL do not pose a risk to human health or the environment. The SMCL for manganese is provided as a recommendation for aesthetic quality only. Elevated concentrations of iron and manganese may affect the flavor and color of water, cause staining, or result in buildup in pipelines, pressure tanks, water heaters and water softeners. Groundwater from SW Well 1 is slightly acidic (pH of 6.2) and is slightly outside of the secondary MCL pH range of 6.5 to 8.5. Low pH levels may affect taste and corrosivity.

The composition of groundwater from SW Well 1 was compared to water quality results from previous studies conducted in Yelm and Thurston County to evaluate its source. The Piper diagram illustrated in Figure 22 plots water compositions from samples of different wells in the Yelm area (Site No. 465625122361701 17N/02E-19N01 and 465637122352805 17N/02E-19J05; USGS, 2010) and median water chemistries of the regional geologic units as presented by the U.S. Geological Survey (USGS; Table 6 in Drost et al., 1998). The tight grouping indicates that groundwater throughout the study area is similar in composition and chemistry type, and can generally be classified as a calcium/magnesium-bicarbonate type. The similarity in chemical signature suggests that groundwater throughout the study area is likely of the same origin (from infiltration of precipitation) and that the various glacial hydrogeologic units are generally similar in mineralogic composition. Water composition of the regional bedrock formation (Tb) is set apart from the cluster due to lower levels of magnesium and higher levels of sodium and potassium.

While groundwater quality in Thurston County is quite similar amongst the various hydrogeologic units, groundwater from the deeper system can be distinguished from shallower sources. The Stiff diagrams presented in Figure 23 compares the ionic composition of SW Well 1 with the same nearby wells and hydrogeologic units as shown in Figure 22. Groundwater from SW Well 1 has a chemical signature that is more similar to characteristic signatures of the deeper aquifer systems (Qc and TQu) rather than the shallow system (Qvr, Qvt, and Qva). The differences are most attributed to the deeper units having slightly elevated concentrations of calcium, sodium, potassium, bicarbonate, silica, iron, and manganese (Drost et al., 1998). In addition, the shallow USGS wells in Yelm also exhibit a lower dissolved solids concentration and proportionally lower magnesium concentrations than other samples (Figure 23) indicating that groundwater in Yelm is somewhat younger than groundwater from deeper sources in the study area, and that they can be distinguished chemically. The relatively low ionic composition of the USGS wells suggests a low residence time, and is consistent with the shallow aquifer system in Yelm, in contrast to the deeper, confined system with higher ion concentrations. The hydrostratigraphic relationships apparent in the SW Well 1 well log (Appendix C) are consistent with those previously published for the area indicating that the well is completed in, and obtains water from, the TQu unit. The lithologic characteristics and water quality similarities indicate that the source aquifer for SW Well 1 is from the deeper, regional groundwater flow regime of the TQu.

## 5.2 SW Well 1A

A suite of water quality samples and field parameters were collected from SW Well 1A to assess drinking water quality and evaluate the source. The samples were collected at the end of the aquifer testing period and submitted to Edge Analytical, Inc. for analyses. Field parameters monitored during the pumping phase are summarized below:

- pH: 7.5
- Temperature: 11.3 $^{o}$C (52.3 $^{o}$F)
- Turbidity: 0.8 NTU
- Specific conductance: 176 µS/cm
- Dissolved oxygen: 0.4 mg/L
- ORP: -60.2 mV

The groundwater samples were analyzed for water-quality constituents required for new source approvals in the State of Washington. Analytes tested included (1) physical parameters, (2) volatile and synthetic organic compounds, (3) inorganic compounds, (4) gross-alpha and gross–beta radiologic indicators, and (5) bacteriologicals (i.e., total Coliform, heterotrophic plate count, and *E. coli*). Summary reports provided by the laboratory and field data sheets are included in Appendices D and E-2.

Based on field measurements and laboratory analyses, the water quality from SW Well 1A is excellent. Aesthetically, the water was cold, clear, odorless, and has a slight metallic/mineral taste. No volatile organic compounds, synthetic organic compounds, herbicides, or hydrogen sulfide were detected. With the exception of manganese, the analytical results show that concentrations for federal and state regulated inorganic compounds to be below regulatory standards for drinking water. The following regulated inorganic constituents were detected:

- Barium was detected at 0.004 mg/L, below the MCL of 2 mg/L;
- Chloride was detected at 3.6 mg/L, below the SMCL of 250 mg/L;
- Fluoride was detected at 0.11 mg/L, below the MCL of 4 mg/L;
- Iron (total) was detected at 0.11 mg/L, below the SMCL of 0.3 mg/L;
- Manganese (total) was detected at 0.14 mg/L, above the SMCL of 0.05 mg/L;
- Odor was noted at 1 color unit, below the SMCL of 3 color units;
- Sodium was detected at 5.45 mg/L. There is no MCL for sodium. The recommended action level is 20 mg/L;
- Specific conductance was detected at 176 µS/cm, below the SMCL of 700 µS/cm;
- Sulfate was detected at 3.4 mg/L, below the secondary MCL of 250 mg/L; and
- Total dissolved solids was detected at 117 mg/L, below the SMCL of 500 mg/L.

The only inorganic constituent having a concentration above its regulatory criteria was manganese. Total and dissolved manganese were detected at 0.14 and 0.15 mg/L, respectively, and are approximately three times the recommended limit. The laboratory results show that manganese is mostly in dissolved form. As previously mentioned, meeting the SMCL for manganese is not a mandatory requirement, and is only provided as a recommendation for aesthetic quality.

A bacteriological sample was submitted to the laboratory for analysis of total coliform, heterotrophic plate count (HPC), and *E. Coli*. The results from this analysis showed:

- *E. coli* to be below the detection limit of <2 MPN/100mL. Because *E. coli* is a specific fecal coliform and its presence is used as an indicator of fecal contamination in drinking water tests, the absence of *E. coli* indicate the absence of fecal coliform bacteria in the water sample. The laboratory confirmed the absence of fecal coliform (Edge Analytical, Inc., personal communication, November 11, 2010);
- Coliforms are naturally present in the environment. Although not a health threat itself, total coliforms are used to indicate whether other potentially harmful bacteria may be present. The total coliform result of 2 MPN/100 mL suggests the presence of coliform bacteria other than fecal coliform and *E. coli* because these were not detected; and
- HPC is a test performed to assess the total number of all types of bacteria common in water. HPC was very low detected at 4 CFU/mL. For reference, federal criteria for HPC require disinfection and/or filtration to maintain HPC levels to less than 500 CFU/mL.

Repeat bacteriological samples should be collected as part of the source approval process to validate the coliform presence result. It is possible that the result is due to a circumstance or condition that is not representative of source water quality (e.g., coliform contamination from drilling or pumping equipment temporarily installed for testing the well). It should be noted that the bacteriological testing was conducted before the well was disinfected and it is possible that the result is due to this circumstance or is a sample collection artifact as coliform is not likely to be present in the system at that depth.

Radiological analysis included testing for gross alpha, gross beta, radium-226 and -228, and radon. Gross alpha and beta, and radium-226 and -228 levels were below detection limits. Radon was detected at 234 pCi/L, below the proposed federal drinking water criteria of 300 pCi/L. It is unclear how radon concentrations will behave during prolonged pumping, and the City should consider monitoring for radon once the well is online for production. The City should consider integrating (or reserving space for) a radon treatment option (e.g., aeration or granular activated carbon systems) as part of any planned treatment facilities to avoid adding infrastructure (or changing existing infrastructure) at a later time.

The chemical signature of groundwater from SW Well 1A is most consistent with groundwater from the deeper, regional TQu flow regime. Groundwater quality from SW Well 1A was compared to water chemistries of the same nearby wells and regional hydrogeologic units as shown in Figure 22. The figure shows SW Well 1A to plot amongst the other wells and units (with the exception of Tb), indicating a similar origin (infiltration of precipitation) and water type (calcium/magnesium-bicarbonate). Although the relative concentrations of calcium, sodium, and potassium are slightly lower in SW Well 1A compared to the other deeper units (Figure 23), bicarbonate/alkalinity, total dissolved solids, silica, pH, and specific conductance values are most consistent with the chemical characteristics of the deep aquifer system (Table 6 in Drost et al., 1998). These findings, coupled with the hydrostratigraphic relationships discussed in Section 3.0, indicate that SW Well 1A is completed in the deeper, regional groundwater flow regime of the TQu.

## 6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The City of Yelm has constructed and tested a new water supply well and has evaluated potential impacts associated with withdrawing groundwater from the deeper portion of the regional aquifer system. Conclusions from the investigation including recommendations for next steps are summarized in the following subsections.

### 6.1 Drilling and Well Construction

A new water supply well (SW Well 1A; Ecology Well Tag No. ALM 113) was constructed in the Tahoma Terra area west of Yelm in Thurston County, Washington (SE¼, SE¼, Section 23, T17N, R1E W.M.) to evaluate the area as a potential new source for groundwater development. The 12-inch diameter well was constructed at a ground surface elevation of approximately 381 feet NGVD29 and extends to a depth of 633 feet below ground surface. A surface casing was set to 327.7 feet bgs to limit the withdrawal from the deepest aquifer unit. Samples collected during drilling were examined and compared to the physical characteristics of regional hydrostratigraphic units indicating that the well is completed in the unconsolidated and undifferentiated deposits of the TQu unit, which is considered part of the deeper, regional groundwater flow system. Three 35-slot screen sections were placed in the water-bearing intervals of 369 to 437 ft bgs, 487 to 547 ft bgs, and 611 to 625 ft bgs. The annular space between the screen assembly and production casing and borehole is filled with 10-20 Colorado silica sand filter pack. The filter pack extends from 353 to 633 ft bgs.

### 6.2 Aquifer Testing

A step-rate test was conducted at pumping rates of 750, 1,300 and 1,800 gpm for a minimum of 90 minutes each as pumping water levels stabilized before increasing the production rate. Total drawdown of approximately 29.1, 49.6, and 68.2 feet were observed in the pumping well for each of the respective pumping rates equating to short-term specific capacity values of 25.8, 26.2, and 26.4 gpm/ft, respectively.

A constant-rate aquifer test, including baseline and recovery monitoring, was conducted over a period of 14 days. The pumping portion of the aquifer test was conducted at a constant rate of 2,100 gallons per minute for a period of 73 hours, which resulted in a maximum drawdown of approximately 82.2 feet. The specific capacity at the end of the test was 25.5 gpm/ft. Based on the ratio of the actual (25.5 gpm/ft) to theoretical (23.9 gpm/ft) specific capacity, the well efficiency is estimated at 93 percent.

The late time recovery response curve trends toward zero residual drawdown at *t/t'* = 1 indicating the recharge to the system was capable of supporting the withdrawal.

Transmissivity estimates of the TQu in the vicinity of SW Well 1A ranged between 58,900 and 42,400 gpd/ft. The geometric mean transmissivity equated to 47,827 gpd/ft. Storativity was estimated at $2.0 \times 10^{-4}$, and is consistent with values for confined aquifers.

A total of 10 wells consisting of piezometers, private domestic wells, and municipal test wells targeting both shallow and deep portions of the aquifer system were included in the observation network and monitored as part of the SW Well 1A testing program. Hydraulic response to pumping SW Well 1A was not apparent in any of the observation wells. Though long term response cannot be precluded, these results indicate that groundwater development from SW Well 1A is not expected to result in significant impact to existing groundwater users or nearby surface water features.

Given the relatively high specific capacity, large available drawdown, and no apparent response in shallower portions of the aquifer system, future groundwater development of the TQu aquifer in the Yelm area appears feasible.

## 6.3 Water Quality

The water quality from SW Well 1A is excellent. Aesthetically, the water was cold, clear, odorless, and has a slight metallic/mineral taste. No volatile organic compounds, synthetic organic compounds, herbicides, or hydrogen sulfide were detected.

The only inorganic constituent having a concentration above its regulatory criteria was manganese. Total and dissolved manganese were detected at 0.14 and 0.15 mg/L, respectively, and are approximately three times the recommended limit

The total coliform result of 2 MPN/100 mL suggests the presence of coliform bacteria (no fecal coliform or *E. coli* were detected). However, the sample was collected before the well was disinfected and it is possible that the result is due to this circumstance or is a sample collection artifact as coliform is not likely to be present in the system at that depth.

Radon was detected at 234 pCi/L, below the proposed federal drinking water criteria of 300 pCi/L.

The chemical signature of groundwater from SW Well 1A is most consistent with groundwater from the deeper, regional TQu flow regime. These findings, coupled with the hydrostratigraphic units encountered during drilling, indicate that SW Well 1A is completed in the deeper, regional groundwater flow regime of the TQu.

## 6.4 Recommendations

Based on the results of the drilling and testing program at SW Well 1A, Golder recommends the following:

- As part of the final design, the well should be equipped with the following:
  - Two water level access pipes for long-term water level monitoring. One pipe should have a ¾-inch inner diameter to accommodate a water level probe and the second should have a 1 ½- inch diameter to allow installation of a pressure transducer for continuous water level monitoring; and

- A filter pack fill tube to allow placement of additional filter pack as it may settle over time and potentially allow finer-grained native formation to pass through the well screen. Filter pack should be 10-20 Colorado silica sand and maintained to a depth of 353 ft bgs.

- Static water levels, pumping rates, and pumping volumes should be monitored on a regular basis to track seasonal water level fluctuations and well performance;
- Based on the aquifer test results and allowances for seasonal groundwater level fluctuations, pump submergence requirements, and uncertainty, the projected pumping water level at 2,100 gpm is estimated at 186 ft bgs and the pump intake should be set to a depth of 266 feet bgs;
- Repeat bacteriological samples should be collected as part of the source approval process to validate the coliform presence result;
- Treatment would likely be required for manganese to maintain the delivered water aesthetic quality and prevent scaling in the City's piping and distribution system;
- Golder recommends the City track radon concentrations over time once the well is online for production to determine if levels increase or decrease after extended pumping. Additionally, the City may consider providing contingency for radon treatment as part of the final treatment facility design;
- According to a well inspection survey completed by Thurston County, the proposed SW Well 1A site meets requirements of WAC 246-290 for new drinking water source approval, provided:
  - A declaration of covenant (public water source) of the 100-ft sanitary control around the well head is recorded with the Thurston County Auditor's office;
  - All surface runoff is conveyed away from the well and out of the 100-ft sanitary control area through standard construction practices such as proper grading and ditching;
  - Any use, handling, or storage of potentially hazardous materials is maintained away from the well and out of the 100-ft sanitary control area;
  - Adequate measures are taken to protect the source from unauthorized access, such as fences and locked gates, as the well site is proposed to be located within a public park;
  - Prior to putting the new source into production for drinking water purposes, the temporary stormwater retention/settling pond adjacent to SW Well 1A must be backfilled with clean soils. Documentation confirming the pond has been properly backfilled must be submitted to Department of Health Office of Drinking Water for their review and approval; and
  - Submit water system plans and specifications to Dan Gariepy at the Washington State Department of Health Office of Drinking Water to obtain approval.
- A wellhead protection plan for SW Well 1A.

