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CONSTRUCTION AND TESTING OF PRODUCTION WELL PW17-1 DURIEU, BC

REPORT TO FRASER VALLEY REGIONAL DISTRICT

Prepared by

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1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The FVRD operates the Hatzic Prairie Water System, providing a water supply to residences between the north end of Hatzic Lake and Seux Road. The current supply is from a well at the intersection of Sylvester and Seux roads. Its source is the Hatzic Prairie Aquifer. Water is pumped to a reservoir east of the Sylvester Road/Pattison Road intersection before entering the distribution system.

Water quality issues have been reported with the existing source, and expansion of the distribution system is planned. To improve water quality and flow capacity, a new supply from a different source was required.

Piteau Associates Engineering Ltd. (Piteau) was retained by the Fraser Valley Regional District (FVRD) to co-ordinate the construction and testing of a new production well identified as PW17-1. This work was conducted in accordance with our proposal dated April 6, 2017. The project is being managed by Urban Systems Ltd. (USL).

The scope of work, as outlined in the following subsection, involved constructing and testing a new source well. The testing was designed to meet the requirements set out in FLNRO guidance documents (Todd et al, 2016; Province of British Columbia, 2016) for assessing effects of well operation on neighbouring wells and surface water features. The program included stream flow monitoring and groundwater level monitoring to facilitate assessment of drawdown.

1.2 SCOPE OF WORK

Hydrogeological engineering services in relation to construction of a new well were provided by Piteau between June and September 2017. Over this period, Piteau has completed the following tasks:

- Preparation of well specifications and assistance with solicitation of bids from well drilling contractors;
- On-site meetings to determine well location, plan drill rig access and address site safety concerns;
- Co-ordination of drilling contractor activities and site visits to monitor borehole advancement, collect representative formation samples and monitor well development;
- Co-ordination of pumping test contractor activities and site visits to plan the handling of well discharge, inspect pumping test set-up and to collect water samples for analyses;
- Monitoring water levels in neighbouring wells, and discharge in Durieu Creek;
- Reviewing contractor invoices for completeness and accuracy;
- Analysing pump testing data and assessment of aquifer characteristics, water quality, and well yield; and
- Preparing the following well completion report describing the well construction and testing program and providing recommendations for well commissioning and operation.

2. BACKGROUND INFORMATION

2.1 PREVIOUS INVESTIGATIONS

Groundwater resources in the Durieu area have been assessed during previously completed water supply investigations for the District of Mission and the FVRD.

The District of Mission assessment (Piteau, 2012) included a review of the Miracle Valley Aquifer and the construction of two test wells. Aquifer pumping tests with the wells confirmed the presence of a highly permeable confined aquifer. Water sampled from TW11-1 (Well Tag No. 105719) on Burns Road was of potable quality, with concentrations of all analyzed parameters within limits recommended in the Guidelines for Canadian Drinking Water Quality.

The FVRD assessment (Piteau, 2014) involved a review of geomorphology, aquifers, land use, existing wells, and potential pollution hazards. Sites for construction of a potential new production well were recommended.

2.2 GEOGRAPHIC SETTING

The Miracle Valley, sometimes referred to as the Upper Hatzic Valley, is located on a topographic bench north of the Hatzic Valley (Figure 1). It extends from Lagace Creek at its south end to the Stave Lake reservoir at its north end, and is bounded by steep mountainous terrain on the east and west sides. Ground elevations rise abruptly north of Durieu Road from 20 to 100 m above sea level (m-asl) (Photo 1), then continue to rise gradually to 140 m-asl at Hartley Road. Continuing northward, ground elevations decline gradually to about 80 m-asl at Stave Lake.

The Valley is partially covered in forest and land use includes rural residential and low-intensity agriculture. There are two fish hatcheries at the south end of the Valley. One is located at 35745 Durieu Road, and the other at 12451 Stave Lake Road (Miracle Valley Springs). A rock quarry (Stave Lake Quarry) is located at the north end of the valley at 13361 Stave Lake Road. A BC Hydro power corridor runs southwest to northeast across the north end of the Valley.

2.3 CLIMATE

The nearest weather station is at the Mission West Abbey, located about 8 km southwest of the Valley at an elevation of 221 m-asl. Data released by Environment Canada for the interval 2007 to 2016 indicate that this station receives 1,845 mm of precipitation annually. Average monthly precipitation amounts range from 37 mm in August to 244 mm in January. Approximately 65% of the total annual precipitation falls between the months of October and March.

2.4 REGIONAL HYDROGEOLOGY AND GROUNDWATER USE

The glaciofluvial sands and gravels underlying the Fort Langley clays comprise a deep-confined aquifer known as the Miracle Valley Aquifer (the Aquifer). Its mapped extents (Kreye et al, 1998) cover about 10 km^2, although there is some uncertainty regarding the northern boundary (Figure 2).

The Aquifer is likely recharged by infiltrating surface runoff from Cascade Creek and ephemeral creeks draining the east wall of the Valley, and by slow infiltration of direct precipitation through the overlying aquitard. Shallow perched aquifers have been encountered in small pockets of sandy material within the clay, but these are considered to have limited supply potential owing to their small size and isolation from surface sources of recharge.

Numerous domestic water supply wells have been drilled into the Aquifer, and those that have been registered in the BC MOE’s water well database are shown on Figure 2. Wells of interest near the south end of the Valley include TW11-1 (Well Tag No. 105719) with an estimated yield of 360 L/s, and an unregistered and unmapped artesian well about 200 m east of the intersection of Durieu Road and Stave Lake Road that had at one time flowed at a rate of 16 L/s. Pursuant to FLNRO guidelines, information on wells within a 1 km radius around PW17-1 must be reviewed. The 1 km radius is indicated by a red circle on Figure 2, and information on wells in this area is summarized in Table I. The estimated yields of these wells are generally greater than 1.5 L/s. This suggests a productive aquifer since most wells are constructed with short screens.

The Aquifer discharges to several springs at the south end of the Valley where the topographic bench intercepts the piezometric surface. The springs are indicated by number on Figure 2 and include:

- A number of spring vents that supply water to the Miracle Springs Hatchery and neighbouring property at 12697 Stave Lake Road (Spring No. 1). These springs are commonly referred to as the Lehmann Springs and at an elevation of about 76 m-asl. The combined flow rate from the springs has been estimated to be about 135 L/s, and is sustained year-round (Piteau, 2012). Most of flow is currently licensed for domestic use, bottled water sales, and pond maintenance.
- A series of springs issuing from coarse sediments in the banks Durieu Creek near its headwaters (Spring No. 2). These have been referred to as the Gadlatis Springs, and are at an elevation of about 79 m-asl. Flow from these springs has been estimated to be on the order of 35 L/s (Piteau, 2012). Water from this spring is licensed for domestic, irrigation, and pond maintenance uses.
- Seux Brook is also reported to be sourced from springs near the top of Seux Road (Spring No. 3). Three residents on Seux Road hold licenses to divert spring water for domestic use. A small hatchery at the 35745 Durieu Road diverts flows from the Seux Brook. Flows are highest in November and decrease to about 40 L/s in August (Piteau, 2012).

Based on the above, Oru, Seux, Belcharton, and possibly Lagace Creek are interpreted to be mostly groundwater-fed, especially along their lower reaches. The toe of the topographic bench is blanketed by coarse landslide debris that will provide little resistance to groundwater discharge.

The springs described above are distinct from springs discharging from fractured bedrock at west margin of the Valley. Fractures and joint sets have been observed in the west wall, and can convey groundwater flow from west to east. One such spring is located at 12699 Stave Lake Road at an elevation of 92 m-asl (above Belcharton Creek near the Miracle Valley Trout Hatchery), and is referred to as the Conroy Spring (Spring No. 4). The other is located on the Marino Creek bed on the north side of the rock quarry above 200 m-asl (Spring No. 5).

2.5 SURFACE WATER HYDROGEOLOGY

Several watercourses drain the east wall of the Valley (Figure 2). Along the north end of the Valley they report to Cascade Creek, which in turn empties into Stave Lake, and along the middle of the Valley they report to Allan Lake via MacNab Creek, or to Lagace Creek. Some creek channels (e.g., Pattison Creek) show signs of extreme flows and channel erosion during periods of high rainfall/snowmelt (Piteau, 2012). Given the coarse nature of their bed materials, these creeks may lose significant amounts of water to the subsurface upon reaching the valley floor. In late summer, many creeks are dry, and the water level in Allan Lake drops considerably.

Lagace Creek crosses the south end of the Valley and then picks up flow from several tributaries on the west side, namely Belcharton Creek, Durieu Creek, Oru Creek, and Seux Brook. These creeks are incised in steep-sided ravines and are mostly spring-fed.

With the exception of Bouchier Creek at the south end and Marino Creek at the north end, there are no significant watercourses draining the west wall of the Valley. This wall is largely outcropping bedrock overlain by a veneer of colluvium and glacial drift. Marino Creek is sourced from spring-fed marshy areas at the foot of the rock quarry, and flows northward to Stave Lake.

A surface water divide exists at the high point in the Valley near Hartley Road. Runoff on the north side of Hartley Road flows towards Stave Lake and runoff on the south side reports to Lagace Creek. A subtle east-west surface water flow divide follows Burns Road. In this part of the Valley the ground is soggy and poorly drained, owing to fine-textured, clayey soils. Boggy conditions also exist in the low-lying areas at the north end of the Valley.

BC Hydro has indicated that that Stave Lake water levels fluctuate between 75 and 82 m-asl over the year (Piteau, 2012).

3. SUMMARY OF WELL CONSTRUCTION AND TESTING ACTIVITIES

3.1 SITE SELECTION AND SOURCE AQUIFER

Based on information provided by previous investigations (Piteau, 2012 and 2014), the Aquifer was selected as a target for its high likelihood of encountering permeable water bearing sediments and good quality groundwater. The site for PW17-1 was selected based on the following criteria:

- likelihood of encountering the Aquifer;
- sufficient wellhead elevation to preclude flowing artesian conditions;
- routing for water main and power line connections; and
- accessibility by a truck-mounted drill rig.

The location of PW17-1 is shown on Figures 1, 2, and 3.

3.2 WATER LEVEL AND STREAM DISCHARGE MONITORING

To assess drawdowns in nearby wells when PW17-1 is pumped, water levels in three wells on nearby properties were monitored using a combination of manual measurements and transducer-dataloggers. Locations of monitored wells are highlighted in yellow on Figure 2, and information about them is included in Table I.

Durieu Creek passes within 110 m of the PW17-1, and this is the nearest surface watercourse. The source for Durieu Creek is a spring situated about 200 m northeast of PW17-1. The spring, in turn, is sustained by artesian flows from the Aquifer. To assess the potential effect of pumping groundwater from PW17-1 on the Durieu Creek discharge, flows were monitored before, during, and after the aquifer pumping tests at two stations near the well. Due to the shallow and rapid flows in this reach, stage could not be reliably measured (Photo 2). Instead, stream stage was continually monitored by a transducer-datalogger deployed in a stream reach having deep water at the Durieu Road culvert. All flow and stage monitoring sites are shown on Figure 3.

3.3 CONTRACTOR ENGAGEMENT

The well construction and testing contract was awarded to Field Drilling Contractors Ltd. (Field), of Surrey, and their subcontractor, Frontier Pumps & Installations Ltd. (Frontier). Well PW17-1 was constructed between August 2 and August 14, 2017 using a DR-24 truck-mounted air rotary drilling rig (Photo 3). The work was divided into the four tasks described in the following sections below.

3.4 ADVANCEMENT OF WELL CASING AND COMPLETION OF SURFACE SEAL

A surface seal was placed and a well casing was advanced to the target well depth between August 2 and August 8, 2017. Since flowing artesian conditions exist in portions of the Aquifer, the following steps were taken to ensure flows could be controlled:

- A 406 mm (16”) nominal diameter surface casing was installed to a depth of 5.5 m-below ground level (m-bgl);
- A 254 mm (10”) diameter casing was telescoped through the 406 mm casing and then drilled and cased to 17.7 m-bgl;
- Bentonite grout was added as the 406 mm casing was withdrawn to create a 51 mm (2”) thick annular seal around the outside of the 254 mm casing; and
- A 203 mm (8”) diameter casing was telescoped through the 254 mm casing and drilled and cased to the 60.0 m depth.

Sediments encountered during drilling comprised silt to a depth of 16.8 m, followed by dense gravely sandy silt (till). Below this, another silt layer was encountered to a depth of 38.9 m, and this was underlain be water-bearing sand and gravel. This unit is part of the Aquifer.

Once in the sand and gravel aquifer, estimated well yield increased with borehole depth. Below a depth of about 53.3 m; however, the colour of the turbidity in water discharged from the borehole turned from grey to reddish brown, suggesting an increase in iron and manganese content. A water sample collected by air lifting from a depth of 60.0 m was analyzed for dissolved metals. The results indicated an elevated manganese concentration (0.107 mg/L). Accordingly, drilling was discontinued.

Based on sediment lithology, water quality, and anticipated well yield, the depth range of 47.2 to 50.3 m-bgl was selected for screen installation. The drill casing was retracted to 50.3 m, allowing the formation sediments to backfill the lower portion of the borehole.

3.5 SCREEN INSTALLATION AND WELL DEVELOPMENT

Grain size analyses were completed on samples of drill cuttings air-lifted to the surface during drilling. The results (Appendix A) were used to select the screen opening size and formation interval to be screened. A 3.05 m (10') long continuous wire-wound, 204 mm (8") pipe size diameter stainless steel well screen, consisting of two 1.5 m long sections, was selected. The opening size is 2.03 mm (0.080"). A 0.30 m (1') length of blank stainless steel riser pipe with a K-Packer seal on top was welded to the top of the screen, and a plate was welded onto the bottom. The assembled screen was lowered to the bottom of the borehole and exposed to aquifer sediments between 47.2 and 50.3 m-bgl by pulling back the 203 mm (8") casing.

The well screen was developed by surging with compressed air from the drill rig's air compressor for approximately 12 hours. At the end of development, the rate of sand entering the well had reduced to a few teaspoons per hour of surging.

A borehole log summarizing lithological observations and well construction information for PW17-1 is included with Appendix A.

3.6 AQUIFER PUMPING TESTS

Frontier Pumps & Installations Ltd. conducted aquifer pumping tests with PW17-1 using a temporarily installed submersible pump, powered by a diesel generator (Photo 4). Water levels were monitored in the pumped well, and in the three nearest known wells, to assess the magnitude of drawdown. The three observed wells are identified by Well Tag Nos. 95945, 78286, and 111867. Their locations are highlighted in yellow on Figure 3, and information pertaining to the wells is included in Table I. Water levels in all wells were monitored using a graduated electric tape and transducer-dataloggers. Pumping rates were measured using an orifice plate meter. Water was discharged in a hay field 120 m southwest of the well (Photo 5), and from there it flowed southwest toward Stave Lake Road.

A variable-rate pumping test was initiated with PW17-1 at 9:30 am on August 23. The purpose of the variable-rate test was to evaluate the performance characteristics of the well and to select a rate for the constant-rate test. The pre-pumping water level was 4.05 m below the top of the well casing (m-btoc). The well was pumped for about 60 minutes at incrementally increasing rates of between 6.3 and 12.7 L/s (100 and 201 USgpm), and water level drawdown in the well was recorded at frequent intervals. Upon cessation of pumping, the water level returned to the pre-pumping level within 10 minutes.

A constant-rate test was initiated at 3:00 pm on August 23 and continued for 25.5 hours. The initial pumping rate was 11.7 L/s (186 USgpm) but was increased to 12.7 L/s (201 USgpm) after eight minutes of pumping. This rate remained constant until the end of the test. When pumping stopped, the water level in PW17-1 the recovered to within 0.50 m (99%) of the pre-test level in nine minutes.

Summary tables of manual measurements collected during the pumping tests are included with Appendix B. Analysis and interpretation of the constant-rate aquifer pumping test data is discussed in Section 4.

Ministry of Environment-issued Well I.D. Plate No. 42943 was affixed to the well casing, and the Ministry subsequently assigned Well Tag No. 113520. UTM coordinates for the well are NAD 83 Zone 10 555037 E, 5453015N.

3.7 COLLECTION AND ANALYSIS OF GROUNDWATER SAMPLES

A sample of groundwater pumped from PW17-1 was collected a few minutes prior the end of the constant-rate test. The sample was collected in three laboratory-supplied bottles, preserved in the field as required, and submitted in a cooler to ALS Environmental’s Burnaby laboratory for analysis of basic potability (including physical parameters, anions, nutrients and metals), and total coliform and E. coli bacteria.

4. ANALYSIS AND INTERPRETATION

4.1 LITHOLOGY AND HYDROGEOLOGY

The sequence of sediments encountered at PW17-1 is comparable to lithology at TW11-1 (WTN 105719, situated 1100 m to the northeast (Piteau, 2012). This indicates that the Aquifer extends across both sites and beyond. It is confined by overlying dense till and marine silt-clay.

