Aquifer Modeling Report
Municipal Water Supply
Valdez, Alaska

August 2016

SHANNON & WILSON, INC.

GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

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Submitted To:

City of Valdez
Capital Projects and Engineering
P.O. Box 307
Valdez, Alaska 99686
Phone: (907)835-5478

By:

Shannon & Wilson, Inc.
AECC125
5430 Fairbanks Street, Suite 3
Anchorage, Alaska 99518
Phone: (907)561-2120
Fax: (907)561-4483
E-mail: sjg@shanwil.com

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VALDEZ, ALASKA

1.0 INTRODUCTION

One of the main supplies of municipal water for the City of Valdez is Well 4, located off of Eagan Road in Valdez, Alaska. The City would like to provide redundancy to the system in the event that there is a problem with Well 4. Additionally, potential future growth could require an additional supply of potable water for the distribution system. The purpose of this study was to evaluate a preferred location for this new well and potential operational impacts on the existing Well 4. This report presents a summary of subsurface explorations, piezometer installation, groundwater level monitoring, and developing a numerical model of the aquifer.

The initial phase of work was conducted in accordance with our October 7, 2015 proposal. Notice-to-proceed (NTP) PO No. 73383 for that work was received from Mr. Dean Day of the City of Valdez on October 14, 2015. Because water levels could only be monitored in one location, the City approved our April 8, 2016 proposal to install two additional piezometers via PO No. 73915 on April 20, 2016.

2.0 SITE AND PROJECT DESCRIPTION

Well 4 is located inside of a wellhouse located on the south side of Eagan Drive as shown in Figure 1. In July 1981, DOWL advanced a test well at the approximate current location of Well 4. The test well was advanced to a depth of 180 feet below ground surface (bgs). DOWL concluded that except for a thin layer from about 54 to 59 feet bgs that the saturated materials would produce significant amounts of water above 75 feet bgs. These materials were described as silty, sandy gravel from 7 to 54 feet bgs and gravelly sand from 59 to 74 feet bgs. Below that depth the silty sand formation did not produce water in the test well. Based on the results of the test well, DOWL concluded that a production well in this location could produce between 1,000 and 1,500 gallons per minute.

In August 1981, a 16-inch diameter production well (Well 4) was installed with a cable tool drill rig. Telescoping screen was installed from 38 to 58 and 62 to 75 feet bgs. The screen was closed bottom and a tail pipe was not installed. The well was developed for 40 hours using horizontal water jetting and surging. This effort reportedly produced significant amounts of sand. However, when test pumped it was found that the well did not produce the amount of water expected; pumping at 600 gpm caused the pump to cavitate. An additional 32 hours of development using a back flushing technique was conducted. After this effort the well was able to produce 2,000 gpm. Two cubic yards of gravel were placed around the well to fill a depression that formed during development. Additionally, 72 bags of cement were reportedly used to fill the void between the surface casing (20-inch diameter) and well casing. Based on a rule-of-thumb that one bag (94 pounds) of cement makes approximately 1 cubic foot of cement it should have taken about 21 bags to fill this void.

While Well 4 can meet current water demand, there is no backup supply if something happens to the well's ability to provide water. Additionally, there is a projected need for additional quantities of water in the future. Due to property ownership and existing infrastructure, the City would prefer that a new well be located on the Herman Hutchens Elementary School site, shown in Figure 1. A total of three piezometers were installed, in two phases, to monitor groundwater response to pumping at the existing Well 4. This information was used to develop aquifer properties and a numerical model. The numerical model was used evaluate the potential for interference if both wells are operated simultaneously.

3.0 SUBSURFACE EXPLORATIONS

Subsurface explorations for this study consisted of drilling and sampling one boring to a depth of 65 feet bgs on October 24 and 25, 2015. Figure 1 shows the project area and Figure 2 shows the relative location of Well 4 (located in a well house) and Boring B-1. Two additional borings, designated Piezometers P-1 and P-2, were advanced on May 17, 2016. The general boring locations were selected by the City of Valdez prior to mobilizing to the site.

Drilling services for Boring B-1 were provided by GeoTek Alaska using a truck mounted CME 75 drill rig. Wheaton Water Wells (Wheaton) installed Piezometers P-1 and P-2 using a REICHdrill T-650 air-rotary drill rig. An experienced representative from our firm was present during drilling to locate the holes, observe drill action, collect samples, log subsurface conditions, and observe groundwater conditions. Prior to mobilizing to the site we contacted the Call Locate Center to locate buried utilities in the project area.