**GOLDER ASSOCIATES INC.**

State of Washington
Hydrogeologist
1315
Licensed Geologist
Phillip A. Brown

Phil Brown, LHG
Associate Hydrogeologist

Kenneth Janssen
Project Hydrogeologist

Lizzie Bartosik
Staff Hydrogeologist

KJ/AC initials

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# TABLES

## TABLE 1
## LITHOLOGIC AND HYDROLOGIC CHARACTERISTICS OF GEOHYDROLOGIC UNITS (Drost et al., 1999)

| System | Series | Geologic unit | | Geohydrologic unit, in this report[1] | Typical thickness (feet) | Lithologic characteristics | Hydrologic characteristics |
|---|---|---|---|---|---|---|---|
| Quaternary | Holocene | | Alluvium | Qvr<br>Qvrm | 10-40 | Alluvial and deltaic sand and gravel along major water courses. Moderately to well-sorted glacial sand and gravel, including kettled end moraine | An aquifer where saturated. Ground-water is mostly unconfined. Perched conditions occur locally. |
| Quaternary | Pleistocene | Vashon Drift | Recessional outwash and end moraine | | | | |
| Quaternary | Pleistocene | Vashon Drift | Till | Qvt[2] | 20-55 | Unsorted sand, gravel, and boulders in a matrix of silt and clay. | Confining bed, but can yield usable amounts of water. Some thin lenses of clean sand and gravel. |
| Quaternary | Pleistocene | Vashon Drift | Advance outwash | Qva | 10-45 | Poorly to moderately well-sorted, well-rounded gravel in a matrix of sand with some sand lenses. | Ground water, mostly confined. Used extensively for public supplies near Tumwater. |
| Quaternary | Pleistocene | Kitsap Formation | | Qf[3] | 20-70 | Predominantly clay and silt, with some layers of sand and gravel. Minor amounts of peat and wood. | Confining bed, but in places yields usable amounts of water. |
| Quaternary | Pleistocene | Salmon Springs(?) Drift (Noble and Wallace, 1966) / Deposits of "penultimate" glaciation (Lea, 1984) | | Qc | 15-70 | Coarse sand and gravel, deeply stained with red or brown iron oxides. | Water is confined. Used extensively for industrial purposes near Tumwater. |
| Quaternary | Pleistocene | Unconsolidated and undifferentiated deposits | | TQu | Not known | Various layers of clay, silt, sand, and gravel of both glacial and nonglacial origin. | Contains both aquifers and confining beds. Water probably confined. |
| Tertiary | Miocene and Eocene | Bedrock | | Tb | Not known | Sedimentary rocks consisting of claystone, siltstone, sandstone, and minor beds of coal. Igneous bodies of andesite and basalt. | Poorly permeable base of unconsolidated sediments. Locally an aquifer, but generally unreliable. Water contained in fractures and joints. Well yields relatively small. Numerous abandoned wells. |

[1]The identification of geohydrologic units in this report is a "best estimate" based on drillers' logs and existing surficial geology maps.
[2]Includes "late Vashon lake deposits" (Washington State Department of Ecology, 1980). May include till of "penultimate" glaciation (Lea, 1984).
[3]Includes alluvium younger than Kitsap Formation in Nisqually River delta. May include some Vashon till (where multiple tills are present). May include till of "penultimate" glaciation (Lea, 1984).

SOURCE: Drost et al., 1999

## TABLE 2
## NETWORK MONITORING WELLS

| Project Well Name | Well Log ID | Well Tag No. | Well Owner | Well Type | Distance From SW Well 1A (ft) | Well Diameter (in) | Well Depth (ft bgs) | (1)Monitoring Method | (2)Estimated Barometric Efficiency, *BE* (dimensionless) | (3)Northing, *y* (ft) | (3)Easting, *x* (ft) | MP (ft ags) | (4)Ground Surface Elevation (ft NGVD29) | MP Elevation (ft NGVD29) | Bottom Elevation of Well (ft NGVD29) | (5)Geohydrologic Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SW Well 1A | n/a | ALM113 | City of Yelm | Municipal test well | 0 | 12 | 633 | T/M | 0.50 | 593518.16 | 1106759.98 | 2.58 | 381 | 383.58 | -252 | Tqu |
| Thompson Creek MW | n/a | n/a | City of Yelm | Monitoring well | 1,855 | 1 | 17 | T/M | 0.75 | 593280.88 | 1108599.37 | 3.8 | 332.79 | 336.59 | 316 | Qvr |
| P18 | 537234 | BAS468 | Thurston Highlands LLC | Piezometer | 1,978 | 2 | 56 | T/M | 0.78 | 594477.37 | 1105030.51 | 2.4 | 378.67 | 381.07 | 323 | Qva |
| Baker Well | 30264 | n/a | Virgil and Darlene Baker | Private domestic well | 2,174 | 6 | 84 | T/M | 0.70 | 595210.16 | 1108125.08 | 0.65 | 345 | 345.65 | 261 | Qva |
| P2 | 492212 | APC066 | Thurston Highlands LLC | Piezometer | 2,441 | 2 | 59 | T/M | 0.52 | 593173.21 | 1104343.34 | 1.5 | 374.35 | 375.85 | 315 | Qvt |
| Purvis Well | 23405 | n/a | David and Rose Purvis | Private domestic well | 2,733 | 6 | 155 | T/M | 0.70 | 596146.14 | 1107510.74 | 0.36 | 382 | 382.36 | 227 | Qc |
| P3 | 492210 | APC063 | Thurston Highlands LLC | Piezometer | 3,887 | 2 | 61.2 | M | --- | 592457.39 | 1103020.35 | 2.74 | 402.38 | 405.12 | 341 | Qvr |
| North Test Well | 120946 | ABV265 | City of Yelm | Municipal test well | 6,309 | 8 | 240 | T/M | 0.53 | 591606.43 | 1100747.11 | 1.92 | 453.87 | 455.79 | 214 | Tqu |
| South Test Well | 120948 | ABV267 | City of Yelm | Municipal test well | 8,393 | 8 | 260 | T/M | 0.53 | 588320.47 | 1100170.69 | 3.27 | 454.48 | 457.75 | 194 | Tqu |
| West Test Well | 120947 | ABV266 | City of Yelm | Municipal test well | 10,326 | 8 | 290 | M | --- | 589658.31 | 1097182.44 | 1.38 | 442.18 | 443.56 | 152 | Tqu |
| SW Well 1 | n/a | n/a | City of Yelm | Municipal test well | 10,394 | 12 | 410 | T/M | 0.62 | 589385.00 | 1097223.00 | 2.46 | 442.12 | 444.58 | 32 | Tqu |

**Notes:** (1) T = pressure transducer; M = manual water level probe

(2) Barometric efficiency (*BE*) estimated by evaluating the change in water level in the well compared to the change in barometric pressure over the same period using baseline data collected prior to conducting the aquifer tests. Domestic use inhibited estimation of *BE* in the Purvis and Baker wells and were assigned values of 0.78 (same as P18).

(3) Washington State Plane NAD 83/91 coordinate system

(4) Ground surface elevations were obtained from survey results reported by Pacific Groundwater Group (2008) with the exception of SW Well 1A and the Baker and Purvis Wells, which were obtained from USGS topographic maps and digital elevation models.

(5) Qvr = recessional outwash; Qvt = glacial till; Qva = advance outwash; Qc = Salmon Springs drift; Tqu = unconsolidated and undifferentiated deposits (nomenclature from Drost et al., 1999)

ft = feet; in = inches; bgs = below ground surface; ags = above ground surface; NGVD29 = National Geodetic Vertical Datum 1929

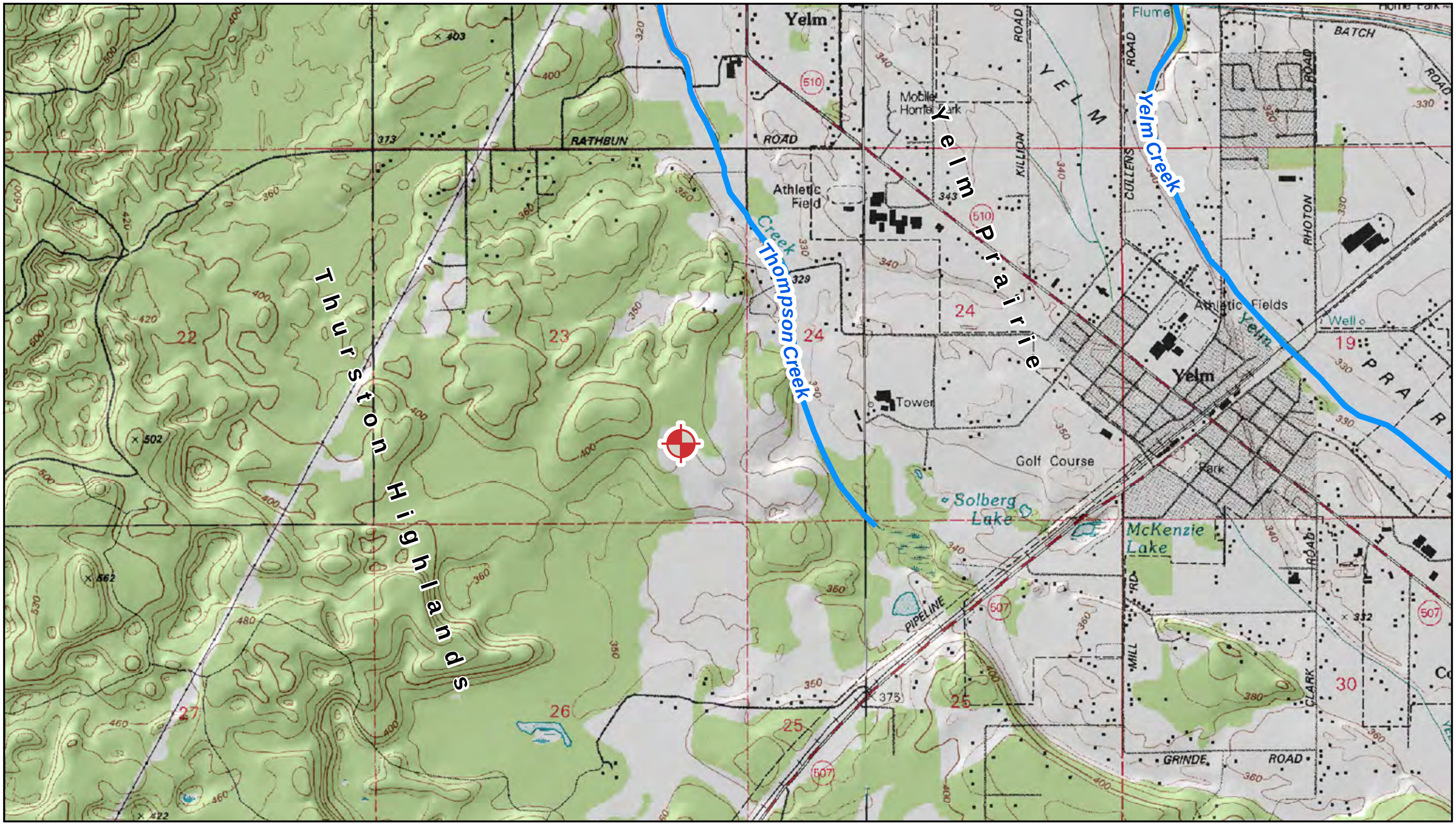
# TABLE 3
# TRANSMISSIVITY AND STORATIVITY ESTIMATES

| Test Type and Solution | Transmissivity (gpd/ft) | Storativity, *S* (dimensionless) |
|---|---|---|
| **Step-Rate Testing** | | |
| *Pumping Data* | | |
| Birsoy and Summers (1980) | 48,000 | 2.0E-04 |
| Eden and Hazel (1973) | 58,900 | --- |
| **Constant-Rate Testing** | | |
| *Pumping Data* | | |
| Theis (1935), Confined | 42,400 | --- |
| Cooper and Jacob (1946), Straight Line Method | 43,650 | --- |
| *Recovery Data* | | |
| Theis, 1946 (Recovery) | --- | --- |
| ***Geometric Mean*** | ***47,827*** | ***2.0E-04*** |



Golder Associates

# FIGURES




LEGEND

SW Well 1A

N

0 2000
Scale in Feet

Map Projection:
UTM NAD27, Zone 10 North

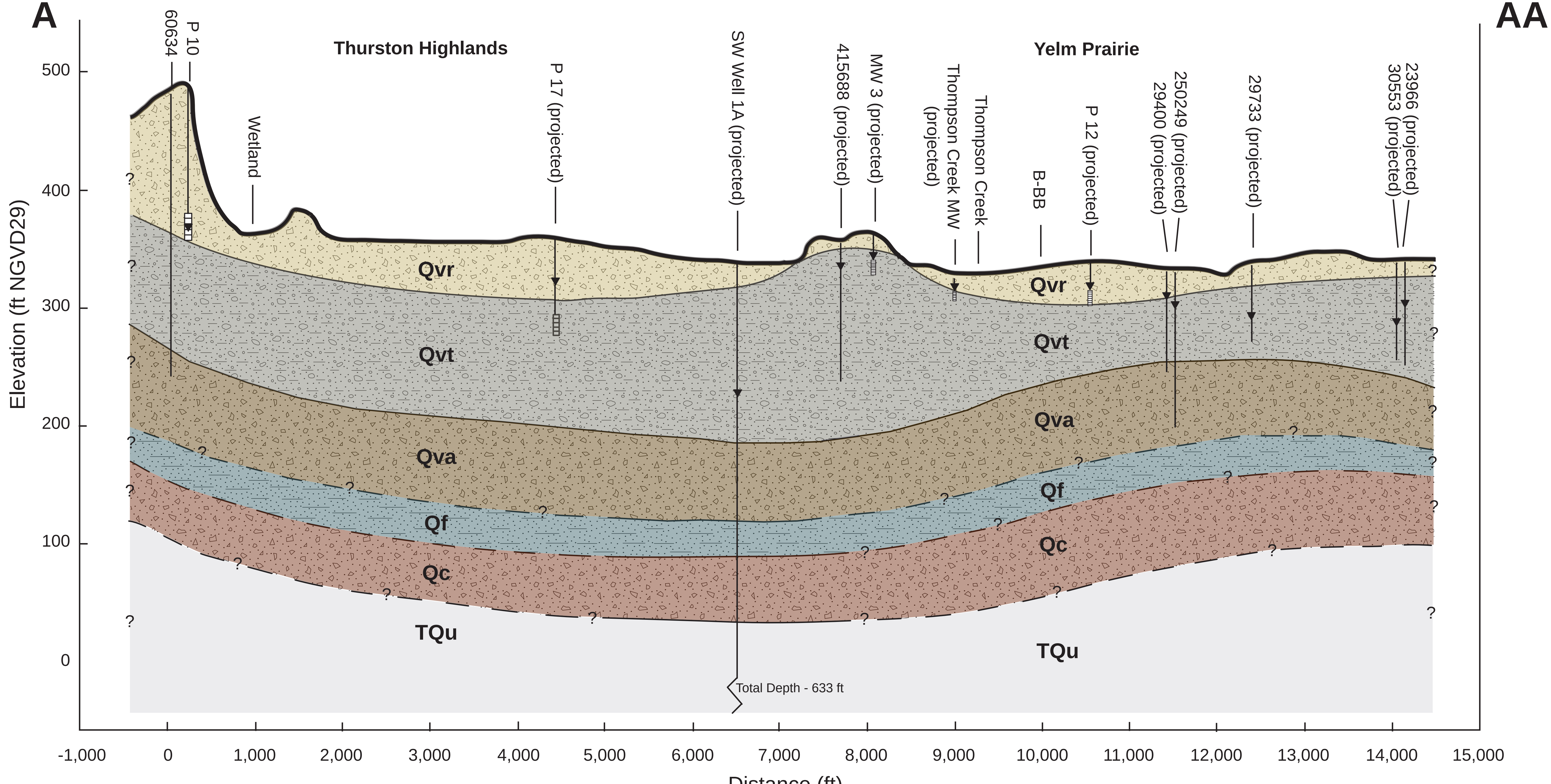
Source:
Washington State Geospatial Data Archive;
Washington Department of Ecology

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

FIGURE 1
**SITE LOCATION**
CITY OF YELM SOUTHWEST WELL 1A DEVELOPMENT PROJECT

103-99709; SWWell1A_SiteLocation.mxd | 3/14/2011 | KDJ

**Golder Associates**




LEGEND

**Recessional Outwash (Qvr)** - Sand and gravel, locally including low-permeability moraine deposits (Qvrm) of unsorted and unlayered rock debris known as till; groundwater is mostly unconfined, but perched water conditions occur in areas of Qvrm deposits.