4.2 WELL HYDRAULICS AND AQUIFER PROPERTIES

The upper portion of Figure 5 includes a semi-logarithmic plot of drawdown measured during the variable-rate test with PW17-1. The lower portion shows pumping rate (Q) versus specific capacity (S_c), which is the rate of discharge from the well per unit drawdown. The specific capacity increased from 0.31 L/s/m at the end of the first step (Q = 6.3) to 0.36 L/s/m at the end of the second step (Q = 10.1 L/s) before decreasing to 0.35 at the end of the third and fourth steps (Q = 11.7 and 12.7 L/s, respectively). The increase in specific capacity between the first and second steps suggests that some additional improvement in development of the natural filter pack around the screen occurred during the test.

Figure 6 shows drawdown measured in PW17-1 during the constant-rate test plotted against the logarithm of time, and residual drawdown during the recovery interval, plotted against the logarithm of the time ratio[1]. The rate of drawdown reduced after about 8 minutes of pumping and drawdown increased by only 0.4 m after 24 hours.

Transmissivity (T) is defined as the rate that groundwater would flow through a vertical slice of aquifer one metre wide under a hydraulic gradient of one metre per horizontal metre. Using the Cooper-Jacob (1946) method of analysis, this was calculated as 7×10^{-3} m^2/s. Analysis of the recovery trend using the Theis (1935) method gave a T of 1×10^{-2} m^2/s. The latter is likely more representative of aquifer conditions since it is not subject to head losses resulting from well loss as the well is pumped. The step-in drawdown at eight minutes is a result of adjusting pump

[1] time ratio = t/t’ where t is time since start of test and t’ is time since pumping stopped.

controls to increase the flow rate and is considered small enough to not significantly affect our analysis.

Time-series hydrographs for water levels observed in the three nearby wells before, during, and after the aquifer pumping test are presented on Figure 4. The pump in Well 111867 was operating continuously, resulting in scatter in the water level data for this well.

Semi-logarithmic plots of the drawdown response measured in observed wells during the constant-rate test with PW17-1 are presented in Figure 7. The linear drawdown trend for Well 95945 indicates that there was no substantial infiltration from surface water features.

The recovery water level trend for TW17-2 after the pump was stopped is shown by green dots on Figure 6. The data, plotted against the time ratio on the x axis, trend toward a zero drawdown at t/t' = 1, indicating that the zone of influence did not encounter any substantial source of recharge during the test.

Transmissivity (T) values were determined from the water level trends in all observed wells during the pumping interval using the Cooper-Jacob (1946). These ranged from 1×10^{-2} m^2/s at PW17-1 to 6×10^{-2} m^2/s in Well 78286. Since they neglect the effect of vertical leakance, the Cooper-Jacob estimates are less reliable than the log-log analysis described below.

Drawdown observed in Well 95945 is plotted on a log-log scale on Figure 8 to enable estimation of T and storativity (S) using the Hantush (1964) curve matching method for a leaky confined aquifer with partial penetration. The data is plotted as 1/u versus W(u,r/B)+f, where:

$$u = \frac{r^2 \times S}{4 \times T \times t}$$

and W(u, r/B)+f is the leaky well function[2] with a correction for partial aquifer penetration. The analysis yields a transmissivity of 1×10^{-2} m^2/s and a storage co-efficient of 8×10^{-4}.

[2] r = radius, S = storativity, T = transmissivity, and t = elapsed time.

These results also indicate that the aquifer is leaky artesian type, and the measured trend best matches with the r/B = 0.2 type curve. Accordingly, the vertical hydraulic conductivity (K_v) of the aquitard overlying the Aquifer is calculated to be 4×10^{-7} m/s.

Aquifer transmissivity (T) is equivalent to the hydraulic conductivity (K) multiplied by the saturated thickness of the aquifer (b). Since it incorporates the effects of vertical leakance, aquifer parameters calculated using the Hantush-Jacob method are judged to be more representative of actual aquifer properties than those estimated from the Cooper-Jacob and Theis Recovery methods. Using a T = 9×10^{-2} m^2/s and b = 20.0 m (thickness of aquifer sediments tested in borehole), K is estimated at 4×10^{-3} m/s. This result is within the range typically reported for clean sand and gravel, and is in the same order of magnitude as the range of K values estimated from the grain size analyses using the Hazen (1911) method (8×10^{-4} to 1×10^{-3} m/s). Estimated hydraulic parameters are summarized below.

Well	Distance from PW17-1 (m)	Analysis	Estimated Transmissivity (m^2/s)	Estimated Storativity S
PW17-1 Pumping	--	Cooper-Jacob (1946)	1×10^{-2}	--
PW17-1 Recovery	--	Theis (1935)	7×10^{-3}	--
PW17-1	--	Hazen (1911)	1×10^{-3}	--
Well 95945	146	Cooper-Jacob (1946)	2×10^{-2}	--
		Hantush (1964)	1×10^{-2}	8×10^{-4}
Well 78286	264	Cooper-Jacob (1946)	6×10^{-2}	--
Well 111867	270	Cooper-Jacob (1946)	1×10^{-2}	--

4.3 DISTANCE – DRAWDOWN ANALYSIS

Pumping of PW17-1 resulted in drawdowns of approximately 0.38, 0.03, and 0.49 m in Well 95945, Well 78286, and Well 111867, respectively (Figure 4). These drawdowns were superimposed on a larger magnitude drawdown event that occurred between August 12 and 29. The cause of this relatively large drawdown was likely caused by continuous pumping of a nearby high-capacity well.

Figure 7 includes projection of drawdown trends in the observation wells to 100 days. Since the tested pumping rate in PW17-1 (12.7 L/s) was greater than the proposed production rate (9.0 L/s), the projected amounts are greater than the expected amounts.

The distance-drawdown relationships are graphed on Figure 9. These were used to estimate the amount of drawdown that can be expected in the Aquifer beneath Durieu Creek, and yielded the following results:

Well	Distance from PW17-1 (m)	Measured drawdown when PW17-1 pumped for 24 hrs at 12.7 L/s	Estimated drawdown when PW17-1 pumped for 100 days at 12.7 L/s (m)	Estimated drawdown when PW17-1 pumped for 100 days at 9.0 L/s (m)
PW17-1	--	36.36	37.21	25.8
Durieu Creek	108	0.66	0.88	0.47
Well95945	146	0.38	0.55	0.27
Well 78286	264	0.03	0.12	0.02
Well 111867	270	0.49	0.69	0.35

Although Well 111867 is located further away from PW17-1, it experienced greater drawdown than at Well 95945 and Well 78286. Well 111867 and PW17-1 draw water from the same layers within the Aquifer, and Wells 95945 and 78286 draw from shallower depths. The damped response in these wells likely reflects the presence of layering within the Aquifer. A silty zone at the intervening elevation was encountered in PW17-1.

4.4 GROUNDWATER FLOW DIRECTION

A hydrostratigraphic profile along the north-south section line A-A’ is presented on Figure 10. At about 92 m-asl, the piezometric surface elevation is highest in the middle portion of the Valley (at Hartley Road; see Figure 2). South of TW11-1 (south end of Burns Road), the piezometric surface elevation drops rapidly as a result of spring discharge to Durieu and Oru creeks. North of Hartley Road, piezometric levels slope gradually toward Stave Lake (max. elevation 82 m-asl).

Our interpretation based on these findings is that a north-south groundwater flow divide is situated in the mid-portion of the Valley, roughly in parallel with the surface water divide. Groundwater flow north of the divide discharges to Stave Lake, Cascade Creek and Marino Creek, and groundwater flow south of the divide discharges primarily to Belcharton, Durieu and Oru creeks and Seux Brook. Inferred groundwater flow directions are indicated on Figure 2.

Figure 11 presents the hydrostratigraphic profile along east-west section line B-B. The piezometric surface elevation rises from west to east across the Valley, indicating a westward component of groundwater flow. The locations of major springs along the west and south margins of the Aquifer (at the end of the groundwater flow path) are consistent with this observation. The east walls of the Valley are blanketed with coarse alluvial deposits that act as effective drains for rainfall runoff and snowmelt. This surface water flows to Lagace Creek, which has downcut a steeply incised ravine downstream of Allan Lake. The section indicates that the Lagace Creek invert elevation is below the base of the confining clay unit and is in direct contact with Aquifer sediments. Therefore, there is likely significant infiltration of surface water into the Aquifer, thus elevating piezometric water levels on this side of the Valley.

4.5 AQUIFER RECHARGE

Most recharge to the Aquifer is inferred to originate from Lagace Creek and its tributaries on the east side of the Valley, and possibly from runoff along the bedrock walls on the west side of the Valley. This interpretation is based on the following rationale:

- Temporal changes in groundwater and surface water levels between December 2011 and February 2012 (Piteau, 2012). Precipitation amounts were compared to flow changes in Durieu and Oru creeks and water levels in two test wells (TW11-1 and TW12-1).

  As would be expected, water levels in Durieu and Oru creeks responded rapidly to heavy precipitation events. A similar response of lesser magnitude was detected in Aquifer water levels at TW11-1. Since the Aquifer is overlain by a thick sequence of clay that would delay groundwater response to recharge events, the response observed is indicative of the Aquifer being recharged directly from surface water. Another possible line of evidence is a steadily rising groundwater levels observed at TW11-1 between the end of December 2011, and mid-January 2012. This was interpreted as a result of gradually increasing water levels and in Allan Lake and overflows to Lagace Creek, since Allan Lake effectively acts as a storage basin for mountain runoff.

- Rudimentary water balance calculations: Average annual recharge by direct infiltration is estimated to be on the order of 140 L/s, assuming an average annual precipitation of 1,800 mm and infiltration rate of 30% across the footprint of the portion of the Aquifer south of the groundwater flow divide. This amount is much smaller than the estimated rate of groundwater discharge to Creeks draining the south end of the Aquifer (on the order of 450 L/s, annual average). The difference can only be made up by infiltrating surface runoff along the Valley margins. For example, if 40% of the average annual precipitation falling within the Lagace and Belcharton creek catchments outside the Aquifer footprint infiltrates the Aquifer, this would constitute another 280 L/s of recharge.

4.6 POTENTIAL CLIMATE CHANGE IMPACTS

Climate change is expected to impact groundwater resources across BC, owing to changes in both temperature and precipitation trends. Since the 1950's, BC's climate has warmed significantly and precipitation has increased slightly, although there are significant variations from region to region (Walker and Sidneysmith, 2008). Climate change models predict that the Coastal region of BC will experience a reduced snowpack, with more precipitation falling as rain during the winter months. Higher rainfall will result more frequent and higher volume runoff events. Warming temperatures will cause the spring freshet to occur earlier in the year, which in turn could extend the duration of the summer low-flow period, resulting in reduced streamflows in the late summer/early fall.

Shifts in the timing and amount of precipitation and streamflows will affect the amount of water recharging the Aquifer. A major proportion of this recharge is expected to be from exfiltration of surface water from Lagace and other creeks on the east side of the Valley. This rate of "leakage" is expected to vary with the wetted surface area of the creek channel. Aquifer water levels are expected to be highest during periods of high surface flow and lowest during periods of low surface flow, with some time lag. Higher streamflows during the winter months may raise groundwater levels more rapidly, but decreased snow accumulations on the local mountains may significantly shorten this recharge interval. Groundwater levels during the summer months will largely follow the rate of depletion of this stored water due to pumping withdrawals and groundwater discharge to creeks at the south end of the Aquifer (Belcharton, Durieu, Oru, Seux). If this recession period is lengthened, aquifer water levels may reach lower than average levels in the late summer/early fall, thereby making less water available for withdrawal and fisheries habitat.

Future shifts in the incidence of extreme climate events are more difficult to predict, and will vary season to season and region to region across BC. Extreme droughts and extreme high rainfall/runoff events are expected to be buffered somewhat by the capacity of the Aquifer to store water, and affect groundwater flow dynamics in the short term.

4.7 WELL DESIGN YIELD

Our analysis of the pumping test data indicate a safe yield for PW17-1 of 9.0 L/s (143 USgpm). This was determined using the following analysis, summarized in Table II.

- A minimum static water level was estimated by subtracting 1.0 m (seasonal) and 1.0 m (projected 20-year decline in static water level) from the static water level measured at the start of the constant rate pumping test on August 23, 2017.
- The available drawdown was calculated by subtracting the minimum static water level from the estimated minimum pumping level and subtracting a 30% factor of safety from this value. The maximum design drawdown was then calculated by subtracting 0.5 m of drawdown interference from the available drawdown. This is a conservative approach since the aquifer test was conducted under the influence of drawdown from another operating well.
- The drawdown trend in PW17-1 over the 24-hour pumping test was extrapolated to 100 days to give a projected drawdown of 37.2 m and projected specific capacity of 0.3 L/s/m. Multiplying this specific capacity by the maximum design drawdown of 26.4 m gives an estimated safe pumping rate of 9.0 L/s (143 USgpm).

- The average entrance velocity of water through the well screen is a consideration when rating a well. It is standard practice to limit this velocity to 0.03 m/s (0.1 ft/s) to minimize head losses across the screen and long-term well maintenance requirements (Driscoll, 1986). Applying this maximum entrance velocity gives a maximum yield of 26.2 L/s (416 USgpm) for PW17-1. As this exceeds the estimated safe pumping rate, screen capacity is not a limitation.

The estimated safe yield for PW17-1 is 9.0 L/s (143 USgpm). When PW17-1 is pumped at 9.0 L/s, maximum drawdowns of 0.27, 0.02, and 0.35 m can be expected at Well 95945, Well 78286, and Well 111867, respectively. These amounts are relatively small, and are unlikely to interfere with normal well operations.

4.8 PW17-1 WATER QUALITY

Laboratory analytical reports for water samples, collected from PW17-1 at the end of the pumping test, are provided in Appendix C and are summarized in Table III. In general, the water has low mineralization (TDS 85 mg/L) and is soft (hardness 52.6 mg/L).

Concentrations of all constituents tested were below Maximum Allowable Concentrations (MACs) and Aesthetic Objectives (AOs) in the Guidelines for Canadian Drinking Water Quality (GCDWQ; Health Canada, 2017).

4.9 GROUNDWATER AT RISK OF CONTAINING PATHOGENS

The potential for groundwater from PW17-1 to be at risk of containing pathogens has been assessed using the BC Ministry of Health's "Guidance Document for Determining Ground Water at Risk of Containing Pathogens (GARP)" (BC Ministry of Health, 2015). These guidelines specify that water supply system wells should be considered potentially at risk of containing pathogens if they have:

a) An intake depth less than 15 m below ground level that is located within the natural boundary of surface water or a flood prone area;
b) An intake depth between the high water mark and surface water bottom;

c) If information is not available on surface water depth, 15 m below the normal water level, and located within; and

d) Less than 150 m outside the natural boundary of any surface water.

The guidelines include a screening tool to assist in assessing GARP hazards for a well. A completed screening form for PW17-1 is included in Appendix D. Since none of the conditions are met, in accordance with these criteria, the potential for groundwater from PW17-1 to yield groundwater that is at risk of containing pathogens is low.

4.10 POTENTIAL SURFACE WATER EFFECTS

Minimizing potential effects on surface water streams were considered while selecting a site for PW17-1. Although the well is situated 108 m west of Durieu Creek, the confining aquitard appears to be relatively thick in this area, providing good separation between the creek and the Aquifer. The potential for pumping from PW17-1 to affect stream flow in Durieu Creek was assessed as follows.

As depicted on the cross sections on Figures 10 and 11, Durieu Creek is perched on a 32 m thick clay-silt aquitard that separates it the creek from the underlying aquifer. The invert elevation of the nearest point on Durieu Creek to PW17-1 is about 53 m-asl.

Based on the distance-drawdown relationships (Figure 9), the estimated maximum drawdown in the Aquifer beneath Durieu Creek resulting from operation of PW17-1 at 9.0 L/s will be 0.47 m. Under these conditions, the average upward hydraulic gradient would drop from 0.28 to 0.27. The distance-drawdown relationships also suggest that the length of the Durieu Creek channel crossing the area of influence (defined as zone with drawdown >0.1m per Figure 9) when PW17-1 operates is about 360 m.

The resulting change in upward seepage from aquifer to stream can be estimated using Darcy's equation for flow through a permeable medium:

$$Q = K_v \times i \times A$$

where:

Q = flow rate (m^3/s).

K_v = vertical hydraulic conductivity of aquitard (m/s).

i = hydraulic gradient (dimensionless).

A = cross sectional area (m^2).

Using the effective vertical hydraulic conductivity for the aquitard material (K_v) estimated from the aquifer pump test results (4×10^{-7} m/s), and allowing for a 2 m average wetted channel width, the decrease in upward seepage to the stream bed that would result from operation of PW17-1 is 0.003 L/s (0.04 USgpm).

The lowest flow measured in Durieu Creek during the August 2017 monitoring program was 60 L/s. A reduction of 0.003 L/s would amount to 0.005% of the stream flow. This analysis indicates that the estimated reduction in stream flow that could be attributable to operation of PW17-1 would be immeasurable.

Results of stream flow monitoring in Durieu Creek during the PW17-1 pumping test are shown on Figure 4. Flows measured on August 15 were about twice as great as those measured on August 22. The decline is attributed to recession following an August 11 precipitation event. The manual stream flow measurements, interpreted together with the stage height at Durieu Road, are not indicative of a change in flow that is attributable to pumping from PW17-1. This is consistent with the foregoing estimate that indicates that the change in flow will be immeasurable.

Potential effects of pumping from PW17-1 on other streams would only be expected if the drawdown area extends to the aquifer beneath the creeks. For a drawdown of less than 0.1 m, effects are unlikely to be noticeable. Based on the distance-drawdown relationship for pumping at 9.0 L/s (green trace on Figure 9), the 0.1 m drawdown is reached at a radius of 220 m from PW17-1. This radius is shown on Figure 3 as a green circle. After Durieu Creek, the streams in closest proximity to PW17-1 are Belcharton Creek (350 m west) and Oru Creek (410 m east). As these distances far exceed the 220 m drawdown radius around PW17-1, pumping from PW17-1 is not expected to have an effect on flows in these streams.

5. RECOMMENDATIONS FOR WELL COMMISSIONING AND OPERATION

5.1 SANITARY SEAL

As indicated on the borehole log, a 5.5 m deep surface seal was created during construction of PW17-1. During installation of a pitless adapter, steps should be taken to ensure that this seal is not compromised. This can be achieved by excavating material from 2 to 3 m around the wellhead during installation and backfilling the excavation with sealant (soil bentonite admix fill).

The ground surface at the wellhead should be built up slightly and sloped away from the well casing to minimize ponding of surface water around the casing. The top of the outermost casing should extend at least 0.3 m above the final ground level.

The annulus between the 254 mm and 203 mm casings is currently open at the bottom, with a welded annular steel plate at the top. The weight of the 203 mm casing is supported by the outer 254 mm casing.

5.2 PUMP INSTALLATION AND WELL COMMISSIONING

A pump capable of supplying a flow of up to 9.0 L/s can be installed in PW17-1. A variable-frequency drive is recommended so the flow rate can be correlated with demand to avoid frequent cycling. As specified in Line "C" of Table II, the recommended depth below ground for a submersible pump intake in PW17-1 is 45.0 m below ground level, which is 1.6 m above the top of the packer. Since the ground level and well casings will be altered during well commissioning works, a datum should be reestablished by sounding the well bottom. The recommended pump intake elevation is 5.3 m higher than the well bottom.

The well should be chlorinated soon after a permanent pump is installed and before the well is put into service. Following chlorination, a water sample should be collected for bacteriological analysis to confirm total disinfection.

When PW17-1 is initially operated, there may be a minor component of sediment in the discharge water. It is therefore suggested that the well be discharged to waste for a few minutes until the water clears up, prior to connection to the distribution system.

As PW17-1 will require periodic maintenance, it is desirable to retain access to enable a service vehicle or drill rig to work over the well. We also recommend that a minimum 25 mm (1") I.D. sounding tube be installed in the well to facilitate the manual measurement of water levels using an electrical water level sounder. The model of pitless unit selected for PW17-1 should make allowance for the installation of a sounding tube.

5.3 WELL OPERATION

Following start-up, PW17-1 should be operated on a regular basis, as a seldom used well may lose efficiency more rapidly. To protect the integrity of the natural sand pack surrounding the well screen, operation of the well should be correlated to system demand so that the well pump is operated with as few stops and starts as possible.

The well should not be:

- Back-washed, unless during development: a simple check valve will prevent rapid back-washing.
- Flushed: If water is allowed to cascade in the well and the well becomes aerated, the well can become clogged with slime from iron bacteria within a few months. Thus, the start-up and the shut-down water must not be allowed to enter the well.
- Raw-Hided: If the pump is allowed to start and stop frequently, the well is "raw-hided." This may destabilize aquifer materials, resulting in increased sediment production and potentially reduced well efficiency. As indicated above, operation of the well should be correlated with system demand. The pump should operate for at least one hour after start-up and should be idle for at least one hour after shutdown.
- Vibrated: If possible, the pump mounting should be separated from the well casing. This will insulate the casing and screen from pump motor vibrations. If vibrations become severe, destabilization of the materials around the well screen could occur.

It is our understanding that, during normal operation, water supplied by PW17-1 will undergo disinfection using a hypochlorite solution.

5.4 WATER LEVEL MONITORING

PW17-1 should be instrumented with a pressure transducer to provide a record of water levels and temperature under pumping and non-pumping conditions. A flow meter should be used to track the amount of water pumped. These instruments should be connected to dataloggers, and the data record should be archived permanently to allow retrospective analysis as required.

The efficiency and operational lifespan of the wells will be enhanced by a proactive maintenance program. This program should include downhole imaging, pumping tests and rehabilitation when well efficiency has dropped by 10-15%.

6. SUMMARY AND RECOMMENDATIONS

Piteau was retained by the FVRD to co-ordinate the design, construction and testing of a new production well, PW17-1, in Durieu. Construction work was carried out between August 2 and August 14, 2017. The formation conditions encountered, key aspects of the well design, the performance of the well during aquifer testing, and estimated effects on streams and other users are summarized below:

1. PW17-1 is screened within the Miracle Valley Aquifer. The aquifer sediments at PW17-1 consist of a layer of sand and gravel more than 12.1 m thick, confined beneath 32 m of till and marine slit/clay.
2. The screen assembly for PW17-1 consists of a 3.1 m length of 204 mm diameter pipe size stainless steel screen set between depths of 47.2 and 50.3 m below ground level. It is surrounded by a natural filter pack and has a 0.6 m long solid riser pipe on top. The well is identified by Well I.D. Plate No. 42943, and registered as Well Tag No. 113520 in the MOE wells database.
3. The well was tested at a rate of 12.7 L/s (201 USgpm) for 25.6 hours. Based on the results of this test, we recommend a design pumping rate of 9.0 L/s (143 USgpm). This rating assumes that a pump will be set above the top of the riser pipe.
4. When PW17-1 is operated at 9.0 L/s, anticipated drawdown at the nearest wells range from 0.2 to 0.4 m. These drawdowns are less than those resulting from other wells in the area, and are not expected to affect the operation of these wells.
5. Durieu Creek is situated 108 m east of PW17-1. Our analysis indicates that pumping of PW17-1 at 9.0 L/s will not cause any measurable change in stream discharge.
6. A groundwater sample collected from PW17-1 at the end of the pumping test met all applicable GCDWQ guidelines. The risk of water pumped from PW17-1 being Groundwater at Risk of containing Pathogens (GARP) has been assessed as low.
7. We recommend that a water level sensor be installed in PW17-1 that can provide regular water level measurements to a datalogger. This information should be permanently archived, as it can be used together with recorded instantaneous pumping rates, to monitor well efficiency over time, and seasonal and year-over-year trends in aquifer water levels.

7. LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of Urban Systems Ltd. and the Fraser Valley Regional District. Any use, interpretation, or reliance on this information by any third party is at the sole risk of that party and Piteau accepts no liability for such unauthorized use.

Respectfully submitted,

PITEAU ASSOCIATES ENGINEERING LTD.

Original Signed

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Senior Hydrogeologist

Original Signed

David J. Tiplady, P.Eng.
Principal Hydrogeologist
Vice President - Groundwater

Att.

8. REFERENCES

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TABLES

TABLE I

WELL INFORMATION

Well Tag No.	Well ID Plate No.	UTM Easting	UTM Northing	Owner	Address	Well Depth (m)	Well Diameter (m)	Depth to top of screen (m-bg)	Depth to bottom of screen (m-bg)	Depth to water (m-below datum)	Driller's Yield Estimate (L/s)	Use	Comment
1110		554938	5452370	Kohozza	Stave Lake Rd.	3.0	0.91			1.8		Private Domestic	
5524		554673	5453373	Bronza		4.9						Unknown Well Use	dry hole
25896		555390	5452080	Nick Koster	35584 Durieu Rd.	6.1	0.91			4.9		Water Supply System	
29229		555535	5452304	Lawrence Stanezyk	35631 Durieru Rd.	52.4	0.15				0.3	Private Domestic	35 slot screen
53757		556191	5452960	Mike Olynyk	Durieu off Sylvester Rd.	31.1	0.15				3.5	Private Domestic	
56492		554876	5453223	Vince Manuck	12530 Stave Lake Rd.		0.15				2.8	Private Domestic	
60484		555421	5452184	Cedar Acres Trailer Park	35584 Durieu Rd.	64.0	0.02				2.1	Private Domestic	
74040		554767	5453653	Parkinson DH	12723 Durieu Rd.	73.5	0.15				1.4	Private Domestic	
78286		554825	5453145	Hugh Davidson	12462 Stave Lake Rd.		0.15	22.3	23.5	11.0	2.1		Obs well for PW17-1 test
92236	10400	554942	5453886	Johnstone	12852 Stave Lake Rd.	53.6		51.9	53.0		3.5	Private Domestic	
92258	15080	555722	5452983	Lilly	12371 Seux Rd.	35.1		33.9	35.1		1.4	Private Domestic	
92333	15065	554805	5453460	Specialty Signs	12628 Stave Lake Rd.	47.5		46.1	47.2		2.8	Private Domestic	
93366		555587	5452199	Usselman	11964 Seux Rd.	12.2						Private Domestic	
94140	21875	554988	5453393	Menic	12556 Stave Lake Rd.	47.5		46.3	47.5	22.9	3.5	Private Domestic	
95945	26447	554896	5453073	Gailitis	12400 Stave Lake Rd.	41.5		40.0	40.2	15.2	5.5	Private Domestic	Obs well for PW17-1 test
101228		555725	5453163	Yard	12403 Seux Rd.	36.3				20.4	3.5		80 slot screen
101253		555689	5453007	Rankal	12391 Seux Rd.	11.4				5.5	0.7		
111867	41522	554772	5453010	Upcountry Lease Holdings	12395 Stave Lake Rd.	60.4	0.20	51.8	55.5	flowing	13.8	Water Supply System	Flowing 0.001 gpm; Obs well for PW17-1 test

Note: m-bg means metres below ground

TABLE II
YIELD CALCULATIONS AND RECOMMENDED PUMP SETTING FOR PW17-1

	PARAMETER	UNIT	PW17-1	Check
A1	Static water level on August 23, 2017	m-BGL	3.6	
A2	Correction for seasonal water level variation	m	1.0	
A3	Correction for year-over-year water level variation (next 20 years)	m	1.0	
A4	Minimum static water level = *A1* + *A2* + *A3*	m-BGL	5.6	
B	Depth to top of packer	m-BGL	46.6	
C	Recommended depth to pump intake	m-BGL	45.0	
D	Estimated lowest pumping level = *C* - 1.0 m	m-BGL	44.0	
E	Available drawdown = *D* - *A4*	m	38.4	
F	Safety Factor (SF)	%	30	
G	Allowable drawdown = *E* x (100-*F*)/100	m	26.9	
H	Allowance for interwell drawdown interference from other wells	m	0.50	
I	Maximum design drawdown = *G* - *H*	m	26.4	
J	Test pumping rate	L/s	12.7	
		USgpm	201	
K	Projected drawdown after 100 days pumping at rate specified in (*J*)	m	37.2	
L	Projected specific capacity at 100 days = *J* / *K*	L/s/m	0.3	
M	Estimated 100 day safe pumping rate = *I* * *L*	L/s	9.0	
		USgpm	143	
N1	Screen Length, 2.03 mm (0.080") slot	m	3.10	
N2	Screen Open Area	m^2/m	0.279	
N3	Maximum Screen Entrance Velocity	m/s	0.03	
N4	**Check:** Nominal Screen Transmitting Capacity = *N1**N2**N3* *1000; should be greater than *M*	L/s	26.2	ok
		USgpm	416	
O	Recommended design pumping rate	L/s	**9.0**	
		USgpm	**143**	
P	Calculated depth to pumping level after 100 days continuous pumping at design rate = *A4* + *O* / *L*	m-BGL	32.0	ok
Q	**Check**: Minimum pump intake submergence after 100 days at design rate = *C* - *P* - *H*; should be > 1.0m	m	12.5	ok
R	**Check**: % of maximum design drawdown used after 100 days at design rate = (*P* - *A4*) / *I* ; should be ≤100%	%	100%	ok

H:\Project\3793\23-08-2017 Pumping Test\[Table II SafeYieldCalc.xlsx]PW17-1

Notes:

m-BGL = metres below ground level

F: For a 30% Factor of Safety, allowable drawdown = 70% of available drawdown.

TABLE III
SUMMARY OF WATER QUALITY ANALYSES RESULTS
PW17-1, DURIEU

	Units	PW17-1	Canadian Drinking Water Quality Guideline[1]	
Date Sample Collected →		24-Aug-17	MAC	AO/OG
Physical Tests				
Hardness (as CaCO3)	mg/L	52.6	-	-
Colour, True	CU	<5.0	-	15
pH	pH Units	7.79	-	6.5-8.5
Total Dissolved Solids	mg/L	85	-	500
Electrical Conductivity	µS/cm	111	-	-
Turbidity	NTU	0.15	1.0	5.0
Dissolved Anions and Nutrients				
Alkalinity-Total (as$CaCO_{3)}$	mg/L	48.2	-	-
Chloride (Cl)	mg/L	1.23	-	250
Fluoride (F)	mg/L	<0.020	1.5	-
Sulphate (SO_4)	mg/L	8.33	-	500
Nitrate (as N)	mg/L	0.239	10	-
Nitrite (as N)	mg/L	<0.0010	1.0	-
Bacteriological Tests				
Coliform Bacteria - Total	MPN/100mL	<1	<1	-
E. coli	MPN/100mL	<1	<1	-
Total Metals				
Aluminum (Al)-Total	mg/L	<0.010	-	0.1
Antimony (Sb)-Total	mg/L	<0.00050	0.006	-
Arsenic (As)-Total	mg/L	0.00167	0.010	-
Barium (Ba)-Total	mg/L	<0.020	1.0	-
Boron (B)-Total	mg/L	<0.10	5	-
Cadmium (Cd)-Total	mg/L	<0.00020	0.005	-
Calcium (Ca)-Total	mg/L	16.3	-	-
Chromium (Cr)-Total	mg/L	<0.0020	0.05	-
Copper (Cu)-Total	mg/L	<0.0010	-	1.0
Iron (Fe)-Total	mg/L	0.040	-	0.3
Lead (Pb)-Total	mg/L	<0.00050	0.010	-
Magnesium (Mg)-Total	mg/L	2.88	-	-
Manganese (Mn)-Total	mg/L	0.0057	- †	0.05 †
Mercury (Hg)-Total	mg/L	<0.00020	0.001	-
Potassium (K)-Total	mg/L	1.09	-	-
Selenium (Se)-Total	mg/L	<0.0010	0.05	-
Sodium (Na)-Total	mg/L	2.8	-	200
Uranium (U)-Total	mg/L	<0.00010	0.02	-
Zinc (Zn)-Total	mg/L	<0.050	-	5.0

H:\Project\3793\Water Quality\[Tab III WQ Summary.xlsx]Water Qualilty

Notes:

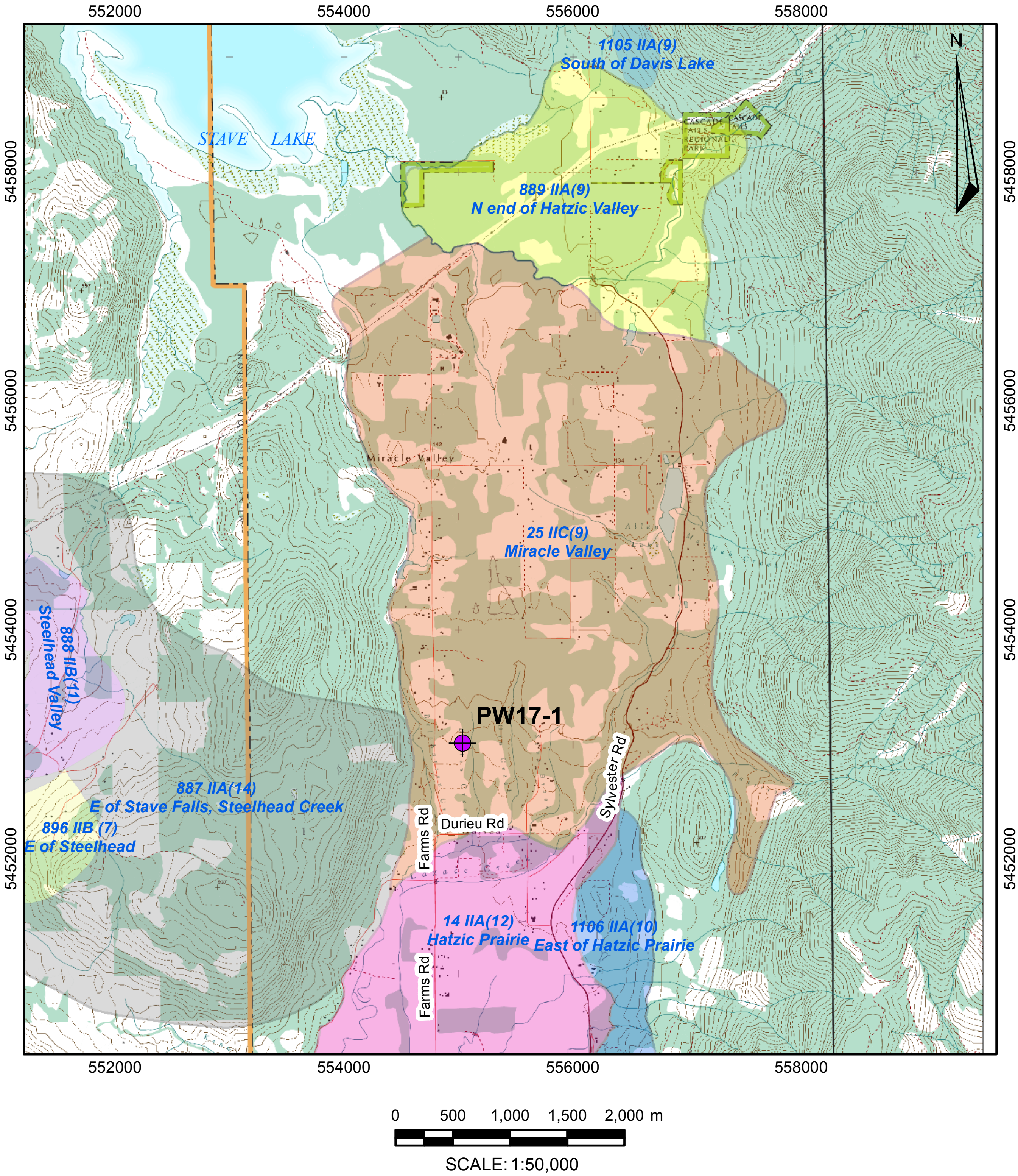
1. Guidelines for Canadian Drinking Water Quality (GCDWQ), Health Canada, February 2017.