**Till (Qvt)** - Unsorted and unlayered deposits of sand, gravel, cobbles, and boulders in a compacted and indurated matrix of silt and clay with some lenses of clean sand and gravel; confining unit.

**Advanced Outwash (Qva)** - Gravel in a matrix of sand with some sand lenses; groundwater is confined.

**Kitsap Formation (Qf)** - Predominately clay and silt, with some layers of sand and gravel, and may include some till or till-like deposits; confining unit.

**Salmon Springs (?) Drift (Qc)** - Pre-Vashon glacial deposits of sand and gravel typically stained red or brown; groundwater is confined.

**(TQu)** - Layers of clay, silt, sand and gravel of glacial and nonglacial origin.

▼ **Water Level**

**Screened Interval**

Note: See Figure A-1 in Appendix A for cross section location.

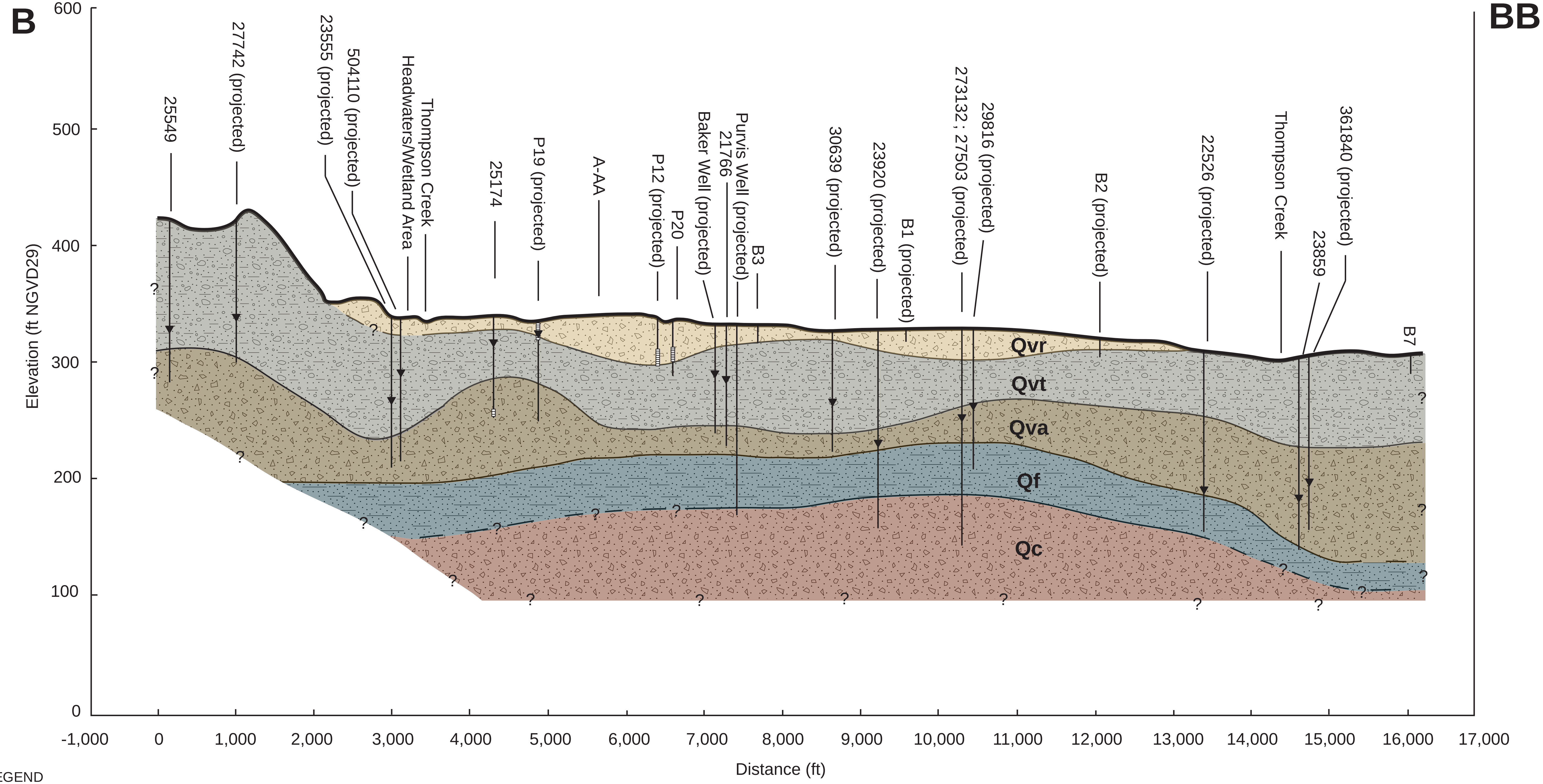
FIGURE **2**

**GEOLOGIC CROSS-SECTION A-AA**

CITY OF YELM SW WELL 1A DEVELOPMENT PROJECT

10399709fig02.ai | Mod: 01/17/11 | LMB

Golder Associates




LEGEND

**Recessional Outwash (Qvr)** - Sand and gravel, locally including low-permeability moraine deposits (Qvrm) of unsorted and unlayered rock debris known as till; groundwater is mostly unconfined, but perched water conditions occur in areas of Qvrm deposits.

**Till (Qvt)** - Unsorted and unlayered deposits of sand, gravel, cobbles, and boulders in a compacted and indurated matrix of silt and clay with some lenses of clean sand and gravel; confining unit.

**Advanced Outwash (Qva)** - Gravel in a matrix of sand with some sand lenses; groundwater is confined.

**Kitsap Formation (Qf)** - Predominately clay and silt, with some layers of sand and gravel, and may include some till or till-like deposits; confining unit.

**Salmon Springs (?) Drift (Qc)** - Pre-Vashon glacial deposits of sand and gravel typically stained red or brown; groundwater is confined.

▼ **Water Level**

**Screened Interval**

Note: See Figure A-1 in Appendix A for cross section location.

FIGURE 3
**GEOLOGIC CROSS-SECTION B-BB**
CITY OF YELM SW WELL 1A DEVELOPMENT PROJECT

10399709fig03.ai | Mod: 03/14/11 | LMB

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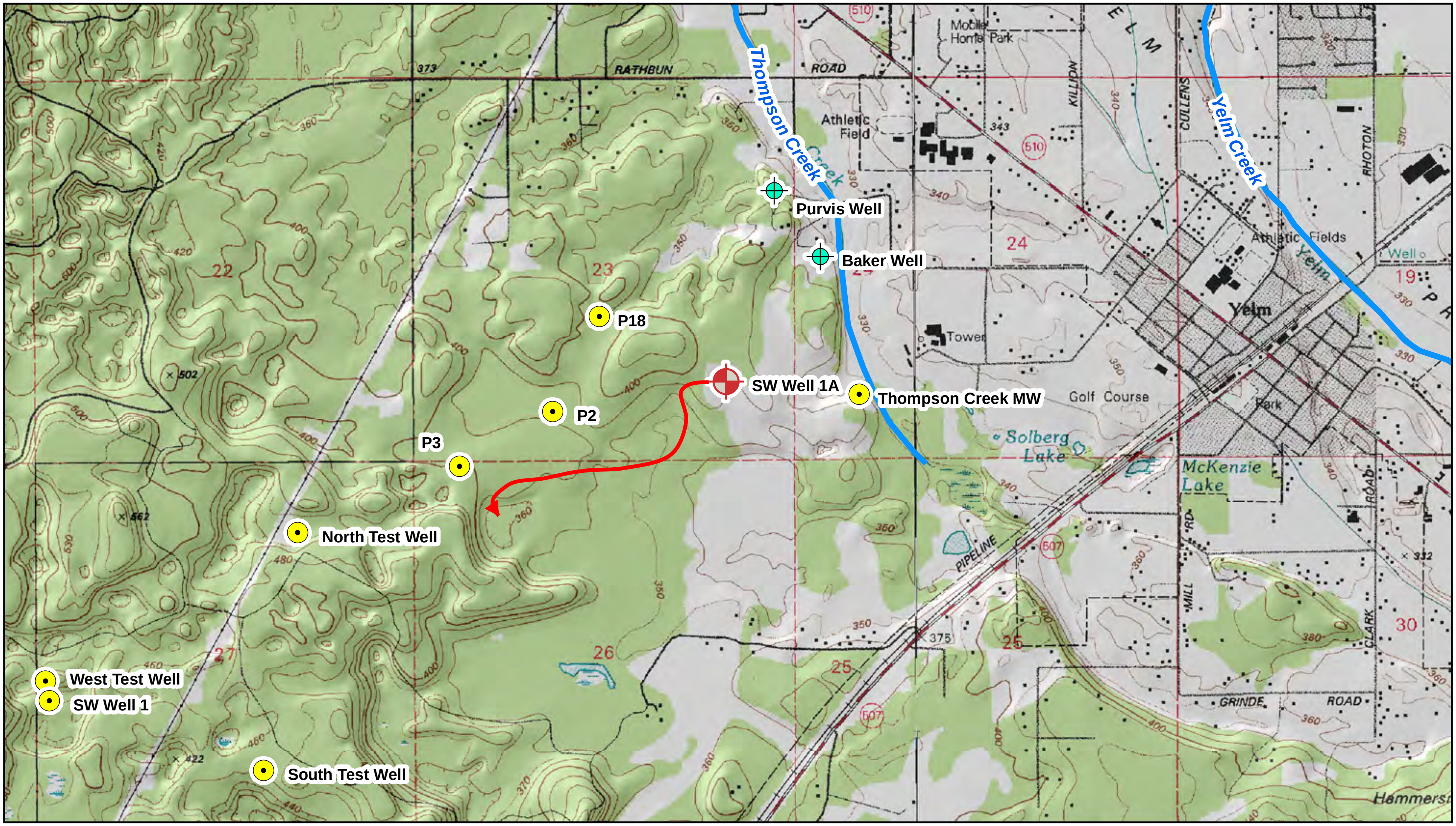



LEGEND

- SW Well No. 1A (pumping well)
- Domestic Well
- Piezometer/Monitoring Well
- Streams
- Aquifer Test Discharge Water

0 2000
Scale in Feet

Map Projection:
UTM NAD27, Zone 10 North

Source:
Washington State Geospatial Data Archive;
Washington Department of Ecology