Abbreviations: MAC = Maximum Allowable Concentration
AO = Aesthetic Objective
OG = Operating Guideline

† Health Canada is reviewing the guideline for Manganese. A proposed MAC of 0.1 mg/L, and proposed AO of 0.02 mg/L are under review.

FIGURES

H:\Project\3793\ArcGis\3793 Aquifers.mxd



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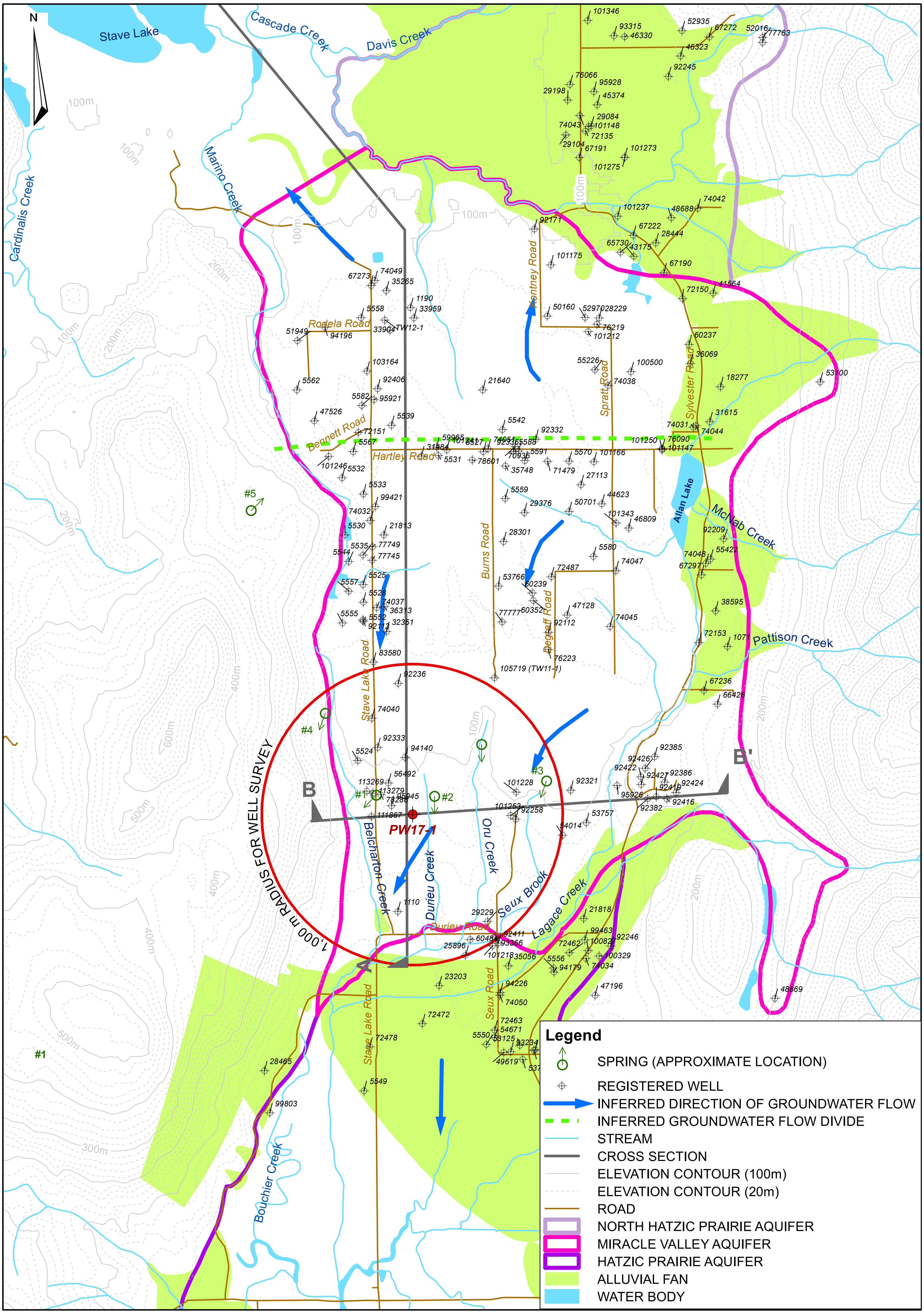
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

LOCATION OF MAPPED AQUIFERS AND PW17-1

BY: AB	DATE: OCT 17
APPROVED: DJT	FIG: 1

H:\Project\3793\ArcGis\Area Plan With Work Details.mxd



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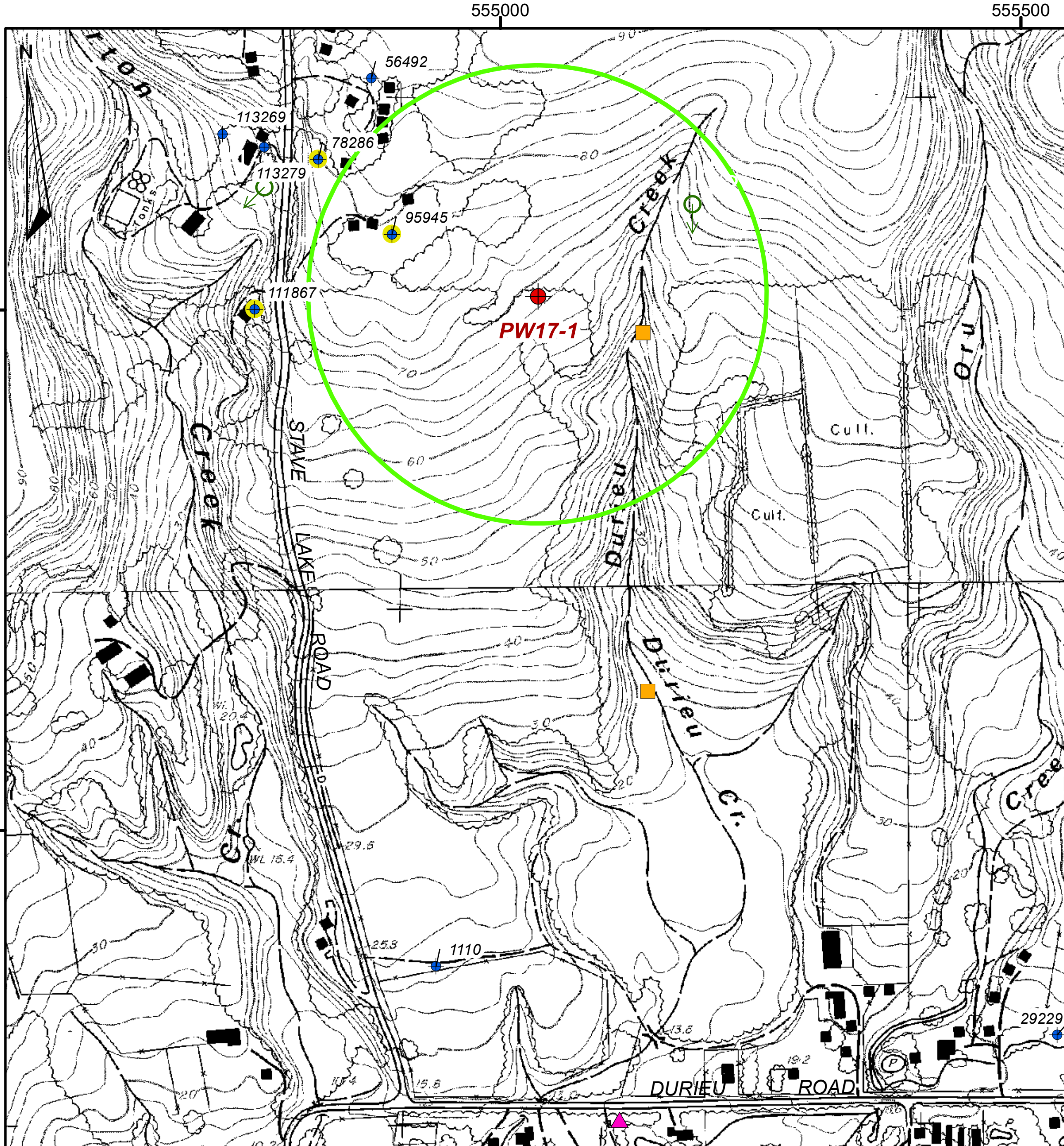
0 250 500 750 1,000 m

SCALE: 1:25,000

AREA HYDROGEOLOGY PLAN

BY:	DATE:
MLS/AB	SEP 17
APPROVED:	FIG:
DJT	2



SCALE: 1:6,000

0 100 200 300 400 m

LEGEND

- STREAM FLOW MONITORING STATION
- STREAM STAGE MONITORING STATION
- SPRING (APPROXIMATE LOCATION)
- REGISTERED WELL
  Yellow highlighting indicates water levels monitored during PW17-1 pumping test
- ESTIMATED EXTENT OF INFLUENCE

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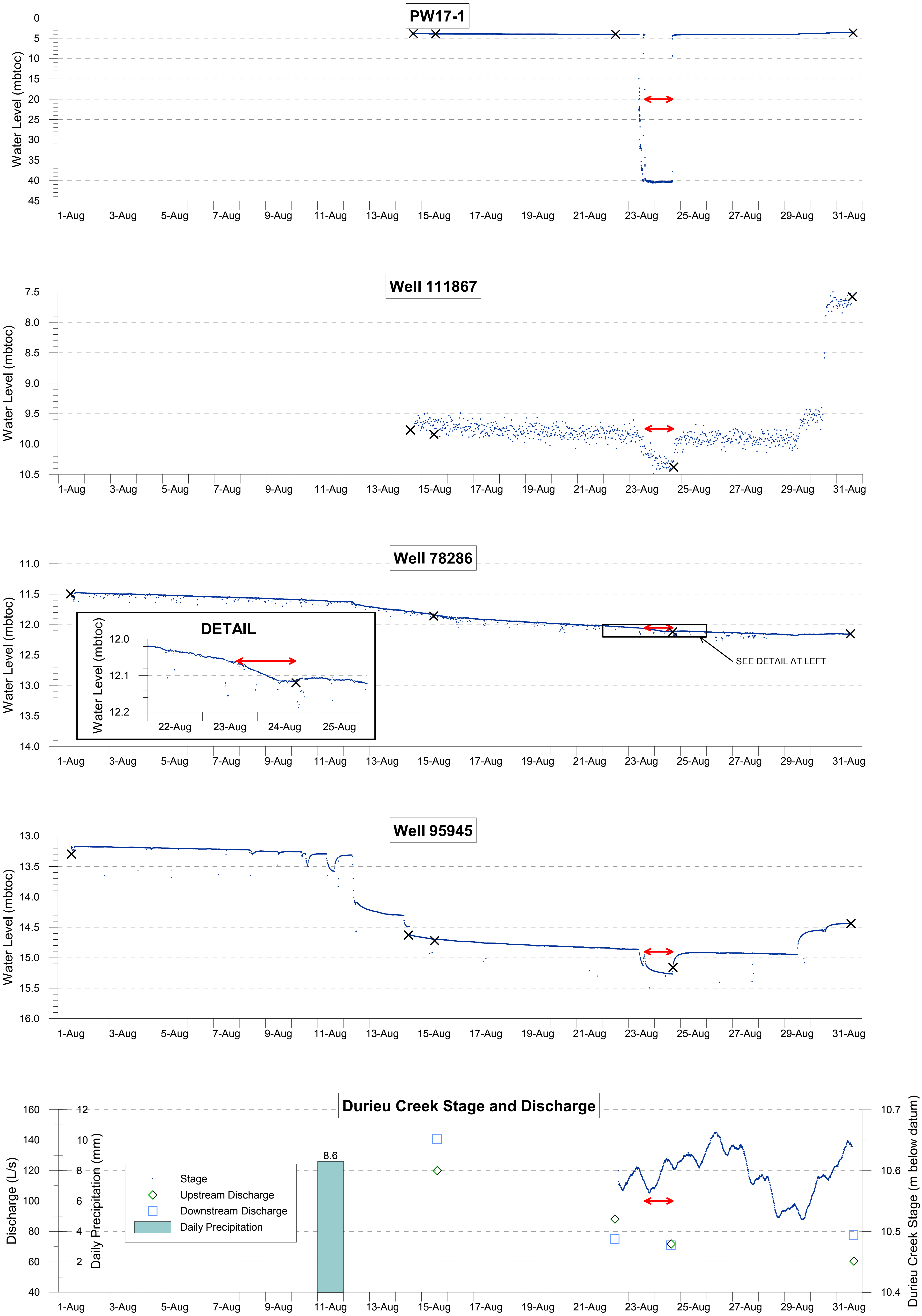
SITE PLAN

BY:	DATE:
AB	OCT 17
APPROVED:	FIG:
DJT	3

H:\Project\3793\Loggers\Loggers.grf



Legend

↔ Duration of Constant Rate Test with PW17-1

× Manual Measurement

NOTE: Precipitation data are from Environment Canada Mission West Abbey Station.

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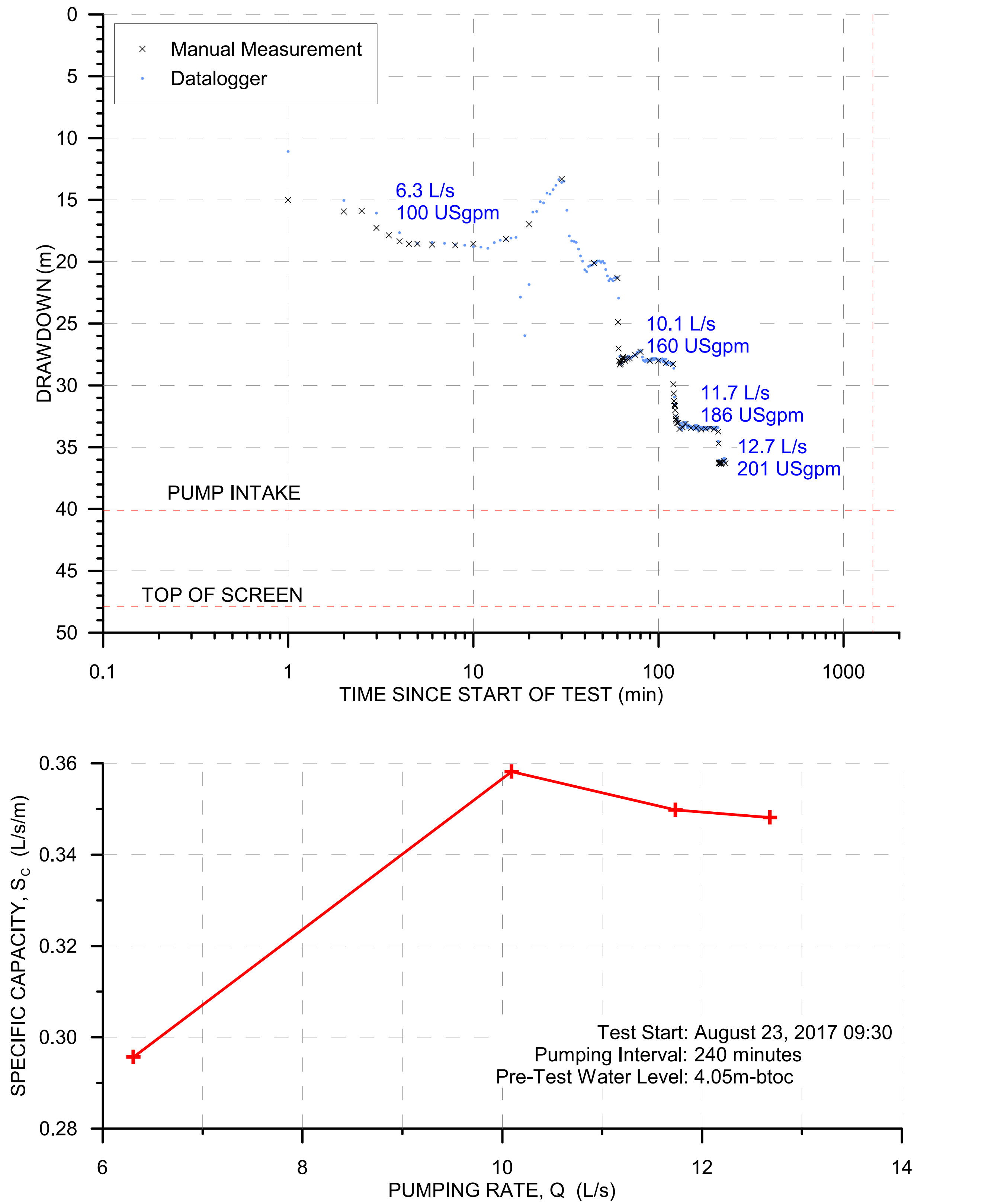
HYDROGRAPHS AND STREAM DISCHARGES

BY:	DATE:
EJ/AB	SEP 17
APPROVED: DJT	FIG: 4

H:\Project\3793\23-08-2017 Pumping Test\Test Data\2017-08-23_EJ_PW17-1 VRT.grf



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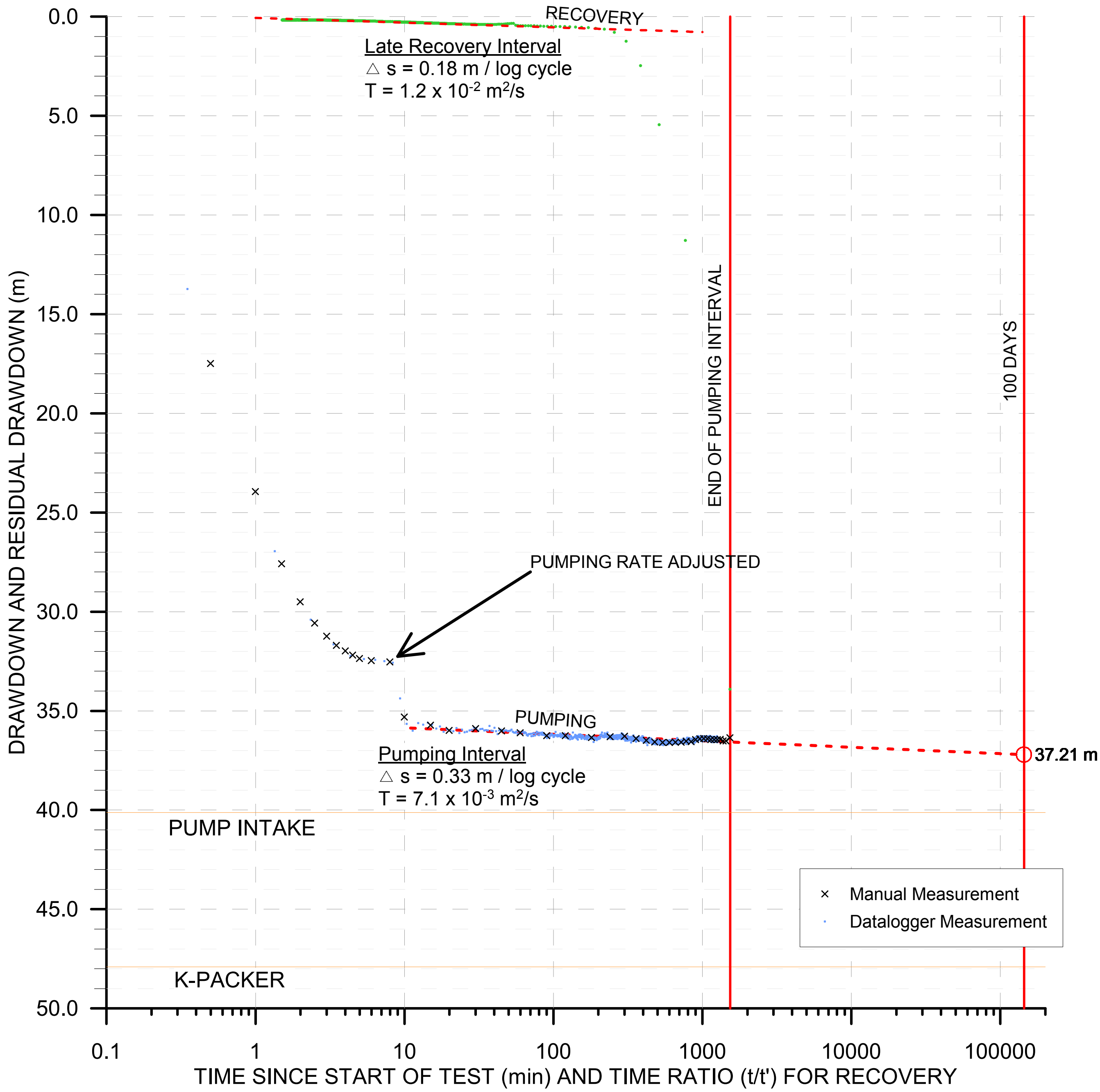
ANALYSIS OF VARIABLE-RATE TEST WITH PW17-1

BY:	DATE:
EJ/AB	AUG 17
APPROVED:	FIG:
DJT	5

H:\Project\3793\23-08-2017 Pumping Test\Test Data\2017-08-23_EJ_PW17-1 CRT.grf



COOPER & JACOB (1946)

$$T = \frac{2.303 * Q * 0.001}{4 * \pi * \Delta s}$$

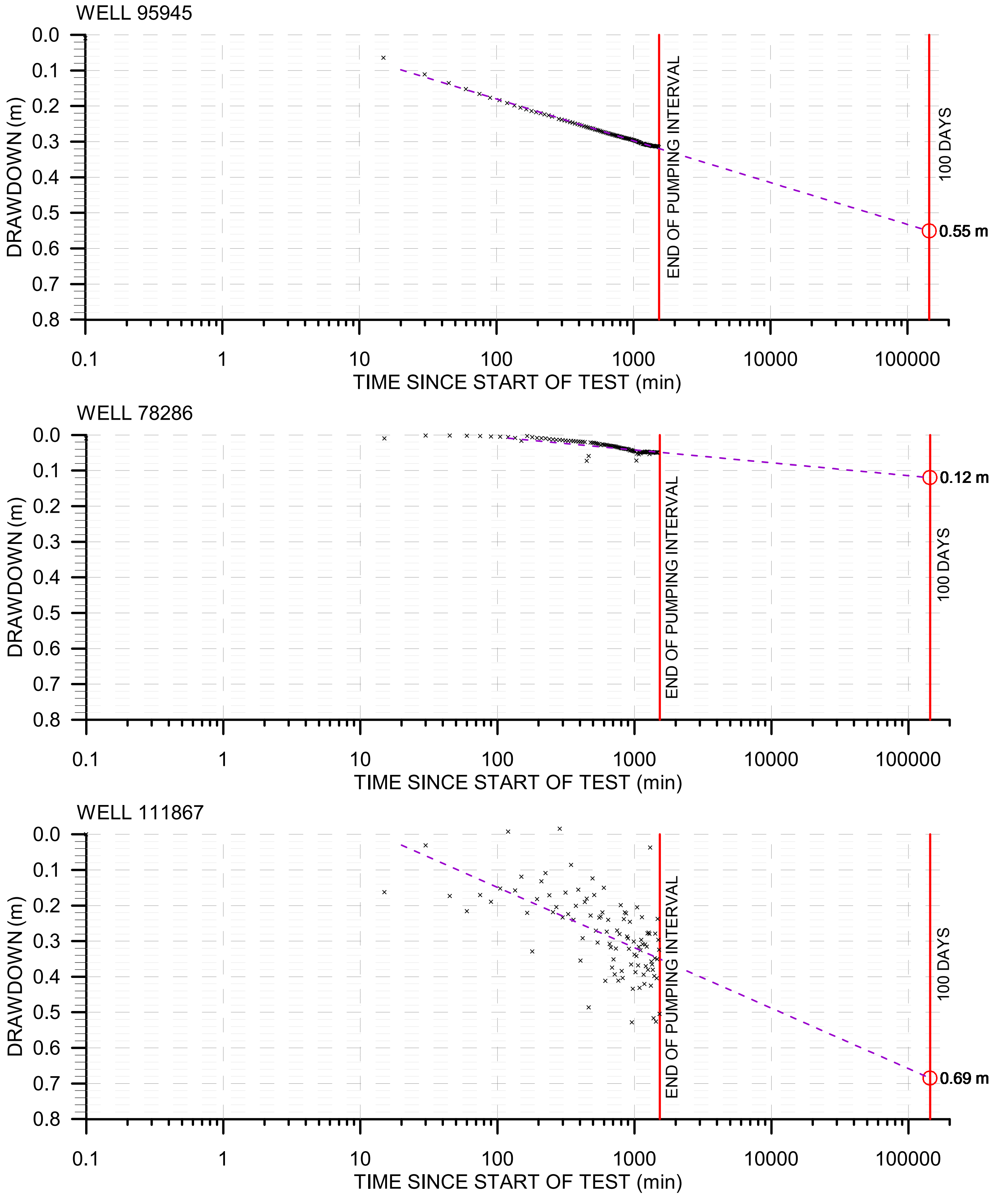
Test Start:	August 23, 2017 15:00
Test Duration:	1536 minutes
Test Rate:	12.7 L/s (201 USgpm)
Pre-Test Water Level:	4.17 m

URBAN SYSTEMS LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION OF PW17-1
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

ANALYSIS OF CONSTANT-RATE TEST WITH PW17-1

BY: EJ/AB
DATE: SEP 17
APPROVED: DJT
FIG: 6



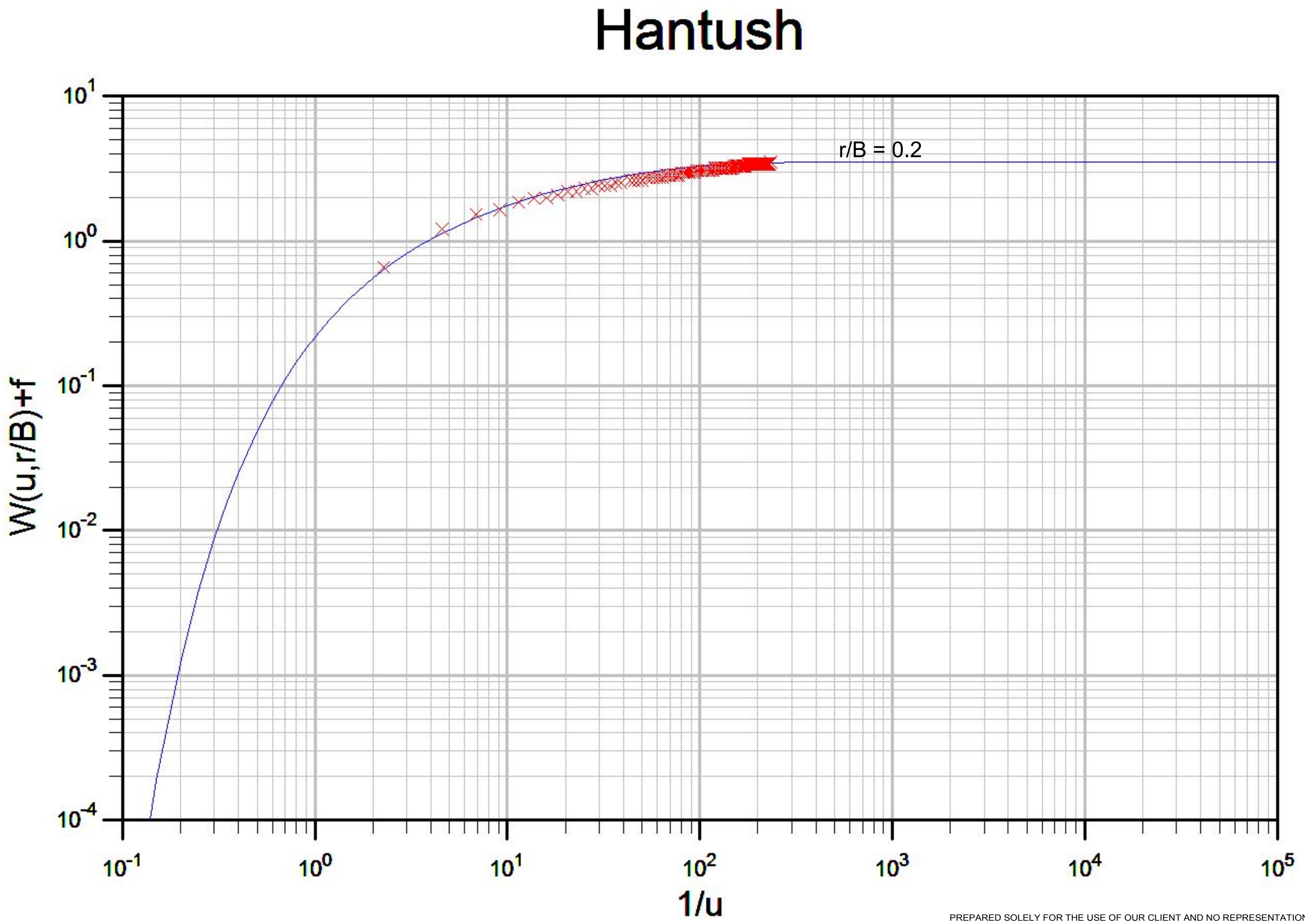
URBAN SYSTEMS LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION AND TESTING OF PW17-1
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

DRAWDOWNS IN OBSERVATION WELLS
DURING CONSTANT RATE TEST WITH PW17-1

BY: AB	DATE: OCT 17
APPROVED: DJT	FIG: 7

H:\Project\3793\Loggers\8 95945 LogLog.grf

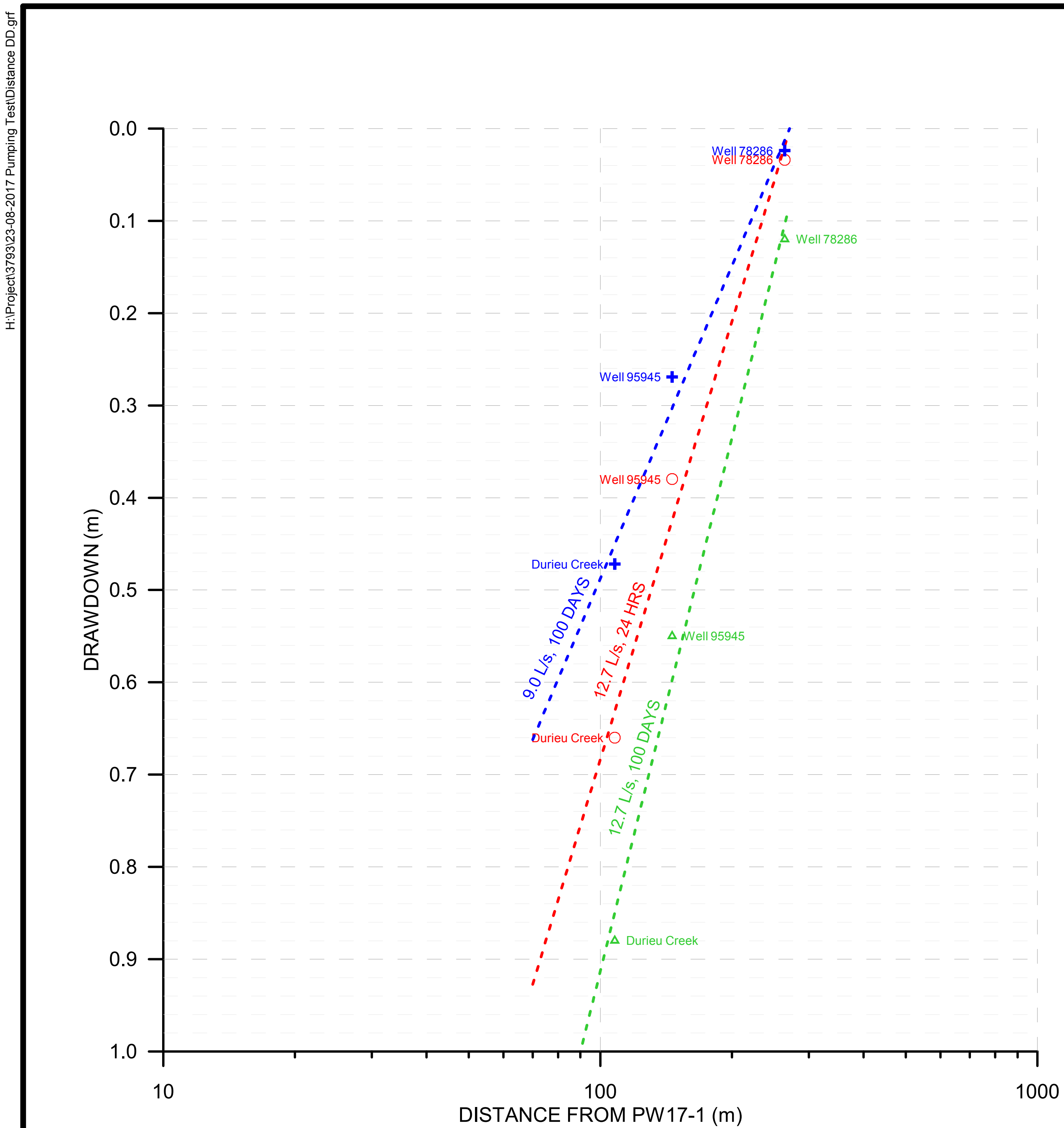


URBAN SYSTEMS LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION AND TESTING OF PW17-1
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