N

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

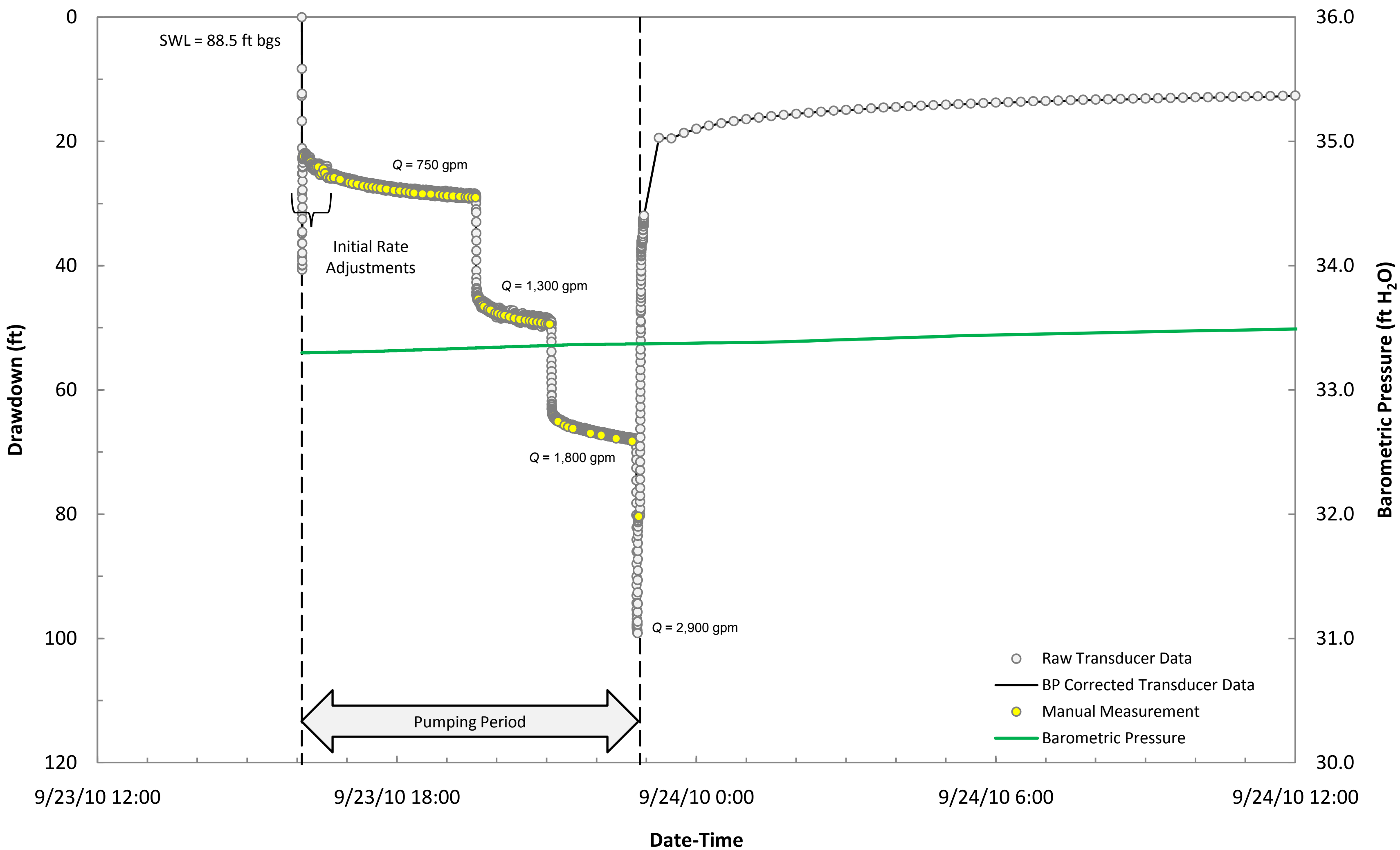
FIGURE 4

**OBSERVATION WELL NETWORK MONITORING LOCATIONS**

CITY OF YELM SOUTHWEST WELL 1A DEVELOPMENT PROJECT

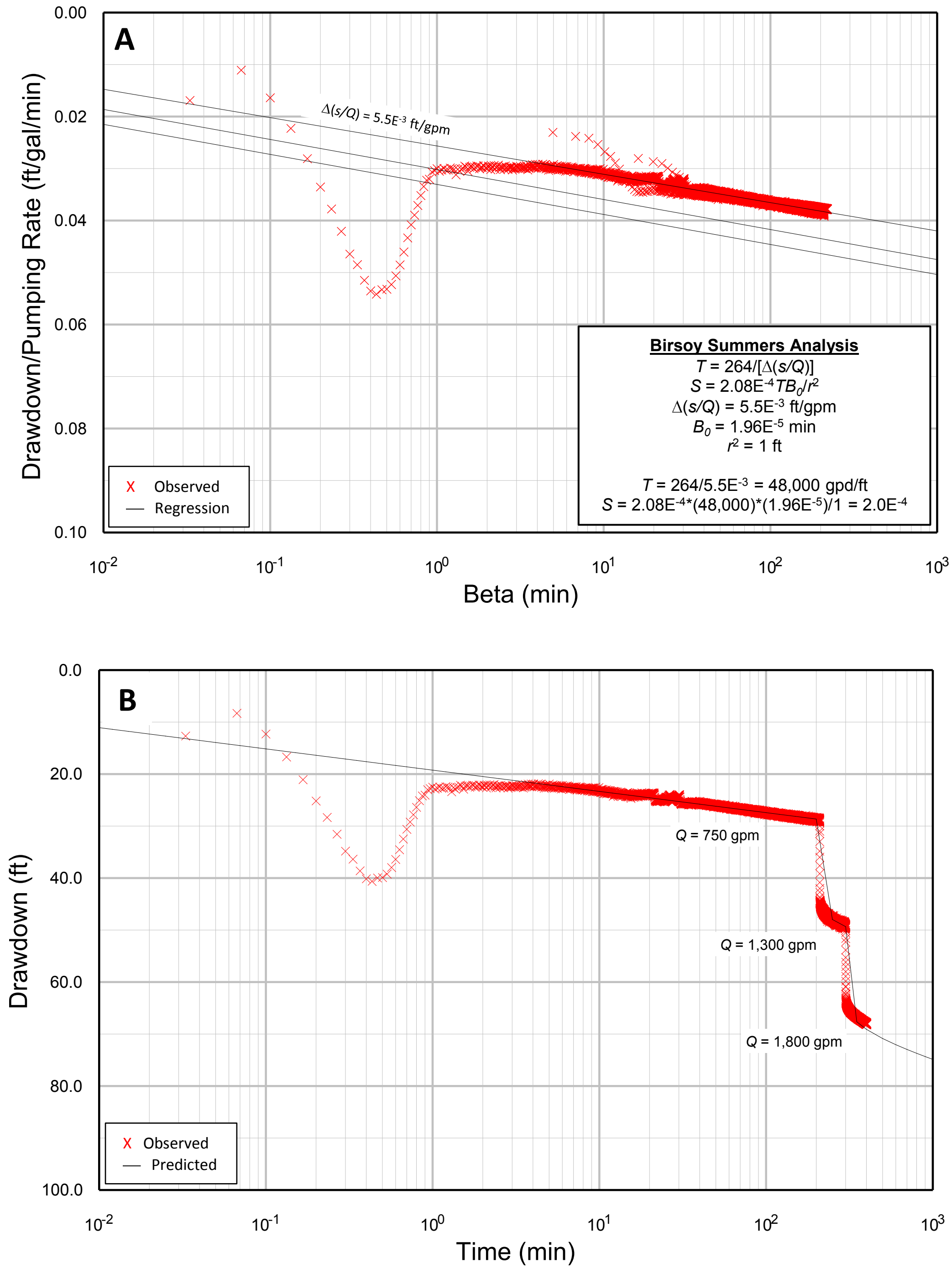
103-99709; SWWell1A_ObsWellNetwork.mxd | 3/14/2011 | KDJ

**Golder Associates**

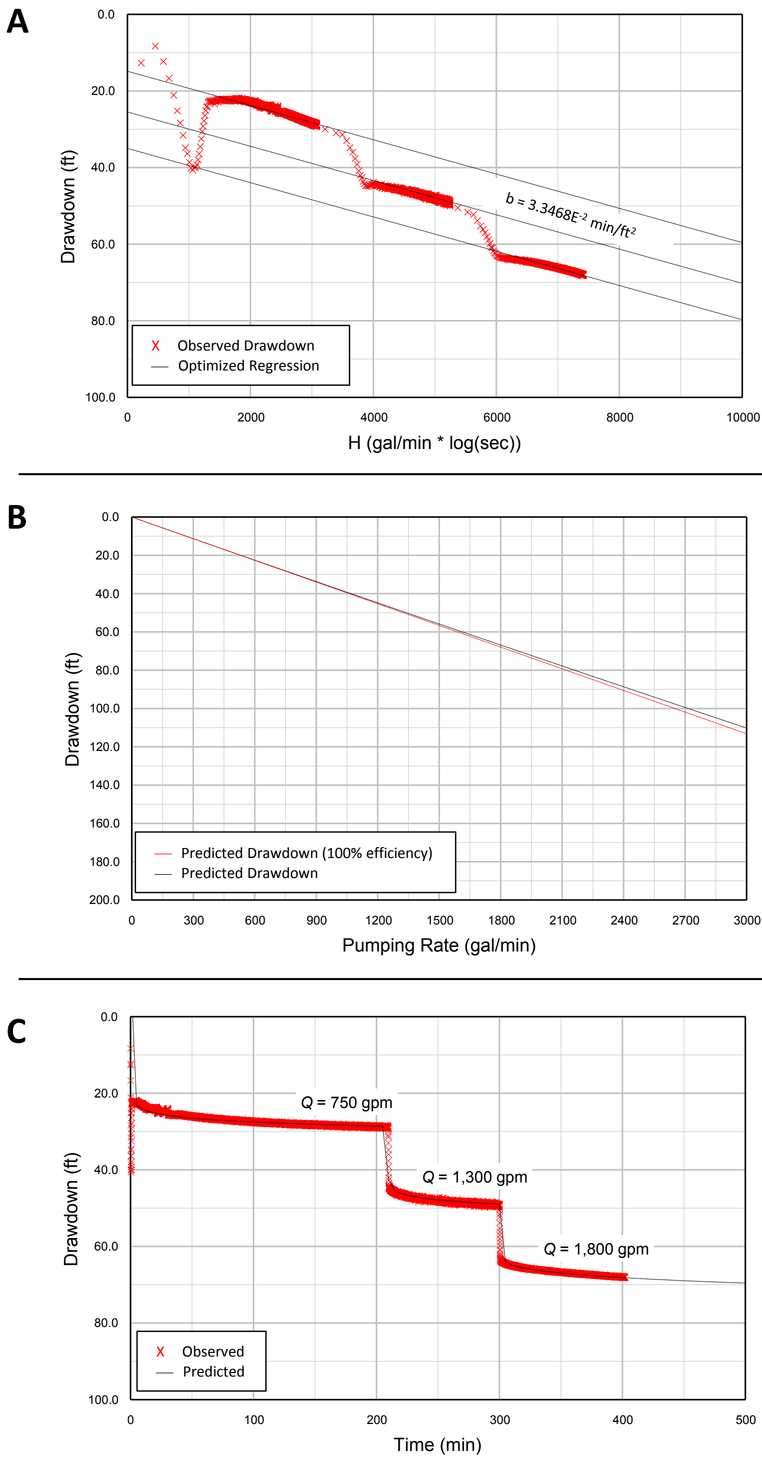



| | | |
|---|---|---|
| Golder Associates | Title | SW WELL 1A STEP-RATE TEST HYDROGRAPH |
| Project Name | SW Well 1A Development Project | Project No. 103-99709 |
| Client Name | City of Yelm, WA | Date January 17, 2011 |

| | |
|---|---|
| Drawn | KDJ |
| Checked | LMB |
| Reviewed | PAB |
| FIGURE | 5 |




| | | | | |
|---|---|---|---|---|
| Golder Associates | Title: SW WELL 1A STEP-RATE TEST RESULTS - BIRSOY AND SUMMERS (1980) | | Drawn | KDJ |
| | | | Checked | LMB |
| | Project Name: SW Well 1A Development Project | Project No.: 103-99709 | Reviewed | PAB |
| | Client Name: City of Yelm, WA | Date: January 17, 2011 | FIGURE 6 | |




**Eden Hazel Analysis**

$T$ = 24,774/4π$b$

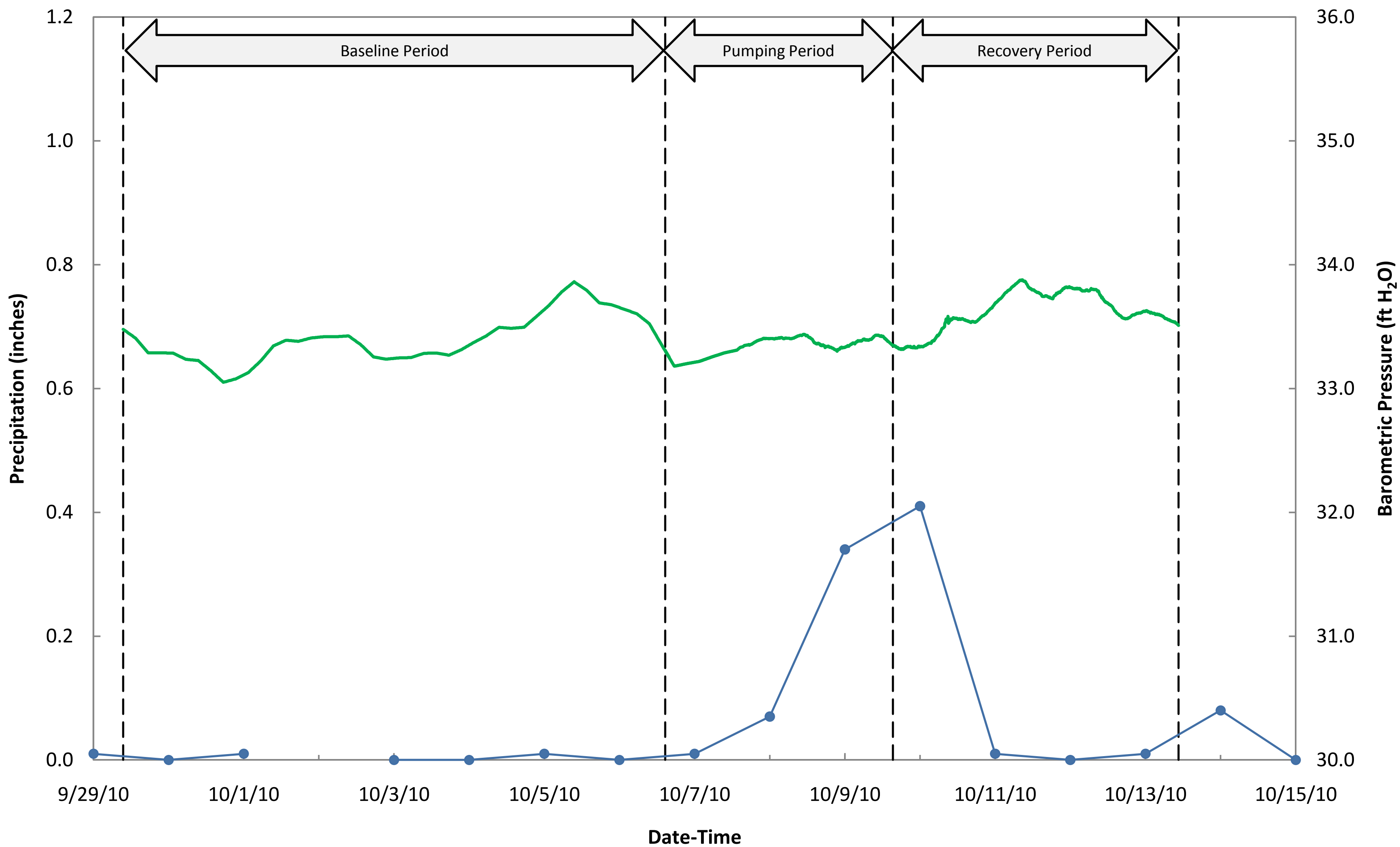
$b$ = slope of best fit lines

$b$ = 3.347E$^{-2}$ min/ft$^2$

$T$ = 58,900 gpd/ft

Golder Associates

| | | | |
|---|---|---|---|
| Title | SW WELL 1A STEP-RATE TEST RESULTS - EDEN AND HAZEL (1973) | Drawn | KDJ |
| | | Checked | LMB |
| Project Name: SW Well 1A Development Project | Project No.: 103-99709 | Reviewed | PAB |
| Client Name: City of Yelm, WA | Date: January 17, 2011 | FIGURE | 7 |




| | | | | | |
|---|---|---|---|---|---|
| Golder Associates | Precipitation<br>Barometric Pressure | Title | PRECIPITATION AND BAROMETRIC PRESSURE | Drawn | KDJ |
| | | | | Checked | LMB |
| | | Project Name | SW Well 1A Development Project | Project No. 103-99709 | Reviewed PAB |
| | | Client Name | City of Yelm, WA | Date January 17, 2011 | FIGURE 8 |

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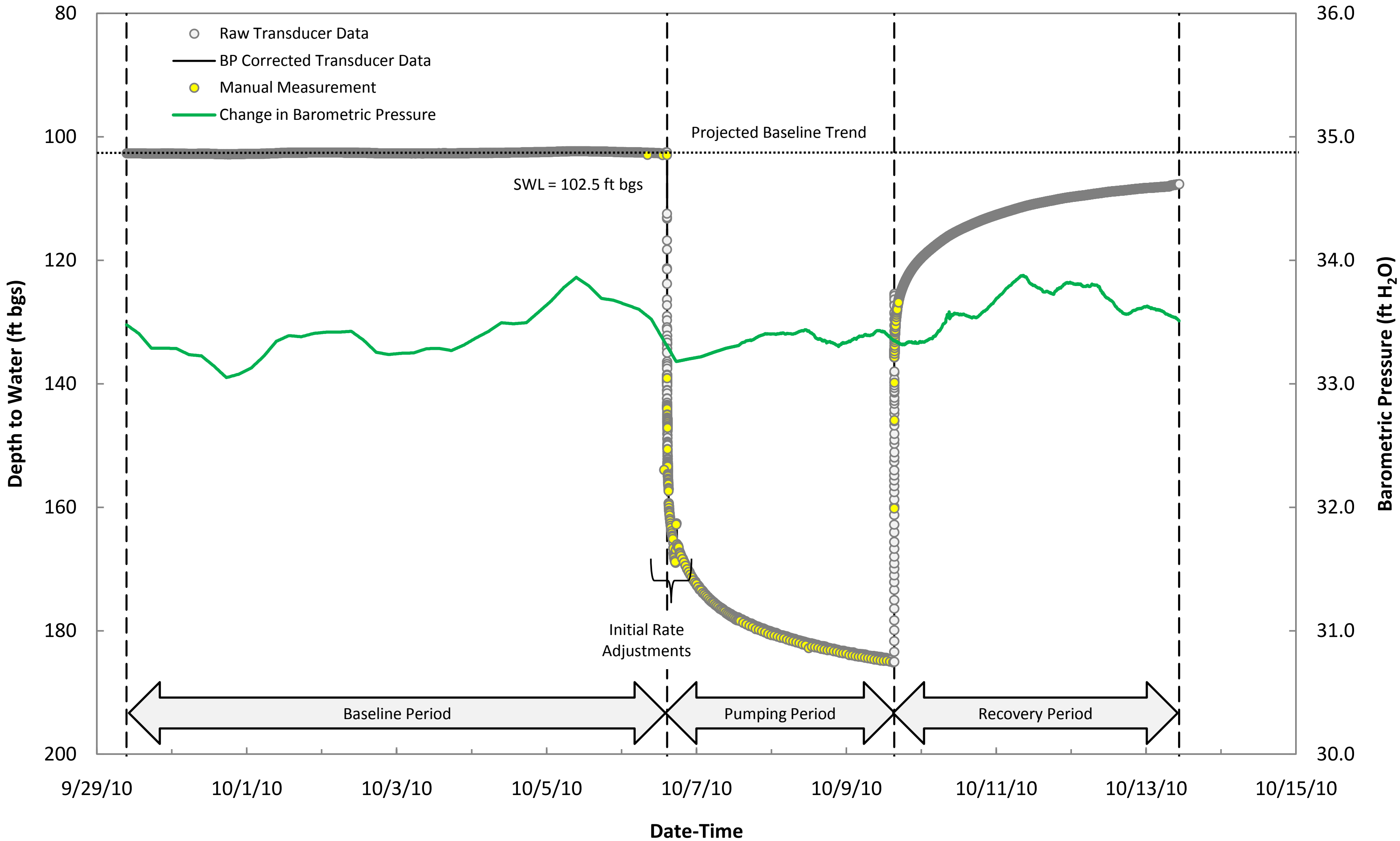


Golder Associates

| | | | |
|---|---|---|---|
| Title | SW WELL 1A CONSTANT-RATE TEST HYDROGRAPH | | |
| Project Name | SW Well 1A Development Project | Project No. | 103-99709 |
| Client Name | City of Yelm, WA | Date | January 17, 2011 |

| | |
|---|---|
| Drawn | KDJ |
| Checked | LMB |
| Reviewed | PAB |
| FIGURE | 9 |

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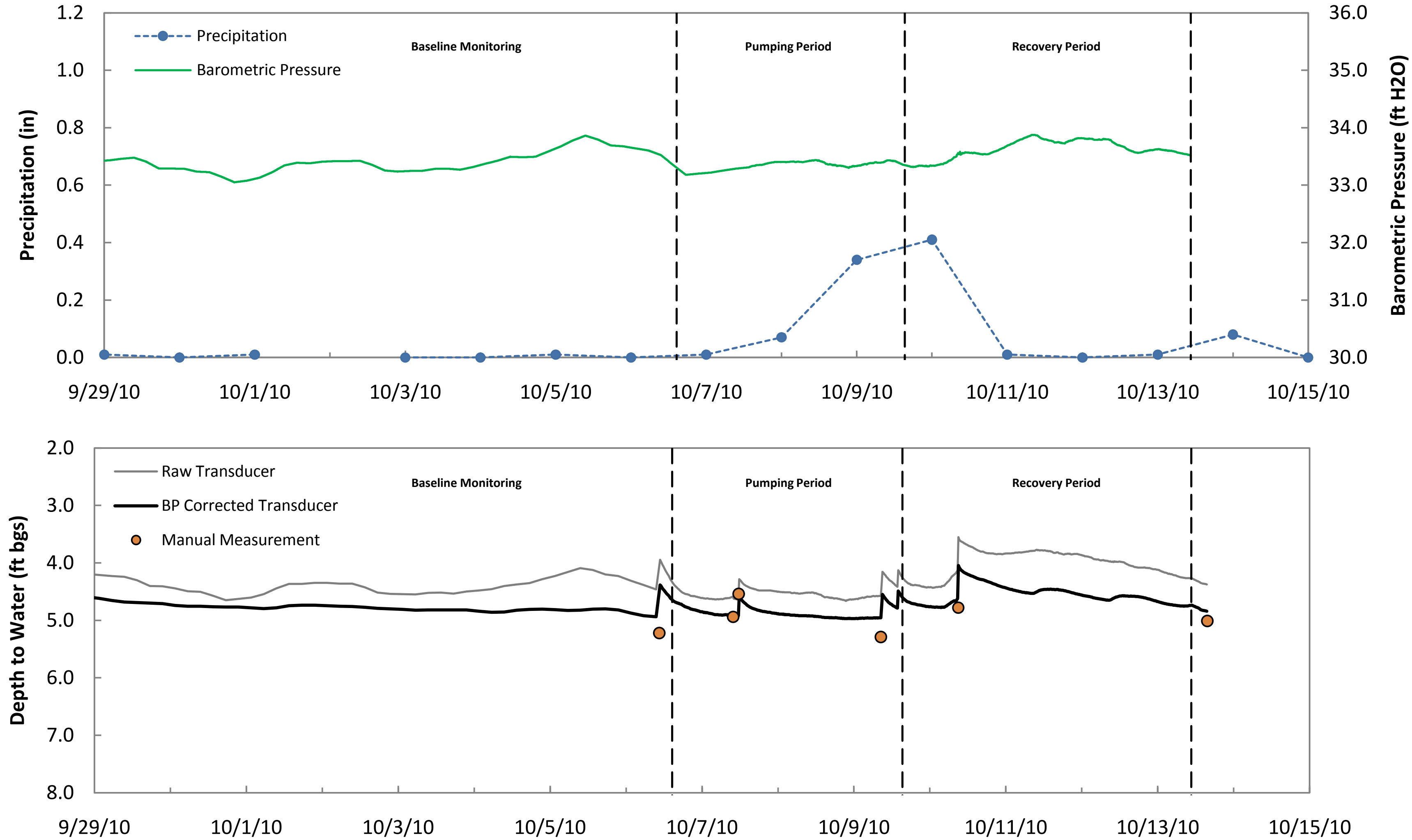
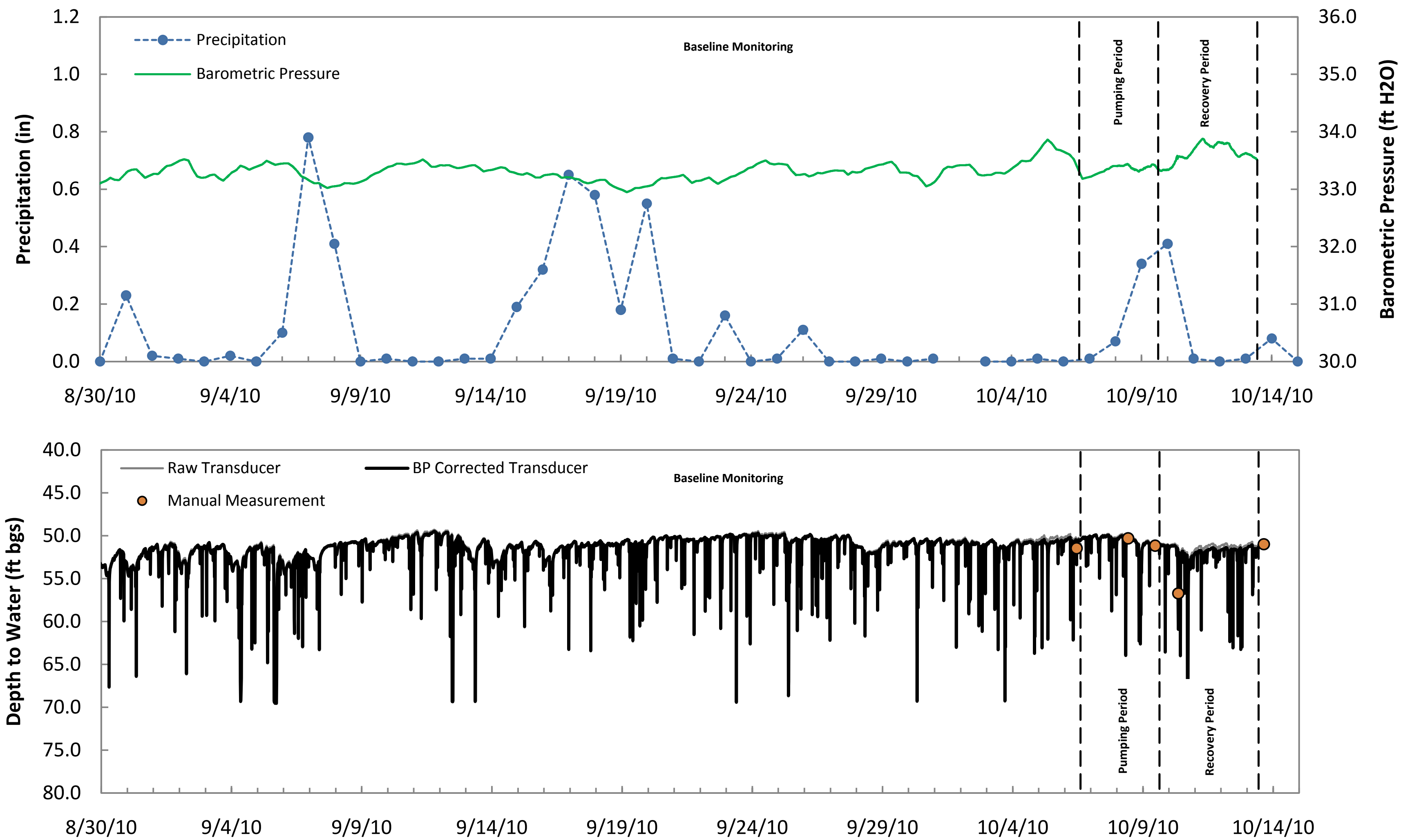



Golder Associates

| | | | |
|---|---|---|---|
| Title | THOMPSON CREEK MONITORING WELL HYDROGRAPH | | |
| Project Name | SW Well 1A Development Project | Project No. | 103-99709 |
| Client Name | City of Yelm | Date | January 17, 2011 |

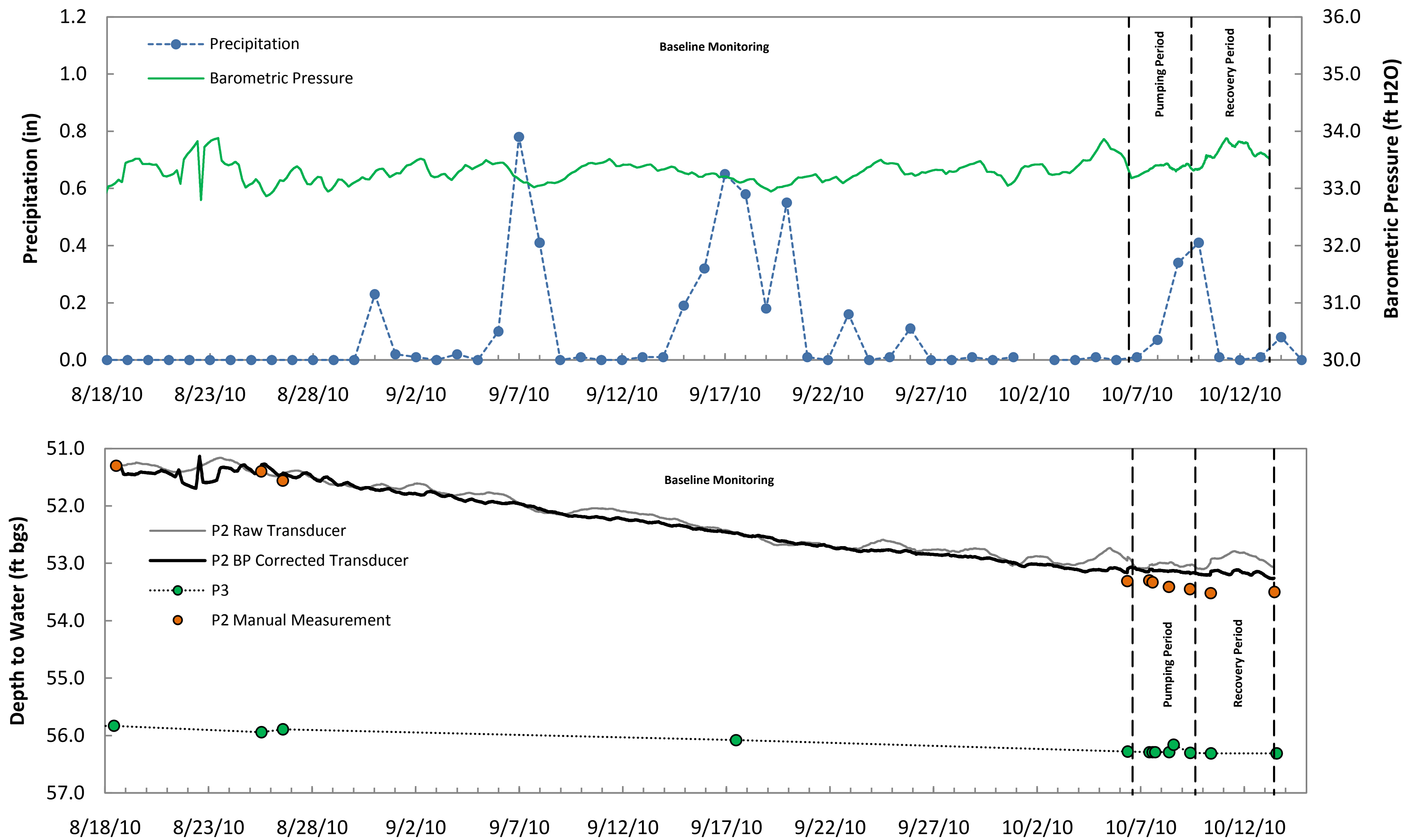
| | |
|---|---|
| Drawn | KDJ |
| Checked | LMB |
| Reviewed | PAB |
| FIGURE | 10 |

S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Constant Rate Test\MW Data\Monitoring Well Data.xlsx




| Golder Associates | | Title: BAKER WELL HYDROGRAPH | | Drawn | KDJ |
|---|---|---|---|---|---|
| | | Project Name: SW Well 1A Development Project | Project No.: 103-99709 | Checked | LMB |
| | | | | Reviewed | PAB |
| | | Client Name: City of Yelm | Date: January 17, 2011 | FIGURE | 11 |