LOG-LOG ANALYSIS OF DRAWDOWN TREND IN WELL 95945 DURING PUMPING TEST WITH PW17-1

BY:	DATE:
AB	OCT 17
APPROVED:	FIG:
DJT	8



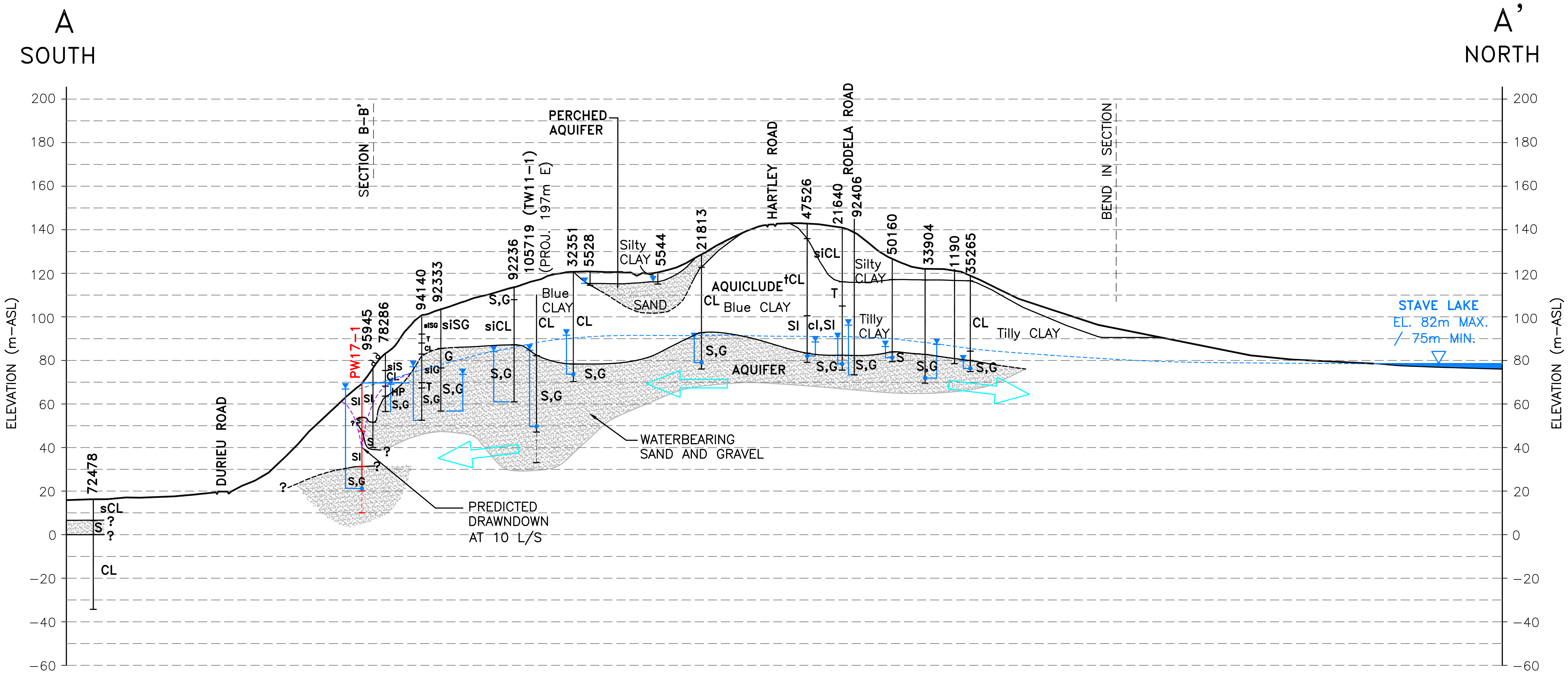
URBAN SYSTEMS LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION AND TESTING OF PW17-1

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

DISTANCE-DRAWDOWN RELATIONSHIPS FOR CONSTANT-RATE TEST WITH PW17-1

BY:	DATE:
EJ/AB	OCT 17
APPROVED:	FIG:
DJT	9

DWG. NUMBER: K:\3793\Cadd\3793-001.dwg (Fig 10)



SECTION A–A'

LEGEND

DRILLED WELL SHOWING WATER ELEVATION AND BCMOE WELL TAG NO.

PIEZOMETRIC ELEVATION

GEOLOGICAL BOUNDARY

PREDICTED DRAWDOWN OF PIEZOMETRIC SURFACE AT 10 L/S

INFERRED DIRECTION OF GROUNDWATER FLOW

SPRINGS

G	GRAVEL
S	SAND
SI	SILT
CL	CLAY
T	TILL
HP	HARDPAN

(LOWER CASE INDICATES MINOR COMPONENT)

0 200 400 600 800 1000m

SCALE 1:25,000

VERTICAL EXAGGERATION 12.5x

NOTE:

SEE LOCATION OF SECTION ON FIG. 1.

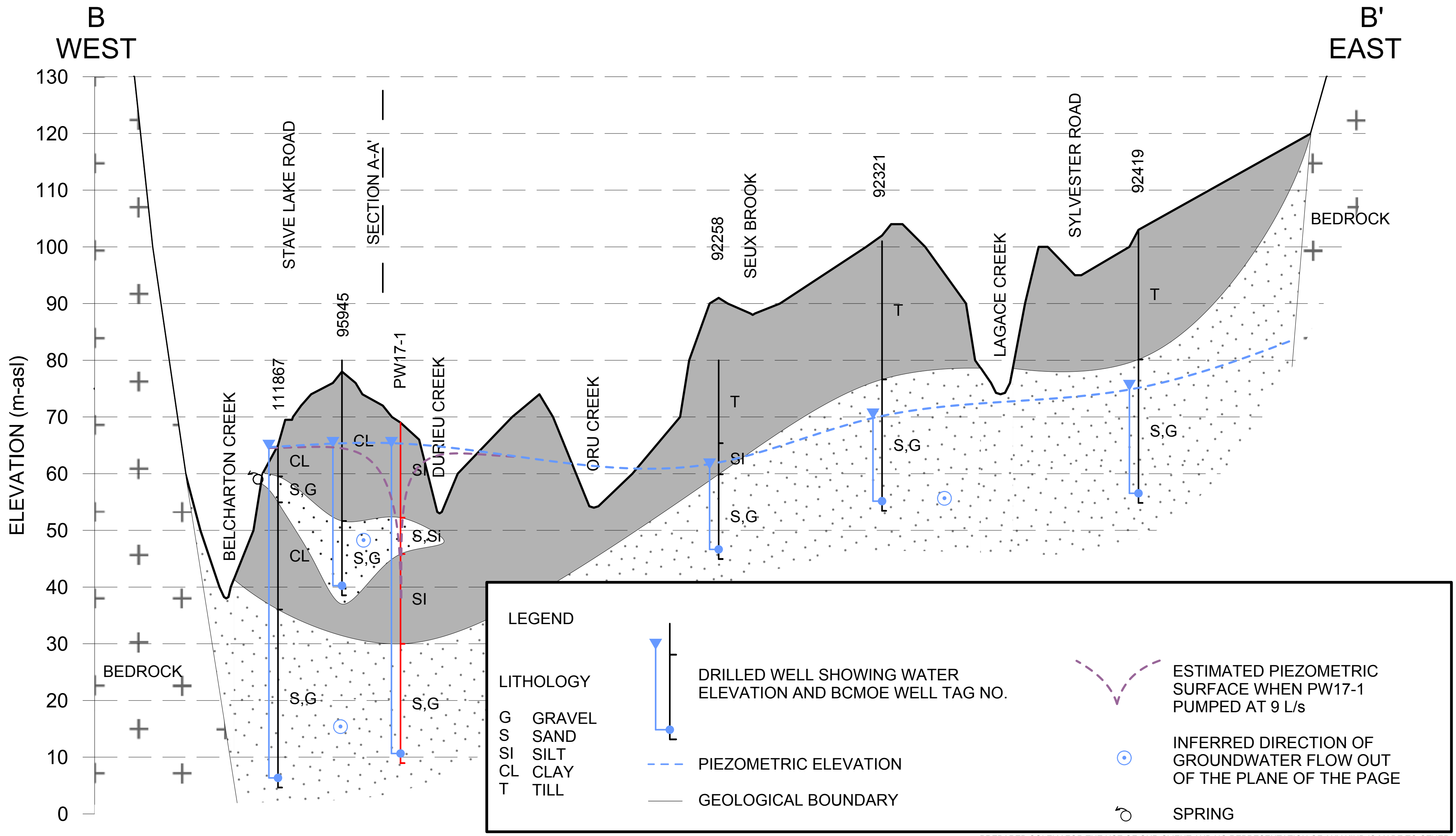
URBAN SYSTEM LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION AND TESTING OF PW17-1
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

HYDROGEOLOGICAL SECTION A-A'

BY: AB/sl
DATE: SEP 17
APPROVED: DJT
FIG: 10

H:\Project\3793\XS\XSB.grf



PREPARED SOLELY FOR THE USE OF OUR CLIENT AND NO REPRESENTATION OF ANY KIND IS MADE TO OTHER PARTIES WITH WHICH PITEAU ASSOCIATES ENGINEERING LTD. HAS NOT ENTERED INTO A CONTRACT.

0 100 200 300 400 500 m

HORIZONTAL SCALE 1:12500

VERTICAL EXAGGERATION 12.5x

URBAN SYSTEMS LTD.
FRASER VALLEY REGIONAL DISTRICT
CONSTRUCTION AND TESTING OF PW17-1

PITEAU ASSOCIATES

GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

HYDROGEOLOGICAL SECTION B-B'

BY:	DATE:
AB	SEP 17
APPROVED:	FIG:
DJT	11

PHOTOS

Photo 1: View south down the abrupt rise north of Durieu Road. Stave Lake Road is visible at the right side of the photo.

Photo 2: Discharge monitoring station on Durieu Creek.

Photo 3: Truck-mounted Foremost DR-24 dual mode air rotary well drilling rig set up on PW17-1.

Photo 4: PW17-1 wellhead with test pump in place.

Photo 5: Water pumped from PW17-1 at a rate of 12.7 L/s during the constant rate test.

APPENDIX A

PW17-1 LOG,
PW17-1 GRAIN SIZE ANALYSES RESULTS, AND
LOGS OF WELLS MONITORED
DURING AQUIFER PUMPING TEST

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

Well Number: PW17-1

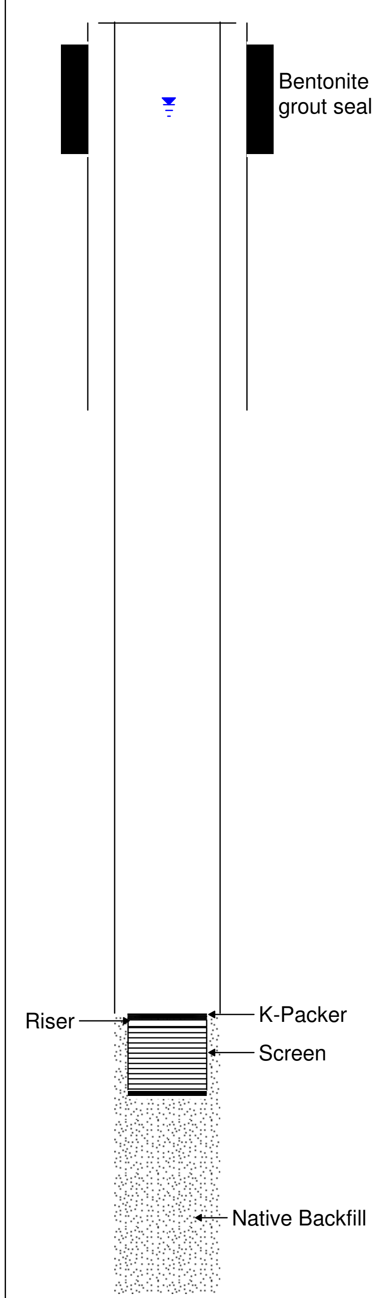
Well I.D. Plate No: 42943
Location: Stave Lake Rd. at Durieu Rd., Durieu, B.C.
Project Number: 3793
Client: Fraser Valley Regional District

Contractor: Field Drilling Contractors Ltd.
Drilling Method: DR-24 Dual Mode Air Rotary
Coordinates: E 555036 N 5453013
Ground Elevation: 70 m-asl

Logged By: EJ
Borehole Diameter: 8"
Date Started: August 2, 2017
Date Completed: August 14, 2017

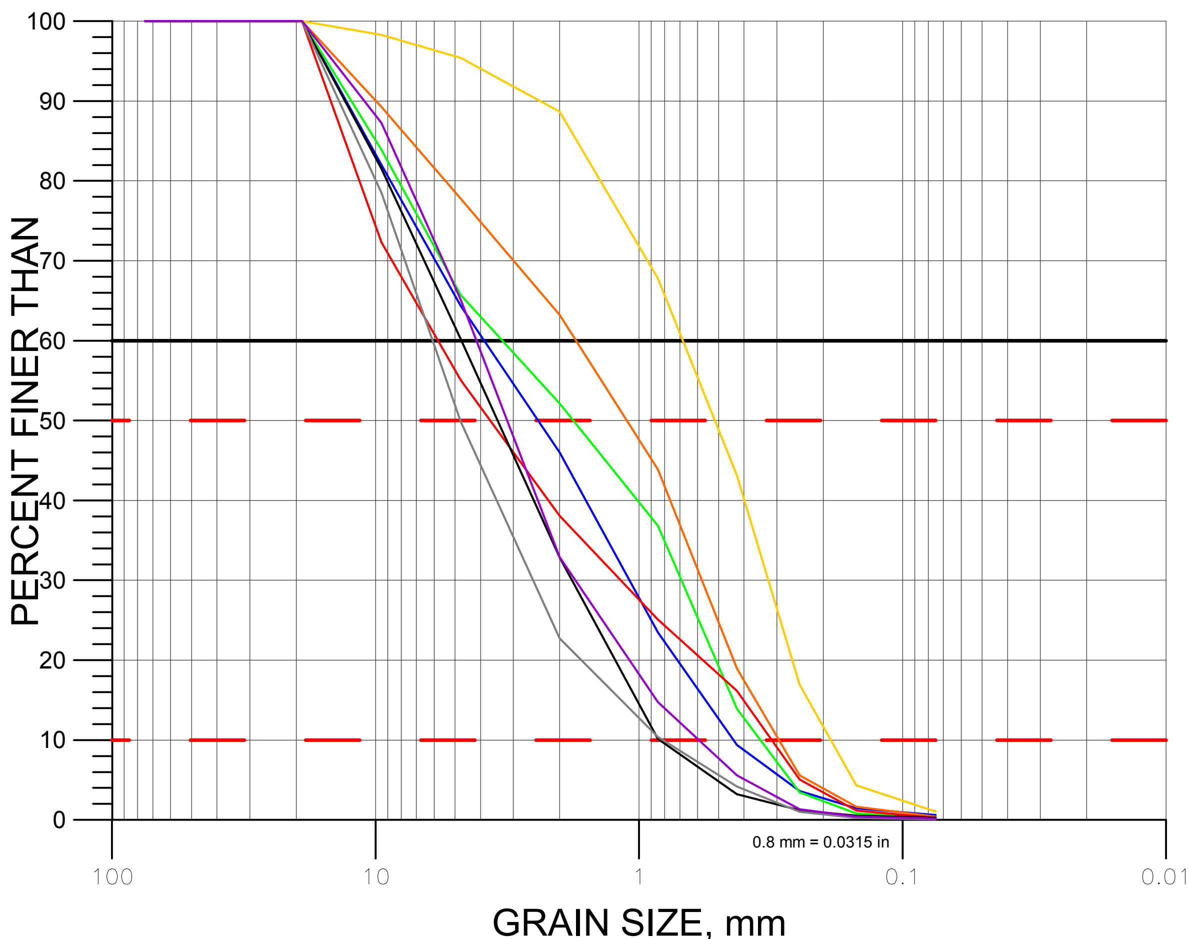
Depth (m-BGS)	Lithologic Description	Sample ID	Remarks
0.0	Ground Surface		bolted steel cap 0.9 m casing stickup 254 mm and 203 mm casings are welded with an annular ring Surface Seal: 406mm surface casing installed to 5.5 m and removed during installation of bentonite grout seal Water level 3.90 m-btoc on Aug.8 2017
0.0 – 16.8	**SILT** Silt		
16.8 – 23.2	**GRAVELLY SANDY SILT** Dense gravelly sandy silt - Till		254 mm casing to 17.7 m
23.2 – 38.9	**SILT** Silt with trace clay, and trace gravel		203mm casing drilled to 60.0 m and pulled back to 47.2 m
38.9 – 53.3	**SAND AND GRAVEL** Sand and gravel with little to no fines content Loose with grey wash	150 155 160 165 170	Telescopic Stainless Steel Wire Wound Well Screen Assembly: Exposed from 46.6 m to 50.3 m K-Packer: 46.6 - 46.9 m Solid Riser: 46.9 - 47.2 m Screen Interval: 47.2 - 50.3 m Slot opening size: 2.03 mm (0.080") Plate Bottom: 50.3 m
53.3 – 60.0	**SAND AND GRAVEL** Sand and gravel with little to no fines content Loose, with reddish brown wash	175 180 185	
60.0	End of Hole		

Constructed Well



H:\Project\3793\Gradations\Grain_Size_3793.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

LEGEND

- Kokosta 150'
- Kokosta 155'
- Kokosta 160'
- Kokosta 165'
- Kokosta 170'
- Kokosta 175'
- Kokosta 180'
- Kokosta 185'

Sample Depth		D_{10}	K
(ft)	(m)	(mm)	(m/s)
150	45.7	0.33	1.1E-03
155	47.2	0.29	8.4E-04
160	48.8	0.34	1.2E-03
165	50.3	0.44	1.9E-03
170	51.8	0.19	3.6E-04
175	53.3	0.84	7.1E-03
180	54.9	0.83	6.9E-03
185	56.4	0.60	3.6E-03
Mean		0.48	2.3E-03

URBAN SYSTEMS LTD.
HATZIC VALLEY WATER SUPPLY DEVELOPMENT
DURIEU, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

GRAIN SIZE ANALYSES
KOKOSTA WELL

BY: EJ
DATE: AUG 17
APPROVED: AB
FIG: A-1

Report 1 - Detailed Well Record

Well Tag Number: 95945 Owner: GAILITIS Address: 12400 STAVE LAKE ROAD Area: MISSION WELL LOCATION: Land District District Lot: Plan: Lot: Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 83): 092G029241 Well: Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Vertical Status of Well: New Licence General Status: UNLICENSED Well Use: Private Domestic Observation Well Number: Observation Well Status: Construction Method: Diameter: inches Casing drive shoe: N Y Well Depth: 136 feet Elevation: 316 feet (ASL) Final Casing Stick Up: 24 inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y	Construction Date: 2008-07-03 00:00:00 Driller: A. & H. Drilling Ltd. Well Identification Plate Number: 26447 Plate Attached By: JOHN MCDONALD Where Plate Attached: UNKNOWN PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 80 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 50 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Y Material: Bentonite clay Method: Depth (ft): 15 feet

File Info Flag: N Sieve Info Flag: N Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	Thickness (in): 2 inches Liner from To: feet WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
131.25	132		null
132	136		40

Casing from	to feet	Diameter	Material	Drive Shoe
0	6	132	Steel	Y
0	15	10	Steel	N

GENERAL REMARKS:
GPS ACCURACY: 43'. RIG# 5.