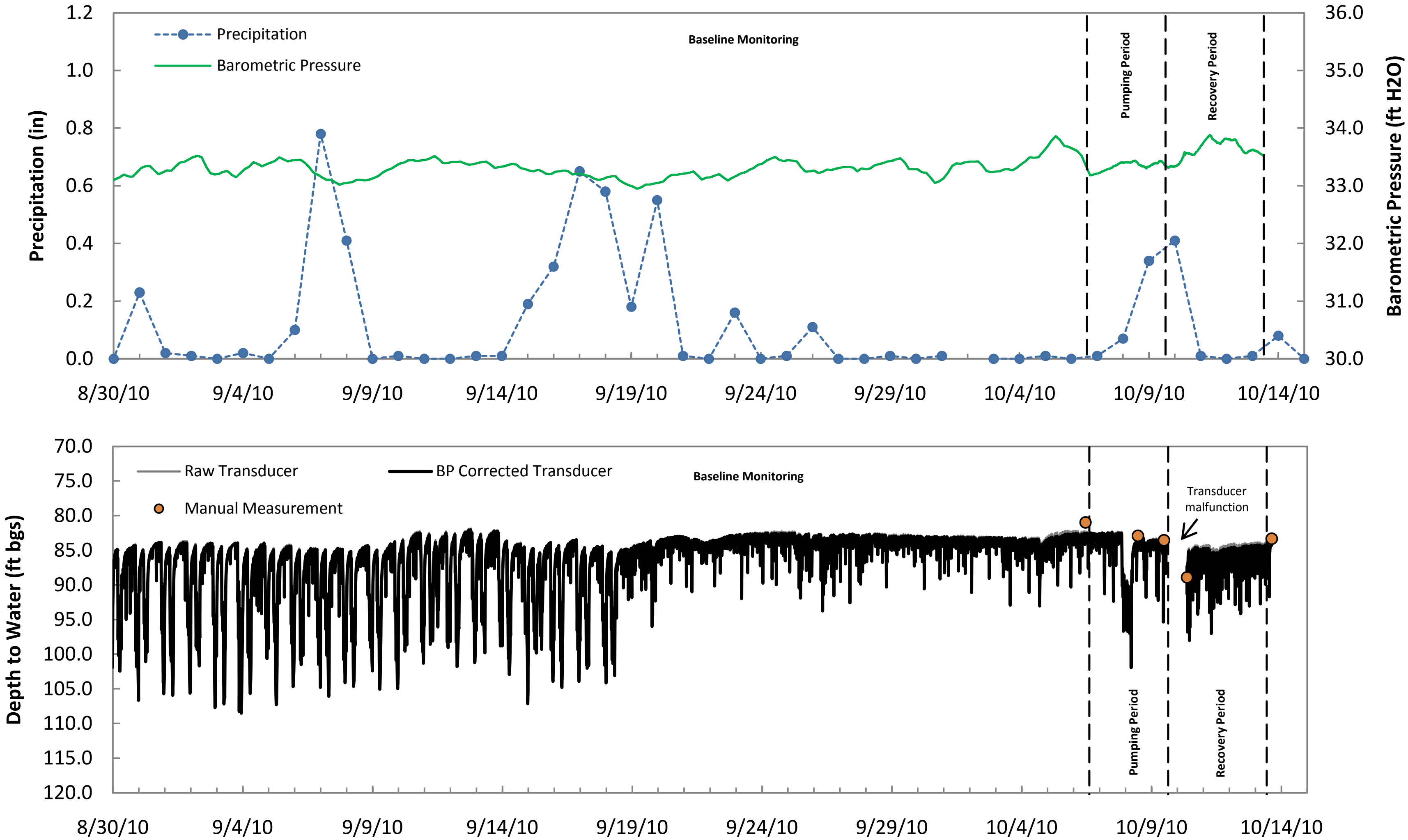
S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Constant Rate Test\MW Data\Monitoring Well Data.xlsx




Golder Associates

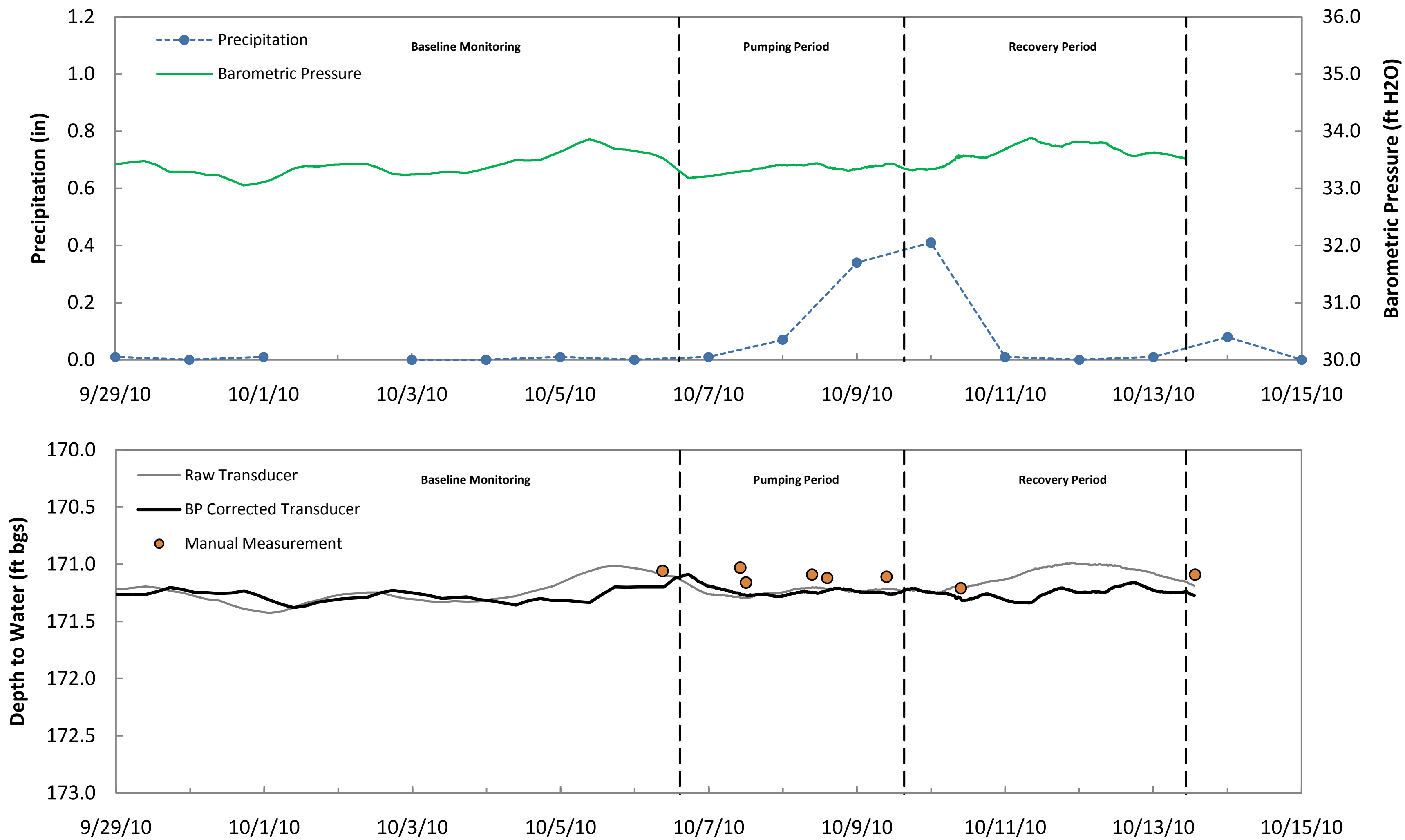
| | | | |
|---|---|---|---|
| Title | P2 AND P3 HYDROGRAPHS | Drawn | KDJ |
| | | Checked | LMB |
| Project Name: SW Well 1A Development Project | Project No. 103-99709 | Reviewed | PAB |
| Client Name: City of Yelm | Date: January 17, 2011 | FIGURE | 12 |

S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Constant Rate Test\MW Data\Monitoring Well Data.xlsx




Golder Associates

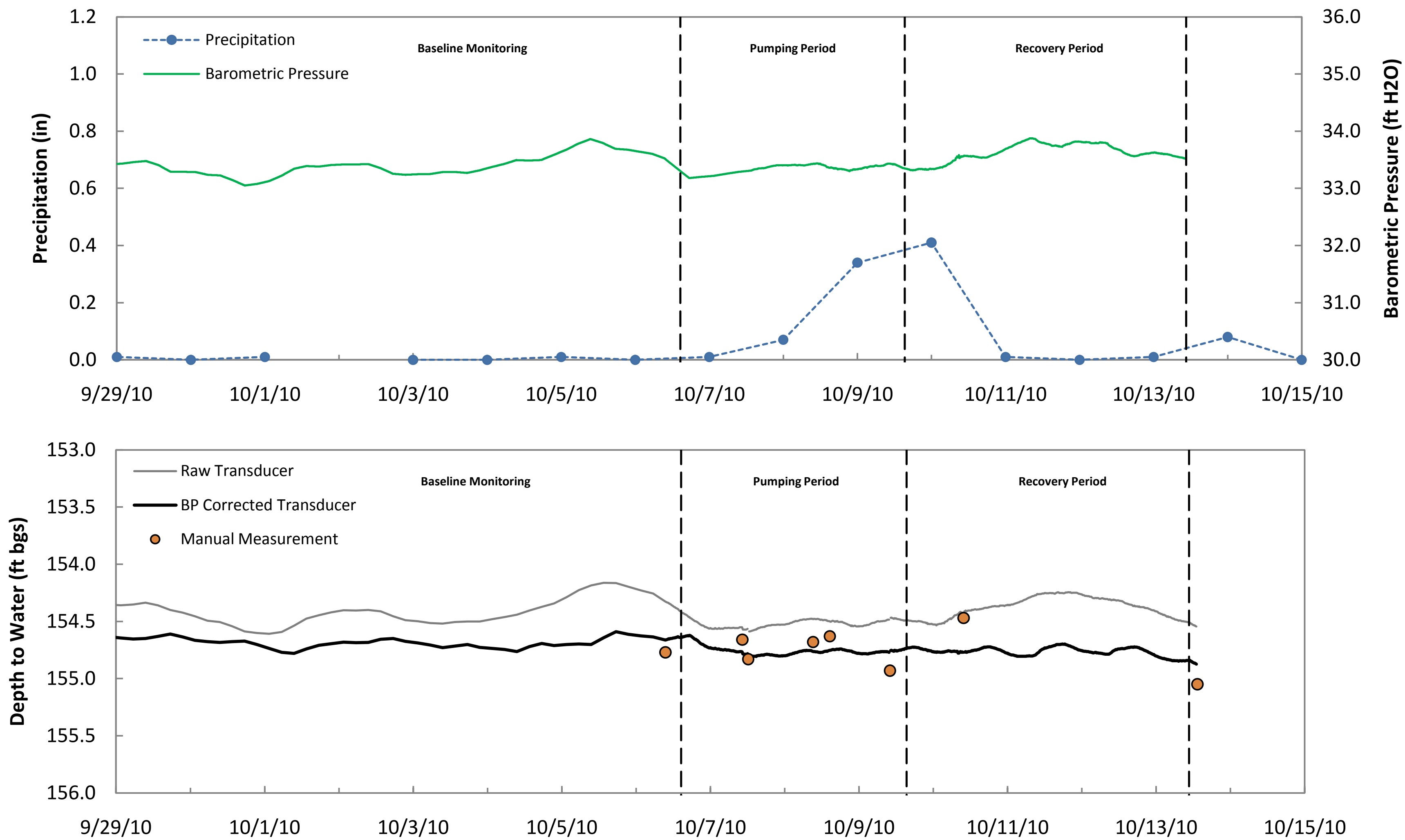
| | | | |
|---|---|---|---|
| Title | PURVIS WELL HYDROGRAPH | Drawn | KDJ |
| | | Checked | LMB |
| Project Name: SW Well 1A Development Project | Project No. 103-99709 | Reviewed | PAB |
| Client Name: City of Yelm | Date: January 17, 2011 | FIGURE | 13 |




Golder Associates

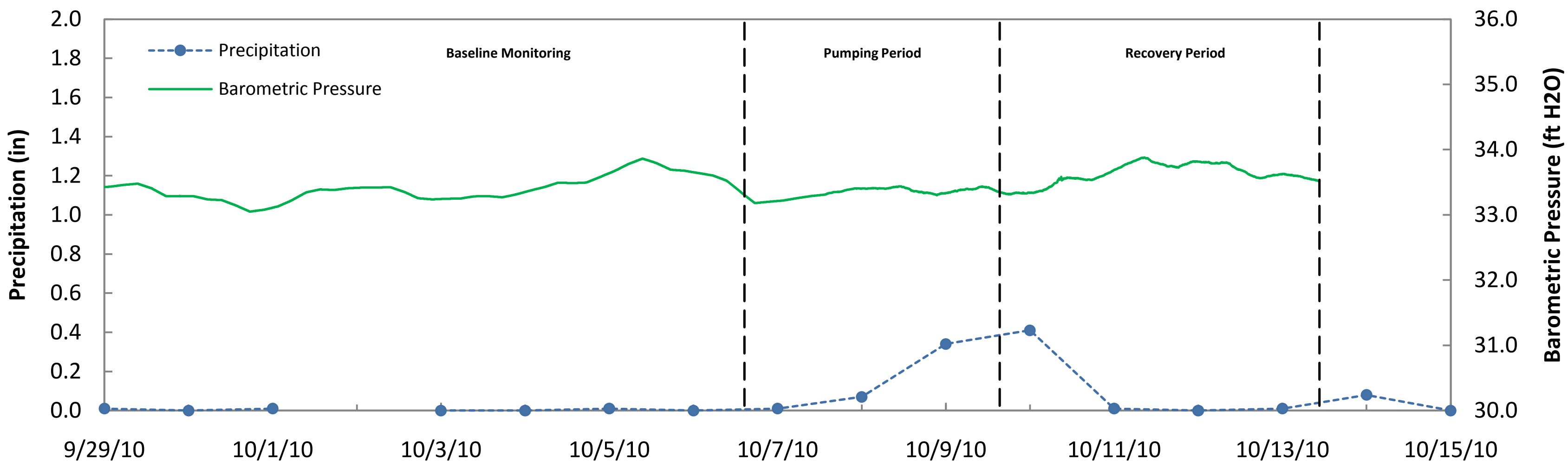
| | | | |
|---|---|---|---|
| Title | NORTH TEST WELL HYDROGRAPH | Drawn | KDJ |
| | | Checked | LMB |
| Project Name: SW Well 1A Development Project | Project No. 103-99709 | Reviewed | PAB |
| Client Name: City of Yelm | Date: January 17, 2011 | FIGURE | 14 |

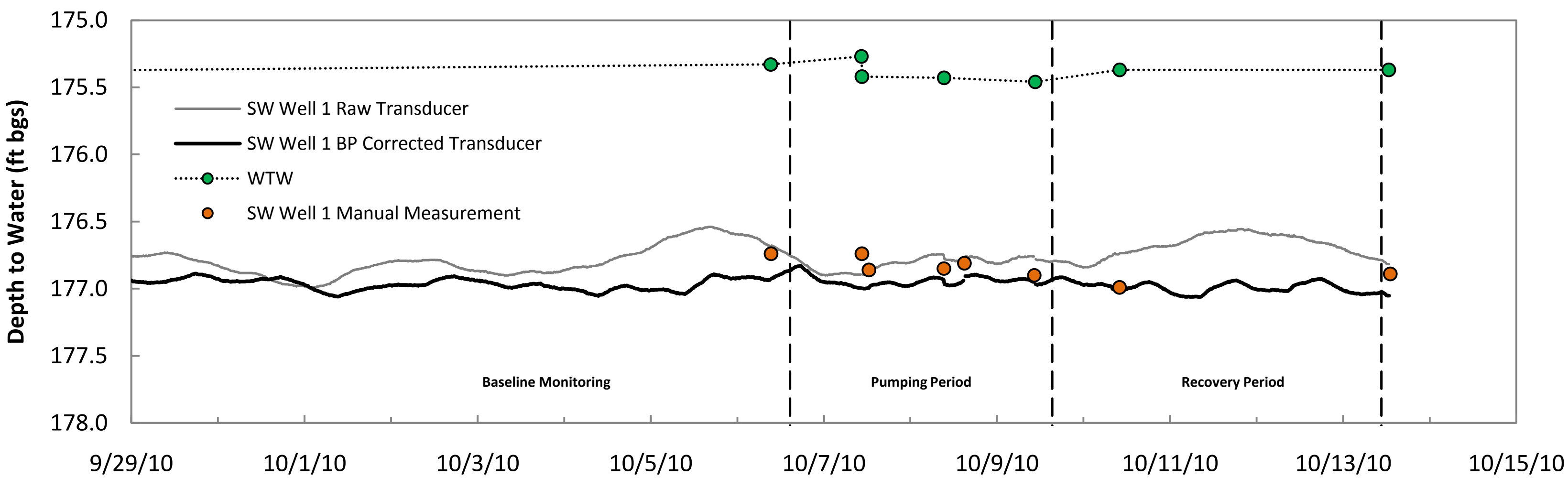
S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Constant Rate Test\MW Data\Monitoring Well Data.xlsx