LITHOLOGY INFORMATION:

From 0 to 2 Ft.

From 2 to 23 Ft. SOME ROCK brown

From 23 to 34 Ft. grey

From 34 to 57 Ft.

From 57 to 65 Ft.

From 65 to 73 Ft.

From 73 to 93 Ft.

From 93 to 136 Ft. SAND & GRAVEL

- Return to Main
- Return to Search Options
- Return to Search Criteria

Report 1 - Detailed Well Record

Well Tag Number: 78286 Owner: HUGH DAVIDSON Address: 12462 STAVE LAKE ROAD Area: MISSION WELL LOCATION: NEW WESTMINSTER Land District District Lot: Plan: 32097 Lot: 2 Township: 18 Section: 24 Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 83): 092G029241 Well: 11 Class of Well: Water supply Subclass of Well: Orientation of Well: Status of Well: New Licence General Status: UNLICENSED Well Use: Observation Well Number: Observation Well Status: Construction Method: Diameter: 6 inches Casing drive shoe: Well Depth: 77 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N	Construction Date: 1997-08-09 00:00:00 Driller: Nor-West Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 30 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 36 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in):

Sieve Info Flag: N Screen Info Flag: Y Site Info Details: Other Info Flag: Other Info Details:	WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size
73	77		40
0	0		0
0	0		0

Casing from	to feet	Diameter	Material	Drive Shoe
null	null	0	null	null

GENERAL REMARKS:
12462 STAVE LAKE RD MISSION BC

LITHOLOGY INFORMATION:

From 0 to 3 Ft. SOILS

From 3 to 10 Ft. SILTY SAND WET

From 10 to 28 Ft. GRAY CLAY

From 28 to 46 Ft. STONEY HARDPAN

From 46 to 52 Ft. WET SAND & GRAVEL

From 52 to 77 Ft. WB SAND & GRAVEL

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 111867

Owner: Upcountry Leaseholds Ltd

Address: 12395 Stave Lake Road

Area: Mission

WELL LOCATION:
NEW WESTMINSTER Land District
District Lot: Plan: 21644 Lot: 3
Township: 18 Section: 23 Range:
Indian Reserve: Meridian: Block:
Quarter:
Island:
BCGS Number (NAD 83): 092G029241 Well:

Class of Well: Water supply
Subclass of Well: Non-domestic
Orientation of Well: Vertical
Status of Well: New
Licence General Status: UNLICENSED
Well Use: Water Supply System
Observation Well Number:
Observation Well Status:
Construction Method:
Diameter: 8 inches
Casing drive shoe:
Well Depth: 182 feet
Elevation: feet (ASL)
Final Casing Stick Up: 24 inches
Well Cap Type: Unknown
Bedrock Depth: feet
Lithology Info Flag: Y
File Info Flag: N
Sieve Info Flag: N
Screen Info Flag: N

Site Info Details:
Other Info Flag:
Other Info Details:

Construction Date: 2015-10-28 00:00:00

Driller: Field Drilling Contractors
Well Identification Plate Number: 41522
Plate Attached By: Driller
Where Plate Attached: Unknown

PRODUCTION DATA AT TIME OF DRILLING:
Well Yield: 200 (Driller's Estimate) Gallons per Minute (U.S./Imperial)
Development Method:
Pump Test Info Flag: N
Artesian Flow: .01 Gallons per Minute (U.S./Imperial)
Artesian Pressure (ft):
Static Level:

WATER QUALITY:
Character:
Colour:
Odour:
Well Disinfected: N
EMS ID:
Water Chemistry Info Flag: N
Field Chemistry Info Flag:
Site Info (SEAM):

Water Utility:
Water Supply System Name:
Water Supply System Well Name:

SURFACE SEAL:
Flag: N
Material:
Method:
Depth (ft):
Thickness (in):
Liner from To: feet

WELL CLOSURE INFORMATION:
Reason For Closure:
Method of Closure:
Closure Sealant Material:
Closure Backfill Material:
Details of Closure:

Screen from	to feet	Type	Slot Size
170	182		80

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
TOTAL 2 SCREENS, W/ K-PACKER AND 2FT RISER. SWL POSSIBLY INDICATES ARTESIAN. CROSS REFERENCED AND ASSOCIATED W/ GW LICENCE APPLICATION

LITHOLOGY INFORMATION:

From	0	to	1	Ft.	GRAVEL
From	1	to	15	Ft.	BROWN STICKY SILT CLAY & SANDS, ODD STONE
From	15	to	33	Ft.	GRAY SILTY GRAVELS
From	33	to	41	Ft.	HARD GRAY CLAY
From	41	to	62	Ft.	HARDER GRAY CLAY
From	62	to	88	Ft.	SOFTER GRAY CLAY
From	88	to	95	Ft.	SOFT GRAY CLAY, ODD STONE
From	95	to	118	Ft.	FINE SILTY SAND, SOME GRAVEL
From	118	to	185	Ft.	W.B. SANDS & GRAVEL
From	185	to	198	Ft.	FINER GRAY SANDS

- Return to Main
- Return to Search Options
- Return to Search Criteria

APPENDIX B

MANUAL DATA COLLECTED DURING AQUIFER TESTING WITH PW17-1

APPENDIX B1
SUMMARY OF VARIABLE-RATE TEST WITH PW17-1

Date	Clock Time (h:m:s)	Elapsed Time (t) (min)	Interval Time (t) (min)	Water Levels			Pumping Rate	Pumping Rate	Comments
				Depth		Drawdown			
				(m-btoc)		(m)	USgpm	L/s	
23-Aug-2017	9:30:00	0	0	4.054	13.30	0.000			
23-Aug-2017	9:31:00	1.0	1.0	19.080	62.60	15.027	100.0	6.3	Lots of sand
23-Aug-2017	9:32:00	2.0	2.0	19.995	65.60	15.941	100.0	6.3	
23-Aug-2017	9:32:30	2.5	2.5	19.964	65.50	15.911	100.0	6.3	
23-Aug-2017	9:33:00	3.0	3.0	21.336	70.00	17.282	100.0	6.3	Water clear still
23-Aug-2017	9:33:30	3.5	3.5	21.915	71.90	17.861	100.0	6.3	
23-Aug-2017	9:34:00	4.0	4.0	22.403	73.50	18.349	100.0	6.3	
23-Aug-2017	9:34:30	4.5	4.5	22.616	74.20	18.562	100.0	6.3	
23-Aug-2017	9:35:00	5.0	5.0	22.616	74.20	18.562	100.0	6.3	
23-Aug-2017	9:36:00	6.0	6.0	22.677	74.40	18.623	100.0	6.3	Jumped to 161 GPM then back to 100 GPM
23-Aug-2017	9:38:00	8.0	8.0	22.738	74.60	18.684	100.0	6.3	Sand is reducing
23-Aug-2017	9:40:00	10.0	10.0	22.616	74.20	18.562	100.0	6.3	
23-Aug-2017	9:45:00	15.0	15.0	22.220	72.90	18.166	100.0	6.3	
23-Aug-2017	9:50:00	20.0	20.0	21.031	69.00	16.977	100.0	6.3	
23-Aug-2017	10:00:00	30.0	30.0	17.374	57.00	13.320	100.0	6.3	
23-Aug-2017	10:15:00	45.0	45.0	24.171	79.30	20.117	100.0	6.3	
23-Aug-2017	10:30:00	60.0	60.0	25.390	83.30	21.336	100.0	6.3	pumping rate increased
23-Aug-2017	10:30:30	60.5	0.0	28.956	95.00	24.902	161.0	10.2	
23-Aug-2017	10:31:00	61.0	0.5	31.090	102.00	27.036	160.0	10.1	
23-Aug-2017	10:31:30	61.5	1.0	32.095	105.30	28.042	160.0	10.1	
23-Aug-2017	10:32:00	62.0	1.5	32.370	106.20	28.316	160.0	10.1	
23-Aug-2017	10:32:30	62.5	2.0	32.309	106.00	28.255	160.0	10.1	
23-Aug-2017	10:33:00	63.0	2.5	32.156	105.50	28.103	160.0	10.1	
23-Aug-2017	10:33:30	63.5	3.0	32.004	105.00	27.950	160.0	10.1	
23-Aug-2017	10:34:00	64.0	3.5	31.852	104.50	27.798	160.0	10.1	
23-Aug-2017	10:34:30	64.5	4.0	31.760	104.20	27.706	160.0	10.1	
23-Aug-2017	10:35:00	65.0	4.5	31.913	104.70	27.859	160.0	10.1	
23-Aug-2017	10:36:00	66.0	5.5	32.065	105.20	28.011	160.0	10.1	
23-Aug-2017	10:38:00	68.0	7.5	31.916	104.71	27.862	160.0	10.1	
23-Aug-2017	10:40:00	70.0	9.5	31.879	104.59	27.825	160.0	10.1	
23-Aug-2017	10:45:00	75.0	14.5	31.602	103.68	27.548	160.0	10.1	
23-Aug-2017	10:50:00	80.0	19.5	31.346	102.84	27.292	160.0	10.1	
23-Aug-2017	11:00:00	90.0	29.5	32.065	105.20	28.011	160.0	10.1	
23-Aug-2017	11:10:00	100.0	39.5	32.071	105.22	28.017	160.0	10.1	
23-Aug-2017	11:20:00	110.0	49.5	32.236	105.76	28.182	160.0	10.1	
23-Aug-2017	11:30:00	120.0	59.5	32.339	106.10	28.285	160.0	10.1	pumping rate increased
23-Aug-2017	11:30:30	120.5	0.0	33.964	111.43	29.910			
23-Aug-2017	11:31:00	121.0	0.5	34.714	113.89	30.660			
23-Aug-2017	11:31:30	121.5	1.0	35.339	115.94	31.285			
23-Aug-2017	11:32:00	122.0	1.5	35.601	116.80	31.547			
23-Aug-2017	11:32:30	122.5	2.0	35.710	117.16	31.657			
23-Aug-2017	11:33:00	123.0	2.5	35.726	117.21	31.672			
23-Aug-2017	11:33:30	123.5	3.0	36.064	118.32	32.010			
23-Aug-2017	11:34:00	124.0	3.5	36.576	120.00	32.522			
23-Aug-2017	11:34:30	124.5	4.0	36.783	120.68	32.729			
23-Aug-2017	11:35:00	125.0	4.5	36.902	121.07	32.848	186.0	11.7	
23-Aug-2017	11:36:00	126.0	5.5	37.088	121.68	33.034	186.0	11.7	

APPENDIX B1
SUMMARY OF VARIABLE-RATE TEST WITH PW17-1

Date	Clock Time (h:m:s)	Elapsed Time (t) (min)	Interval Time (t) (min)	Water Levels			Pumping Rate	Pumping Rate	Comments
				Depth		Drawdown			
				(m-btoc)		(m)	USgpm	L/s	
23-Aug-2017	11:38:00	128.0	7.5	37.094	121.70	33.040	186.0	11.7	
23-Aug-2017	11:40:00	130.0	9.5	37.591	123.33	33.537	186.0	11.7	
23-Aug-2017	11:45:00	135.0	14.5	37.460	122.90	33.406	186.0	11.7	
23-Aug-2017	11:50:00	140.0	19.5	37.189	122.01	33.135	186.0	11.7	
23-Aug-2017	12:00:00	150.0	29.5	37.490	123.00	33.437	186.0	11.7	
23-Aug-2017	12:10:00	160.0	39.5	37.484	122.98	33.430	186.0	11.7	
23-Aug-2017	12:20:00	170.0	49.5	37.628	123.45	33.574	186.0	11.7	
23-Aug-2017	12:30:00	180.0	59.5	37.545	123.18	33.491	186.0	11.7	
23-Aug-2017	12:40:00	190.0	69.5	37.460	122.90	33.406	186.0	11.7	
23-Aug-2017	12:50:00	200.0	79.5	37.609	123.39	33.555	186.0	11.7	
23-Aug-2017	13:00:30	210.5	90.0				201.0	12.7	pumping rate increased
23-Aug-2017	13:01:00	211.0	0.0	37.795	124.00	33.741	201.0	12.7	
23-Aug-2017	13:01:30	211.5	0.5	38.771	127.20	34.717	201.0	12.7	
23-Aug-2017	13:02:00	212.0	1.0	40.386	132.50	36.332	201.0	12.7	
23-Aug-2017	13:02:30	212.5	1.5	40.356	132.40	36.302	201.0	12.7	
23-Aug-2017	13:03:00	213.0	2.0	40.295	132.20	36.241	201.0	12.7	
23-Aug-2017	13:03:30	213.5	2.5	40.295	132.20	36.241	201.0	12.7	
23-Aug-2017	13:04:00	214.0	3.0	40.325	132.30	36.271	201.0	12.7	
23-Aug-2017	13:04:30	214.5	3.5	40.325	132.30	36.271	201.0	12.7	
23-Aug-2017	13:05:00	215.0	4.0	40.325	132.30	36.271	201.0	12.7	
23-Aug-2017	13:05:30	215.5	4.5	40.325	132.30	36.271	201.0	12.7	
23-Aug-2017	13:06:30	216.5	5.5	40.310	132.25	36.256	201.0	12.7	
23-Aug-2017	13:08:30	218.5	7.5	40.423	132.62	36.369	201.0	12.7	
23-Aug-2017	13:10:30	220.5	9.5	40.295	132.20	36.241	201.0	12.7	
23-Aug-2017	13:15:30	225.5	14.5	40.188	131.85	36.134	201.0	12.7	
23-Aug-2017	13:20:30	230.5	19.5	40.356	132.40	36.302	201.0	12.7	

Note: btoc means below top of casing.

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APPENDIX B2
SUMMARY OF CONSTANT-RATE TEST WITH PW17-1

Date	Clock Time (h:m:s)	Elapsed Time (t) (min)	Interval Time (t') (min)	Time Ratio (t/t') ()	Water Levels Depth	Drawdown	Pumping Rate	pH	Temper-ature	Turbidity	Comments
					(m-btoc)	(m)	(L/s)	-	(ºC)	(NTU)	
23-Aug-2017	15:00:00	0	0.0		4.170	0.000					
23-Aug-2017	15:00:30	0.5	0.5		21.662	17.492	11.7				
23-Aug-2017	15:01:00	1	1.0		28.127	23.957	11.7				
23-Aug-2017	15:01:30	1.5	1.5		31.763	27.594	11.7				
23-Aug-2017	15:02:00	2	2.0		33.680	29.511	11.7				
23-Aug-2017	15:02:30	2.5	2.5		34.756	30.587	11.7				
23-Aug-2017	15:03:00	3	3.0		35.418	31.248	11.7				
23-Aug-2017	15:03:30	3.5	3.5		35.875	31.705	11.7				
23-Aug-2017	15:04:00	4	4.0		36.152	31.983	11.7				
23-Aug-2017	15:04:30	4.5	4.5		36.363	32.193	11.7				
23-Aug-2017	15:05:00	5	5.0		36.539	32.370	11.7				
23-Aug-2017	15:06:00	6	6.0		36.643	32.473	11.7				30" at orifice, 6" pipe, 3" orifice
23-Aug-2017	15:08:00	8	8.0		36.710	32.540	11.7				Valve up
23-Aug-2017	15:10:00	10	10.0		39.484	35.314	12.7				35" at orifice manometer
23-Aug-2017	15:15:00	15	15.0		39.901	35.732	12.7				
23-Aug-2017	15:20:00	20	20.0		40.160	35.991	12.7				
23-Aug-2017	15:30:00	30	30.0		40.063	35.893	12.7				
23-Aug-2017	15:45:00	45	45.0		40.182	36.012	12.7				
23-Aug-2017	16:00:00	60	60.0		40.279	36.110	12.7				
23-Aug-2017	16:30:00	90	90.0		40.420	36.250	12.7				35" at manometer, 6" pipe c/w 3" orifice
23-Aug-2017	17:00:00	120	120.0		40.426	36.256	12.7				
23-Aug-2017	18:00:00	180	180.0		40.517	36.347	12.7				
23-Aug-2017	19:00:00	240	240.0		40.484	36.314	12.7				
23-Aug-2017	20:00:00	300	300.0		40.453	36.283	12.7				
23-Aug-2017	21:00:00	360	360.0		40.578	36.408	12.7				
23-Aug-2017	22:00:00	420	420.0		40.669	36.500	12.7				
23-Aug-2017	23:00:00	480	480.0		40.746	36.576	12.7				
24-Aug-2017	0:00:00	540	540.0		40.776	36.606	12.7				
24-Aug-2017	1:00:00	600	600.0		40.764	36.594	12.7				
24-Aug-2017	2:00:00	660	660.0		40.758	36.588	12.7				
24-Aug-2017	3:00:00	720	720.0		40.758	36.588	12.7				
24-Aug-2017	4:00:00	780	780.0		40.703	36.533	12.7				
24-Aug-2017	5:00:00	840	840.0		40.727	36.558	12.7				
24-Aug-2017	6:00:00	900	900.0		40.621	36.451	12.7				
24-Aug-2017	7:00:00	960	960.0		40.584	36.414	12.7				
24-Aug-2017	8:00:00	1020	1020.0		40.575	36.41	12.7				
24-Aug-2017	9:00:00	1080	1080.0		40.584	36.41	12.7				
24-Aug-2017	10:00:00	1140	1140.0		40.627	36.46	12.7				
24-Aug-2017	11:00:00	1200	1200.0		40.621	36.45	12.7				
24-Aug-2017	12:00:00	1260	1260.0		40.621	36.45	12.7				
24-Aug-2017	13:00:00	1320	1320.0		40.605	36.44	12.7				
24-Aug-2017	14:00:00	1380	1380.0		40.697	36.53	12.7				
24-Aug-2017	15:00:00	1440	1440.0		40.691	36.52	12.7				
24-Aug-2017	16:36:00	1536	1536.0		40.529	36.36	12.7				pump stopped

Note: btoc means below top of casing.

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APPENDIX C

LABORATORY ANALYSIS CERTIFICATE

PITEAU ASSOC. ENGINEERING LTD.
ATTN: Eric Johnson
#300-788 Copping Street
North Vancouver BC V7M 3G6

Client Phone: 604-986-8551

Date Received: 24-AUG-17
Report Date: 05-SEP-17 12:46 (MT)
Version: FINAL

Certificate of Analysis

Lab Work Order #: L1980943

Project P.O. #: NOT SUBMITTED
Job Reference: 3793
C of C Numbers: 15-610448
Legal Site Desc:

Brent Mack, B.Sc.
Account Manager

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID	L1980943-1				
	Description					
	Sampled Date	24-AUG-17				
	Sampled Time	18:47				
	Client ID	PW17-1 GWS 2				
Grouping	**Analyte**					
WATER						
Physical Tests	Colour, True (CU)	<5.0				
	Conductivity (uS/cm)	111				
	Hardness (as CaCO3) (mg/L)	52.6 HTC				
	pH (pH)	7.79				
	Total Dissolved Solids (mg/L)	85				
	Turbidity (NTU)	0.15				
Anions and Nutrients	Alkalinity, Total (as CaCO3) (mg/L)	48.2				
	Chloride (Cl) (mg/L)	1.23				
	Fluoride (F) (mg/L)	<0.020				
	Nitrate (as N) (mg/L)	0.239				
	Nitrite (as N) (mg/L)	<0.0010				
	Sulfate (SO4) (mg/L)	8.33				
Bacteriological Tests	E. coli (MPN/100mL)	<1				
	Coliform Bacteria - Total (MPN/100mL)	<1				
Total Metals	Aluminum (Al)-Total (mg/L)	<0.010				
	Antimony (Sb)-Total (mg/L)	<0.00050				
	Arsenic (As)-Total (mg/L)	0.00167				
	Barium (Ba)-Total (mg/L)	<0.020				
	Boron (B)-Total (mg/L)	<0.10				
	Cadmium (Cd)-Total (mg/L)	<0.00020				
	Calcium (Ca)-Total (mg/L)	16.3				
	Chromium (Cr)-Total (mg/L)	<0.0020				
	Copper (Cu)-Total (mg/L)	<0.0010				
	Iron (Fe)-Total (mg/L)	0.040				
	Lead (Pb)-Total (mg/L)	<0.00050				
	Magnesium (Mg)-Total (mg/L)	2.88				
	Manganese (Mn)-Total (mg/L)	0.0057				
	Mercury (Hg)-Total (mg/L)	<0.00020				
	Potassium (K)-Total (mg/L)	1.09				
	Selenium (Se)-Total (mg/L)	<0.0010				
	Sodium (Na)-Total (mg/L)	2.8				
	Uranium (U)-Total (mg/L)	<0.00010				
	Zinc (Zn)-Total (mg/L)	<0.050				

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

Reference Information

QC Samples with Qualifiers & Comments:

QC Type Description	Parameter	Qualifier	Applies to Sample Number(s)

Qualifiers for Individual Parameters Listed:

Qualifier	Description
HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-TITR-VA	Water	Alkalinity Species by Titration	APHA 2320 Alkalinity

This analysis is carried out using procedures adapted from APHA Method 2320 "Alkalinity". Total alkalinity is determined by potentiometric titration to a pH 4.5 endpoint. Bicarbonate, carbonate and hydroxide alkalinity are calculated from phenolphthalein alkalinity and total alkalinity values.

CL-IC-N-VA	Water	Chloride in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

COLOUR-TRUE-VA	Water	Colour (True) by Spectrometer	BCMOE Colour Single Wavelength

This analysis is carried out using procedures adapted from British Columbia Environmental Manual "Colour- Single Wavelength." Colour (True Colour) is determined by filtering a sample through a 0.45 micron membrane filter followed by analysis of the filtrate using the platinum-cobalt colourimetric method.
Colour measurements can be highly pH dependent, and apply to the pH of the sample as received (at time of testing), without pH adjustment. Concurrent measurement of sample pH is recommended.

EC-PCT-VA	Water	Conductivity (Automated)	APHA 2510 Auto. Conduc.

This analysis is carried out using procedures adapted from APHA Method 2510 "Conductivity". Conductivity is determined using a conductivity electrode.

EC-SCREEN-VA	Water	Conductivity Screen (Internal Use Only)	APHA 2510

Qualitative analysis of conductivity where required during preparation of other tests - e.g. TDS, metals, etc.

ECOLI-COLI-BCDW-VA	Water	E.coli by Colilert	APHA METHOD 9223

This analysis is carried out using procedures adapted from APHA Method 9223 "Enzyme Substrate Coliform Test". E. coli and Total Coliform are determined simultaneously. The sample is mixed with a mixture hydrolyzable substrates and then sealed in a multi-well packet. The packet is incubated for 18 or 24 hours and then the number of wells exhibiting a positive response are counted. The final result is obtained by comparing the positive responses to a probability table.

F-IC-N-VA	Water	Fluoride in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

HARDNESS-CALC-VA	Water	Hardness	APHA 2340B

Hardness (also known as Total Hardness) is calculated from the sum of Calcium and Magnesium concentrations, expressed in CaCO3 equivalents. Dissolved Calcium and Magnesium concentrations are preferentially used for the hardness calculation.

HG-TOT-CVAFS-VA	Water	Total Hg in Water by CVAFS LOR=50ppt	EPA 1631E (mod)

This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedure involves a cold-oxidation of the acidified sample using bromine monochloride prior to reduction of the sample with stannous chloride. Instrumental analysis is by cold vapour atomic fluorescence spectrophotometry or atomic absorption spectrophotometry (EPA Method 245.7).

MET-T-CCMS-VA	Water	Total Metals in Water by CRC ICPMS	EPA 200.2/6020A (mod)

Water samples are digested with nitric and hydrochloric acids, and analyzed by CRC ICPMS.

Method Limitation (re: Sulfur): Sulfide and volatile sulfur species may not be recovered by this method.

NO2-L-IC-N-VA	Water	Nitrite in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

NO3-L-IC-N-VA	Water	Nitrate in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

PH-PCT-VA	Water	pH by Meter (Automated)	APHA 4500-H pH Value

This analysis is carried out using procedures adapted from APHA Method 4500-H "pH Value". The pH is determined in the laboratory using a pH electrode

It is recommended that this analysis be conducted in the field.

SO4-IC-N-VA	Water	Sulfate in Water by IC	EPA 300.1 (mod)

Reference Information

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

TCOLI-COLI-BCDW-VA Water Total coliform by Colilert APHA METHOD 9223

This analysis is carried out using procedures adapted from APHA Method 9223 "Enzyme Substrate Coliform Test". E. coli and Total Coliform are determined simultaneously. The sample is mixed with a mixture hydrolyzable substrates and then sealed in a multi-well packet. The packet is incubated for 18 or 24 hours and then the number of wells exhibiting a positive response are counted. The final result is quantified by a statistical estimation of bacteria density (most probable number).

TDS-VA Water Total Dissolved Solids by Gravimetric APHA 2540 C - GRAVIMETRIC

This analysis is carried out using procedures adapted from APHA Method 2540 "Solids". Solids are determined gravimetrically. Total Dissolved Solids (TDS) are determined by filtering a sample through a glass fibre filter, TDS is determined by evaporating the filtrate to dryness at 180 degrees celsius.

TURBIDITY-VA Water Turbidity by Meter APHA 2130 Turbidity

This analysis is carried out using procedures adapted from APHA Method 2130 "Turbidity". Turbidity is determined by the nephelometric method.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
VA	ALS ENVIRONMENTAL - VANCOUVER, BRITISH COLUMBIA, CANADA

Chain of Custody Numbers:

15-610448

GLOSSARY OF REPORT TERMS

Surrogate - A compound that is similar in behaviour to target analyte(s), but that does not occur naturally in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery.
mg/kg - milligrams per kilogram based on dry weight of sample.
mg/kg wwt - milligrams per kilogram based on wet weight of sample.
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight of sample.
mg/L - milligrams per litre.
< - Less than.
D.L. - The reported Detection Limit, also known as the Limit of Reporting (LOR).
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

ALS Environmental
www.alsglobal.com

Chain of Custody (COC) / Analytical Request Form

Canada Toll Free: 1 800 668 9878

L1980943-COFC

COC Number: 15 - 610448

Page of

Report To	Contact and company name below will appear on the final report
Company:	Piteau
Contact:	Eric Johnson
Phone:	604-379-1370
	Company address below will appear on the final report
Street:	788 Copping Street #300
City/Province:	North Vancouver BC
Postal Code:	V7M 3G7

Invoice To		
Same as Report To	☑ YES	☐ NO
Copy of Invoice with Report	☑ YES	☐ NO
Company:	Piteau	
Contact:	Eric Johnson	

Report Format / Distribution

Select Report Format: ☑ PDF ☐ EXCEL ☐ EDD (DIGITAL)

Quality Control (QC) Report with Report ☑ YES ☐ NO

☐ Compare Results to Criteria on Report - provide details below if box checked

Select Distribution: ☑ EMAIL ☐ MAIL ☐ FAX

Email 1 or Fax: EJohnson@Piteau.com

Email 2

Email 3

Invoice Distribution

Select Invoice Distribution: ☐ EMAIL ☐ MAIL ☐ FAX

Email 1 or Fax

Email 2

Select Service Level Below - Please confirm all E&P TATs with your AM - surcharges will apply

Regular [R] ☑ Standard TAT if received by 3 pm - business days - no surcharges apply

PRIORITY (Business Days): 4 day [P4] ☐ 3 day [P3] ☐ 2 day [P2] ☐

EMERGENCY: 1 Business day [E1] ☐ Same Day, Weekend or Statutory holiday [E0] ☐

Date and Time Required for all E&P TATs:

For tests that can not be performed according to the service level selected, you will be contacted.

Project Information	
ALS Account # / Quote #:	
Job #:	3793
PO / AFE:	
LSD:	
ALS Lab Work Order # (lab use only)	

Oil and Gas Required Fields (client use)	
AFE/Cost Center:	PO#
Major/Minor Code:	Routing Code:
Requisitioner:	
Location:	
ALS Contact:	Sampler:

Analysis Request

Indicate Filtered (F), Preserved (P) or Filtered and Preserved (F/P) below

ALS Sample # (lab use only)	Sample Identification and/or Coordinates (This description will appear on the report)	Date (dd-mmm-yy)	Time (hh:mm)	Sample Type	Full Drinking Water E.coli + total coliform	Number of Containers
	PW17-1 GWS 2	24-08-17	18:47		✓	

Drinking Water (DW) Samples[1] (client use)

Are samples taken from a Regulated DW System? ☐ YES ☑ NO

Are samples for human drinking water use? ☑ YES ☐ NO

Special Instructions / Specify Criteria to add on report by clicking on the drop-down list below (electronic COC only)

SAMPLE CONDITION AS RECEIVED (lab use only)

Frozen ☐ SIF Observations Yes ☐ No ☐

Ice Packs ☐ Ice Cubes ☒ Custody seal intact Yes ☐ No ☐

Cooling Initiated ☐

INITIAL COOLER TEMPERATURES °C:

FINAL COOLER TEMPERATURES °C: 5

SHIPMENT RELEASE (client use)			INITIAL SHIPMENT RECEPTION (lab use only)			FINAL SHIPMENT RECEPTION (lab use only)		
Released by: [signature]	Date: 24/08/2017	Time: 6:52pm	Received by:	Date:	Time:	Received by: [signature]	Date: 8/24/17	Time: 18:55

REFER TO BACK PAGE FOR ALS LOCATIONS AND SAMPLING INFORMATION WHITE - LABORATORY COPY YELLOW - CLIENT COPY

Failure to complete all portions of this form may delay analysis. Please fill in this form LEGIBLY. By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified on the back page of the white - report copy.

1. If any water samples are taken from a **Regulated Drinking Water (DW) System**, please submit using an **Authorized DW COC form**.

APPENDIX D

GARP SCREENING

GARP-GWUDI SCREENING TOOL

WATER SYSTEM NAME	BCMOE WELL TAG NO.				
Fraser Valley Regional District Hatzic Prairie	PW17-1; WTN 113520				
SITE LOCATION	Well Log Examined (Y/N) Y				
Stave Lake Road UTM 555037E, 5453016N	Site Survey Conducted (Y/N) Y				
WATER WELL AND SOURCE EVALUATION	STAGE 1: HAZARD SCREENING		STAGE 2: HAZARD ASSESSMENT		COMMENTS
HAZARDS	PRESENT (Stage 2 Assess-ment Required)	NOT PRESENT	AT RISK	AT LOW RISK	
A. Water Quality Results					
A1: Exhibits recurring presence of total coliform bacteria, fecal coliform bacteria, or Escherichia coli (E. coli).		X			New well; no operational history.
A2: Has reported intermittent turbidity or has a history of consistent turbidity greater than 1 NTU.		X			New well; no operational history.
B. Well Location					
B1: Situated inside setback distances from possible sources of contamination as per Section 8 of the HHR.		X			No known probable source of contamination.
B2: Has an intake depth <15 m below ground surface that is located within a natural boundary of surface water or a flood prone area.		X			Top of well screen is 47.2 m below ground level.
B3: Has an intake depth between the high-water mark and surface water bottom (or < 15 m below the normal water level), and located within, or less than 150 m from the natural boundary of any surface water.		X			
B4: Located within 300m of a source of probable enteric viral contamination without a barrier to viral transport.		X			Aquifer confined by 32.4 m of overlying silt and clay.
C. Well Construction					
C1: Does not meet GWPR (Part 3, Division 3) for surface sealing.		X			
C2: Does not meet GWPR (Part 4) for well caps and covers.		X			
C3: Does not meet GWPR (Part 3, Division 5) for floodproofing.		X			
C4: Does not meet GWPR (Part 3, Division 2 and Part 5) for wellhead protection.		X			
D. Aquifer Type and Setting					
D1: Has an intake depth <15 m below ground surface.		X			
D2: Is situated in a highly vulnerable, unconfined, unconsolidated or fractured bedrock aquifer.		X			
D2: Is completed in a karst bedrock aquifer, regardless of depth.		X			

H:\Project\3793\Water Quality\[ScreeningTool_GARP.xlsx]Garp Screening