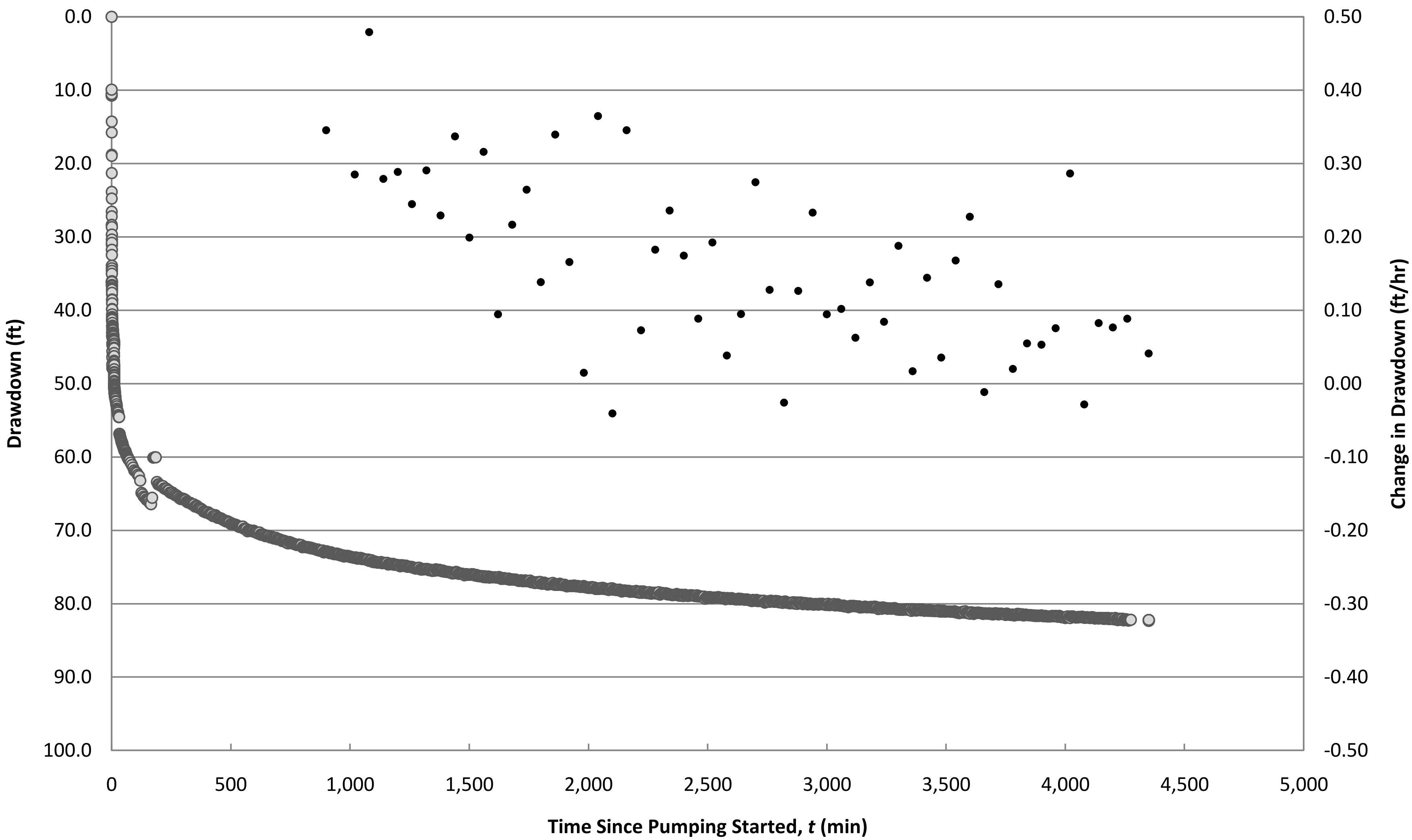

| | | | | |
|---|---|---|---|---|
| Golder Associates | Title | SOUTH TEST WELL HYDROGRAPH | Drawn | KDJ |
| | | | Checked | LMB |
| | Project Name | SW Well 1A Development Project | Project No. 103-99709 | Reviewed: PAB |
| | Client Name | City of Yelm | Date January 17, 2011 | FIGURE 15 |

S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Constant Rate Test\MW Data\Monitoring Well Data.xlsx




| | | | |
|---|---|---|---|
| Golder Associates | Title: SW WELL 1 AND WEST TEST WELL HYDROGRAPHS | | Drawn: KDJ |
| | Project Name: SW Well 1A Development Project | Project No.: 103-99709 | Checked: LMB |
| | | | Reviewed: PAB |
| | Client Name: City of Yelm | Date: January 17, 2011 | FIGURE 16 |



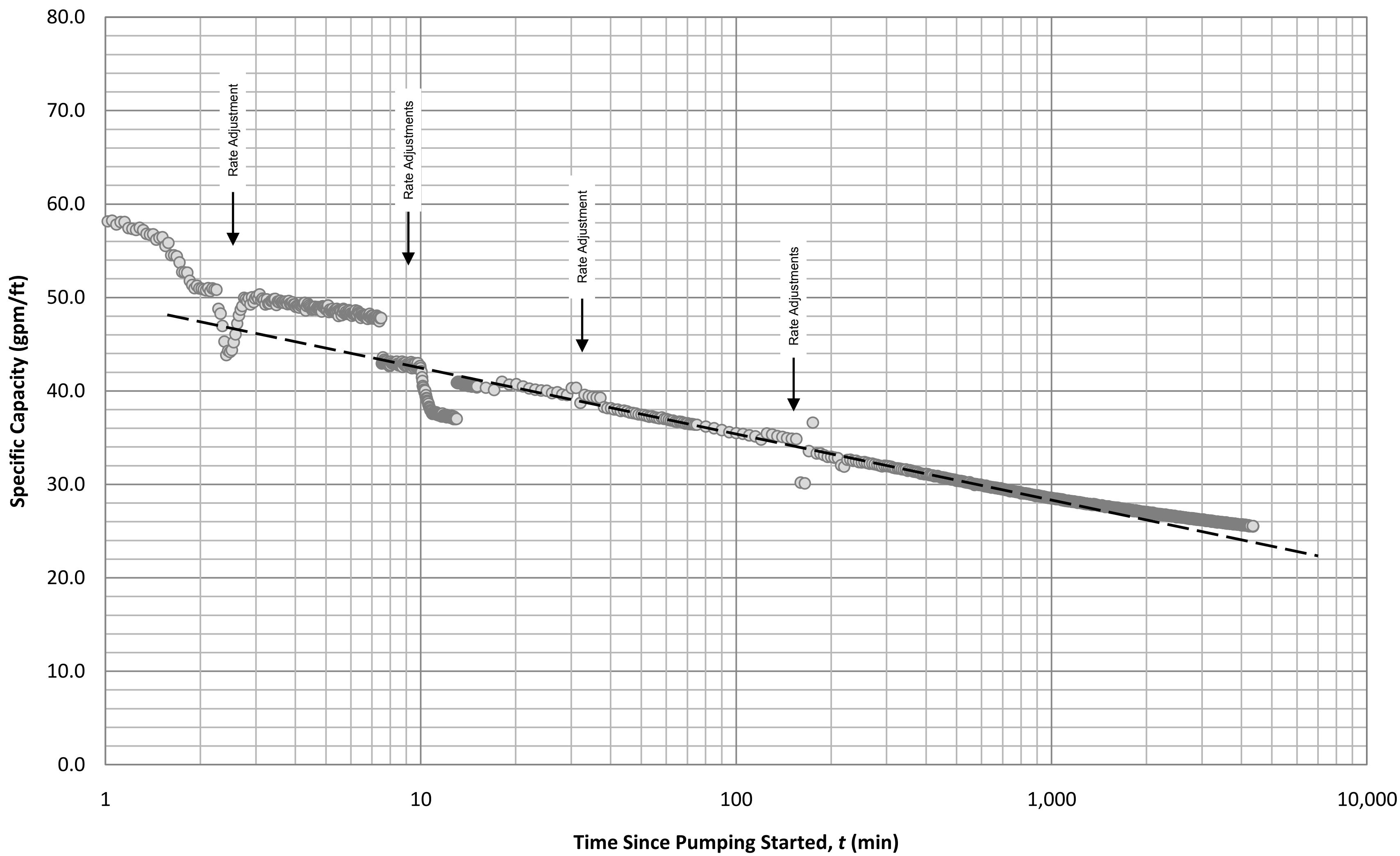

Golder Associates

BP Corrected Transducer Data

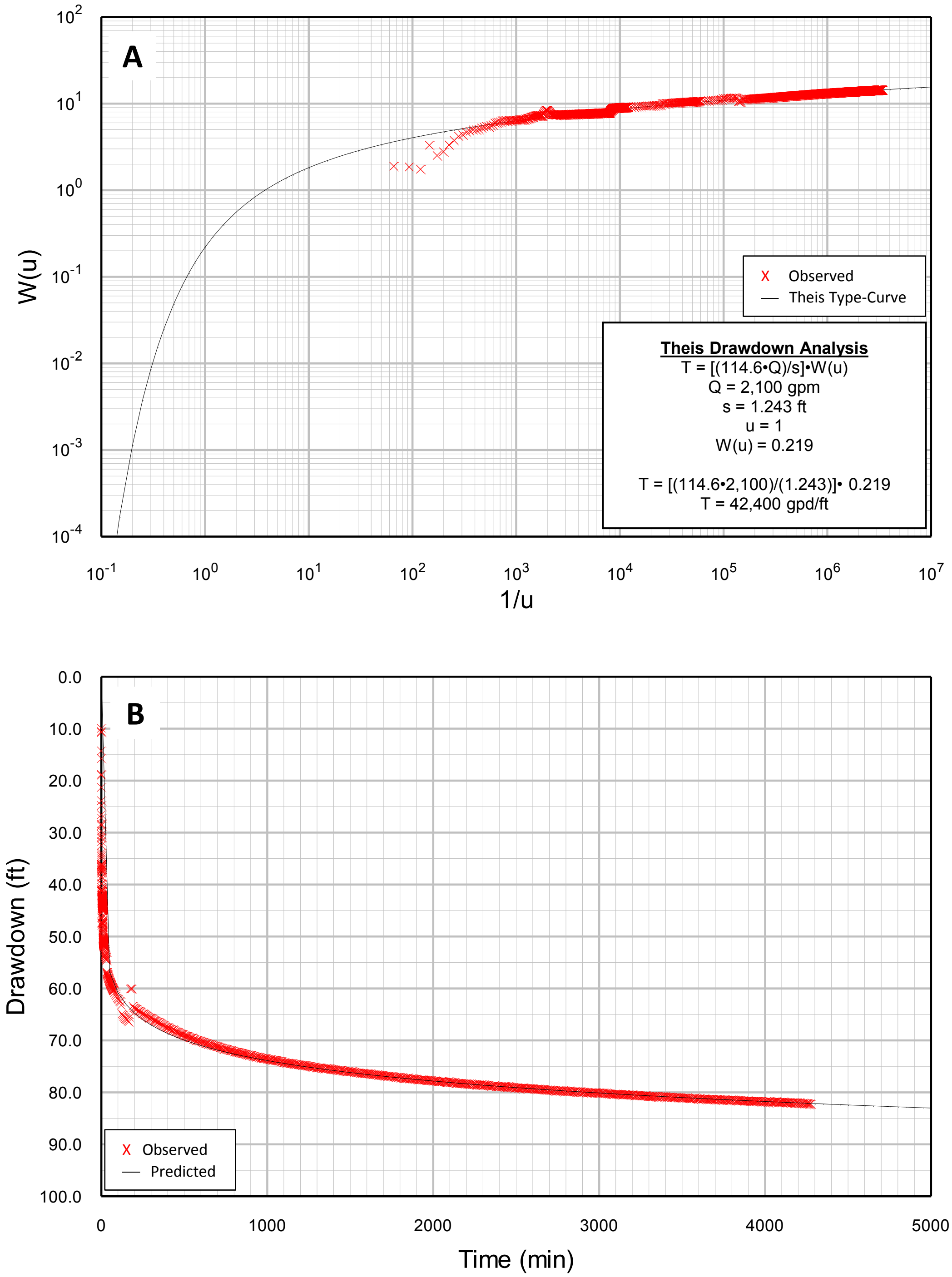
Change in Drawdown

| | | | | | |
|---|---|---|---|---|---|
| Title | SW WELL 1A CHANGE IN DRAWDOWN DURING PUMPING | | | Drawn | KDJ |
| | | | | Checked | LMB |
| Project Name | SW Well 1A Development Project | Project No. | 103-99709 | Reviewed | PAB |
| Client Name | City of Yelm, WA | Date | January 17, 2011 | FIGURE | 17 |

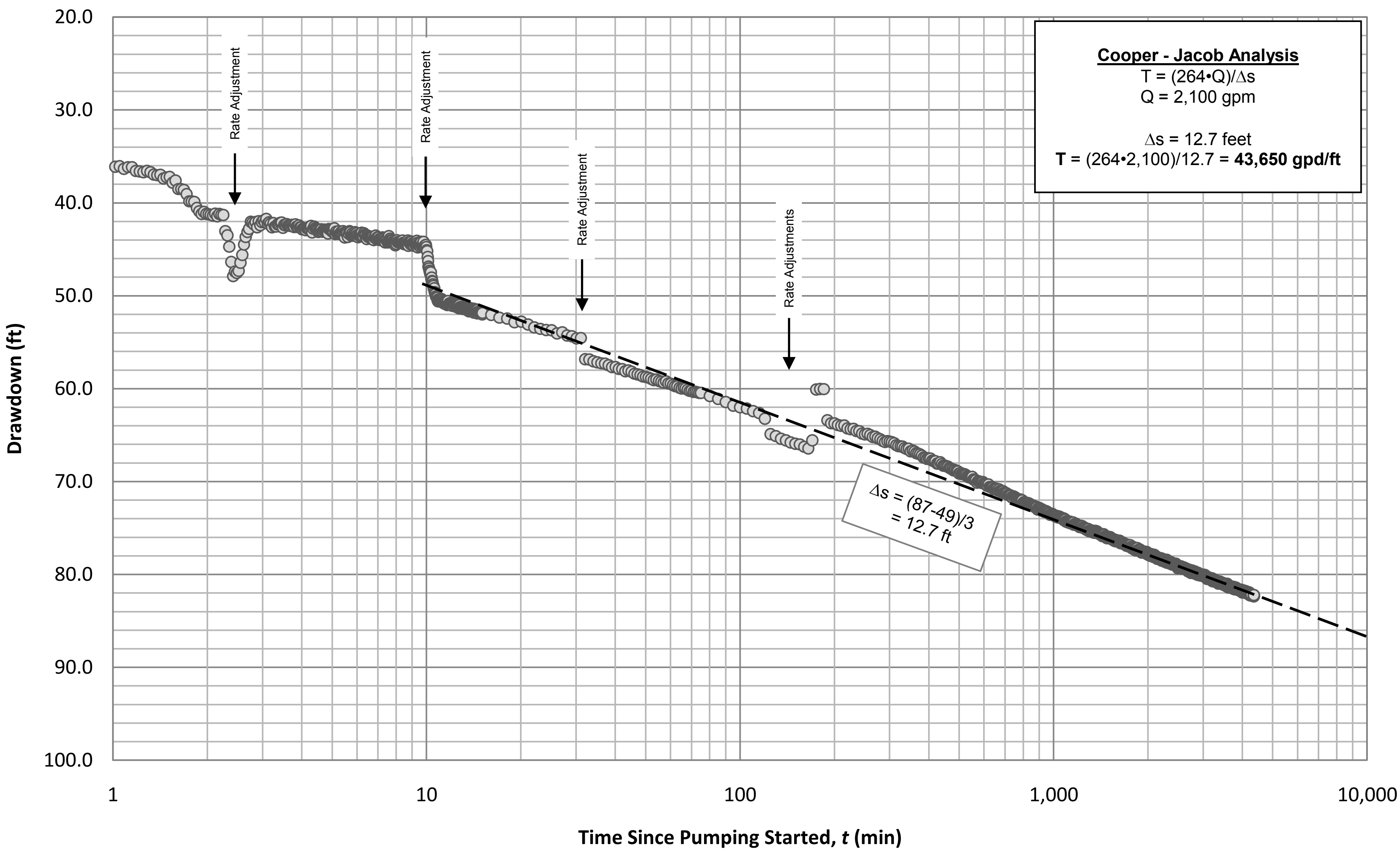
S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Step Test\SW Yelm Well No1 StepTest_3.xlsx



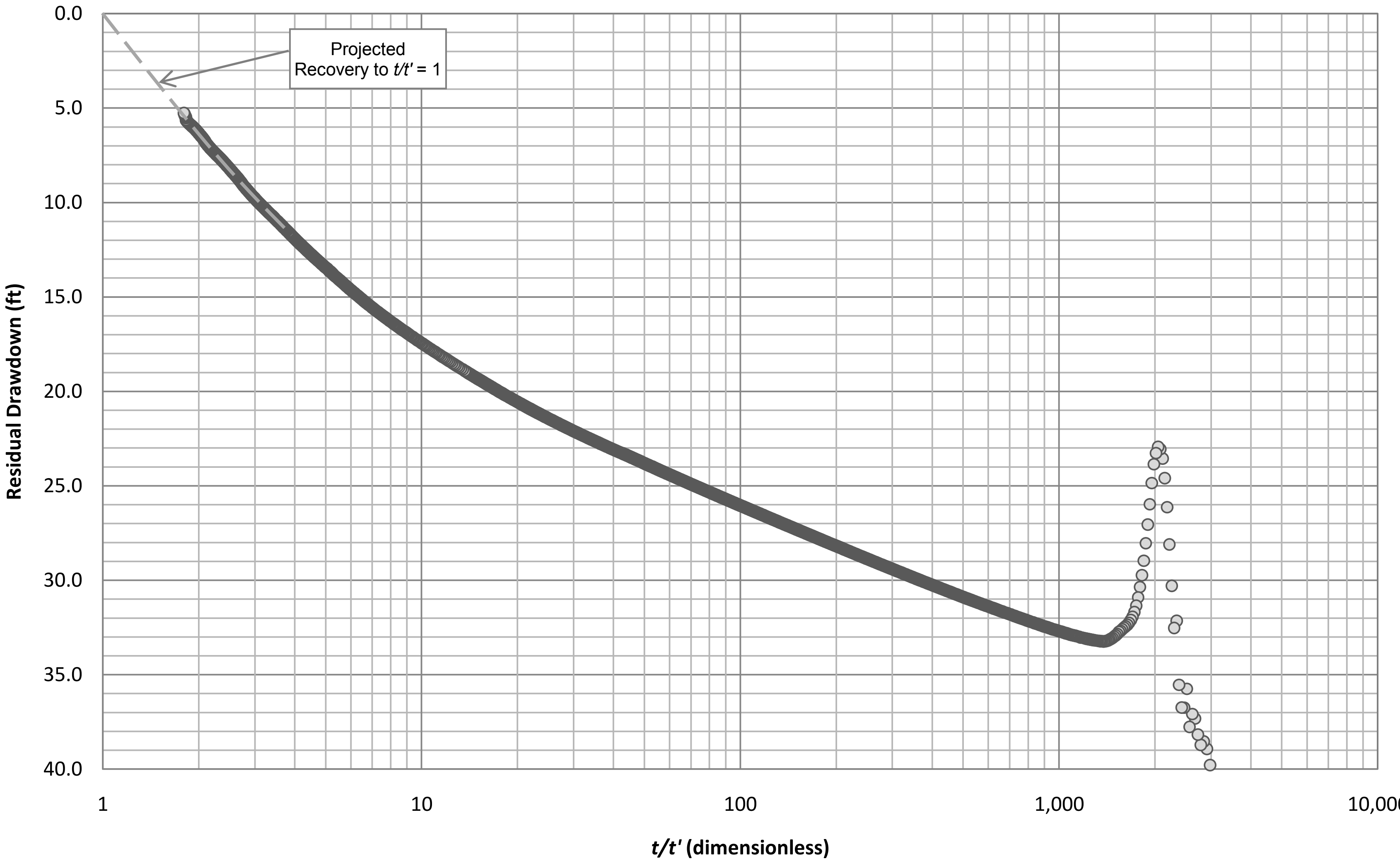

| | | | |
|---|---|---|---|
| Golder Associates | Title: SW WELL 1A HYDRAULIC RESPONSE – SPECIFIC CAPACITY VS. PUMPING TIME | | Drawn: KDJ<br>Checked: LMB<br>Reviewed: PAB |
| | Project Name: SW Well 1A Development Project | Project No.: 103-99709 | |
| | Client Name: City of Yelm, WA | Date: January 18, 2011 | FIGURE 18 |



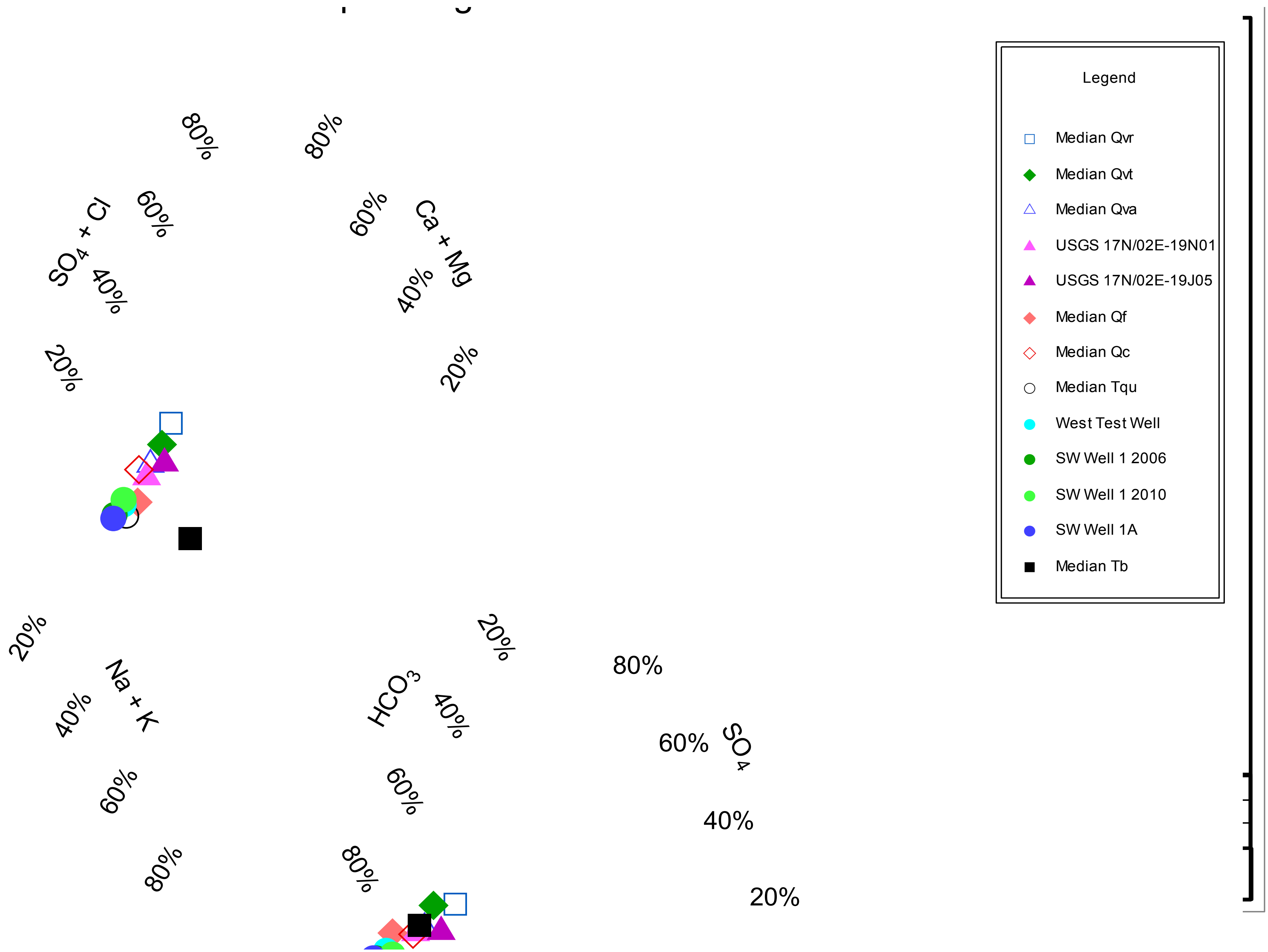

| | | | | |
|---|---|---|---|---|
| Golder Associates | Title: SW WELL 1A HYDRAULIC RESPONSE – THEIS (CONFINED; 1935) | | Drawn | KDJ |
| | | | Checked | LMB |
| | Project Name: SW Well 1A Development Project | Project No.: 103-99709 | Reviewed | PAB |
| | Client Name: City of Yelm, WA | Date: January 17, 2011 | FIGURE 19 | |




| | | | |
|---|---|---|---|
| Golder Associates | ○ BP Corrected Transducer Data | Title: SW WELL 1A SEMILOG DRAWDOWN – COOPER AND JACOB (STRAIGHT LINE METHOD; 1946) | Drawn: KDJ<br>Checked: LMB<br>Reviewed: PAB |
| | | Project Name: SW Well 1A Development Project<br>Project No.: 103-99709 | |
| | | Client Name: City of Yelm, WA<br>Date: January 17, 2011 | FIGURE 20 |




| | | | |
|---|---|---|---|
| Golder Associates | ○ BP Corrected Transducer Data | Title: SW WELL 1A SEMILOG RECOVERY – THEIS (1946) | Drawn: KDJ |
| | | Project Name: SW Well 1A Development Project | Checked: LMB |
| | | Project No.: 103-99709 | Reviewed: PAB |
| | | Client Name: City of Yelm, WA | FIGURE 21 |
| | | Date: January 17, 2011 | |




S:\Projects\2010\2010 Water Group Projects\10399709 COY SW Well No 2\Phase 3 - Aquifer Testing\Water Quality\FIG22_Piper Plot.xlsx

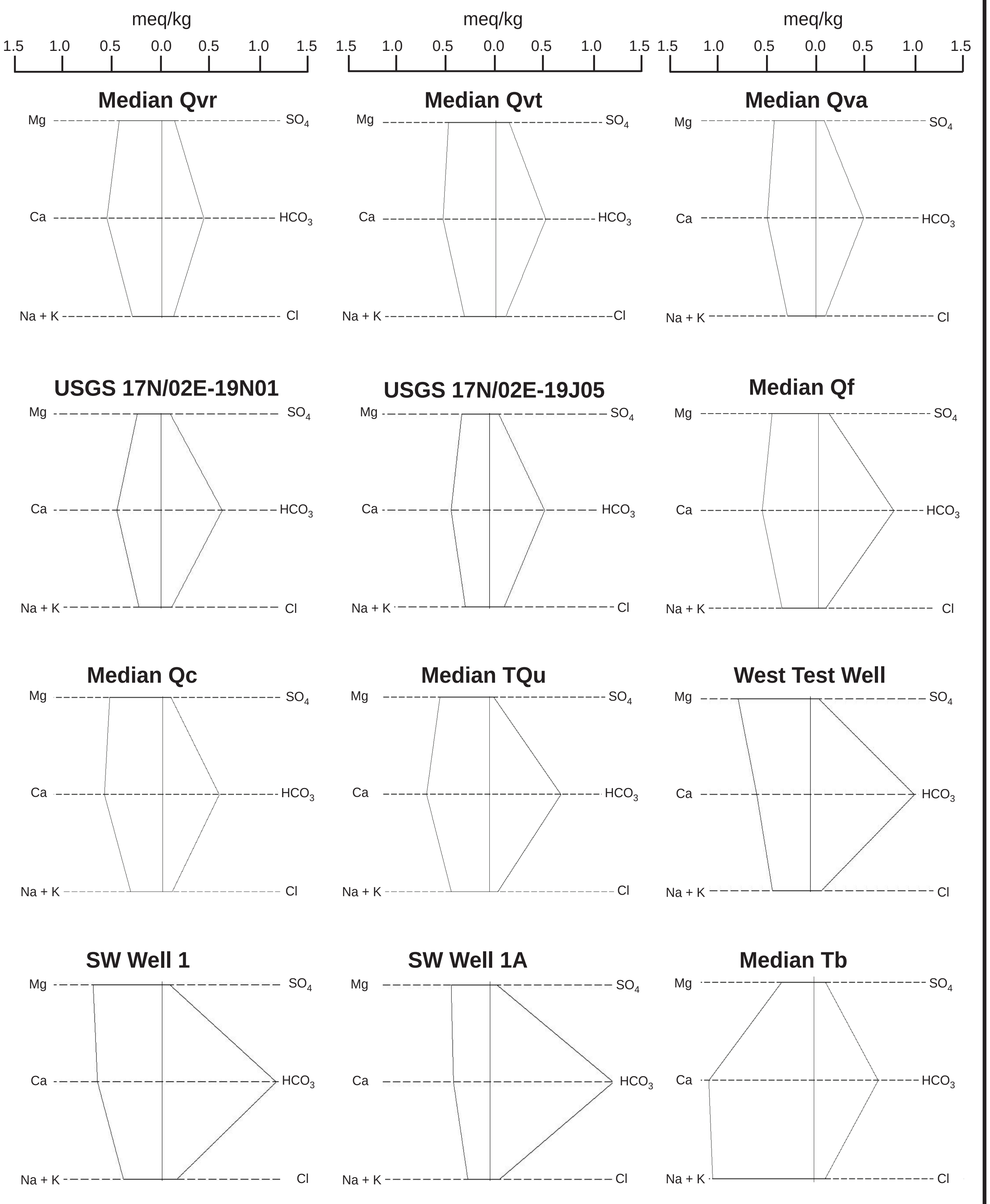



FIGURE 23
STIFF DIAGRAMS
CITY OF YELM SW WELL 1A DEVELOPMENT PROJECT