Boring B-1 was advanced with 3¼-inch inner diameter (ID), continuous flight, hollow-stem augers to a depth of approximately 65 feet bgs. We had planned on being able to reach a depth of 75 feet bgs in the allocated day of drilling but the drilling was slower than expected due to subsurface conditions. As the boring was advanced, samples were typically recovered using Modified Penetration Test (MPT) methods at 2.5-foot intervals to 20 feet bgs and 5-foot intervals thereafter. In the MPT method, samples are recovered by driving a 3-inch outer diameter (OD) split-spoon sampler into the bottom of the advancing hole with blows of a 340-pound hammer free falling 30 inches onto the drill rod. The number of blows required to advance the sampler the final 12 inches of an 18-inch penetration is termed the penetration resistance. Blow counts are shown graphically on the boring log figures as "penetration resistance" and are displayed adjacent to sample depth. The penetration resistance values give a measure of the relative density (compactness) or consistency (stiffness) of cohesionless or cohesive soils, respectively. In addition to the split-spoon samples, a grab sample of the near-surface soils was collected from the auger cuttings in the upper foot of the boring.

Borings for Piezometers P-1 and P-2 were advanced with an air-rotary drill rig and six-inch casing. As the borings were advanced, disturbed grab samples were periodically collected from the drill cuttings.

Recovered samples were observed and described in the field in general accordance with the classification system described by ASTM International (ASTM) D2488. Selected samples recovered during drilling in Boring B-1 were tested in our laboratory to refine our soil descriptions in general accordance with the Unified Soil Classification System, which is described in Figure A-1. Summary logs of the borings are presented as Figures A-2 to A-4.

Upon completion of each boring, piezometers were installed in the open borehole to facilitate measuring groundwater levels. The piezometers consisted of a 10-foot long, machine-slotted, 2-inch polyvinylchloride (PVC) screen and solid PVC riser pipe. The boreholes were backfilled with cuttings and a bentonite seal was placed around each casing. The top 18 feet of Boring B-1 was backfilled at a later date with pea gravel to address subsidence of the original backfill. The PVC casings were terminated approximately 2.5 feet above grade and a 6-inch diameter, steel protective casing was installed.

4.0 LABORATORY TESTING

Laboratory tests were performed on selected soil samples recovered from Boring B-1 to support our soil descriptions and to estimate the hydrogeological properties of the typical materials encountered at the site. The laboratory testing was formulated with emphasis on determining gradation properties and natural water content.

Water content tests were performed on the samples returned to our laboratory. Water content tests were performed in general accordance with ASTM D2216. The results of the water content measurements are presented graphically on the boring logs (Appendix A, Figure A-2). Grain size classification (gradation) testing was performed on select samples to estimate the particle size distribution. The gradation testing generally followed the procedures described in ASTM C117/C136. The test results are presented in Appendix A, Figure A-5 (2 pages) and summarized on the boring log as percent gravel, percent sand, and percent fines. Percent fines on the boring log are equal to the sum of the silt and clay fractions indicated by the percent passing the No. 200 sieve.

5.0 SUBSURFACE CONDITIONS

The subsurface conditions encountered are presented graphically on the boring/piezometer logs included as Figures A-2 through A-4. Boring B-1 was advanced through an organic mat less than 1 foot thick. Layers of loose silt, silty sand, and sandy silt were encountered to a depth of about 7.5 feet bgs. Between 7.5 and 45 feet bgs a layer of well-graded sand with silt and gravel was encountered. This layer is interpreted to be alluvium and, based on laboratory testing, contained about 6 percent fines. A marked difference in drill action and blow counts was observed at the boundary of this layer and the deeper poorly-graded gravel that was encountered to the bottom of the boring at 65 feet bgs. In addition to being denser and containing more gravel particles, this layer also contained a higher fines content (10 to 22 percent). While Piezometers P-1 and P-2 were logged by cuttings, the soil types generally appeared to be consistent with Boring B-1.

Groundwater was encountered in Boring B-1 at approximately 19.5 feet bgs during drilling. Static groundwater measurements were collected on January 20 and May 18, 2016; groundwater was measured in Boring B-1 at 20.87 and 16.35 feet bgs, respectively. Groundwater was encountered during drilling in Piezometers P-1 and P-2 at 13 and 18 feet bgs, respectively, with static levels measured the following day at 10.66 and 17.86 feet bgs.

6.0 AQUIFER PROPERTIES

The City has not been able to operate Well 4 at its full pumping rate for a significant length of time. Well 4 is not instrumented for water levels or flow. It reportedly operates at a pumping rate of about 1,800 gallons per minute (gpm) and demand is driven by the water level in the storage tank into which it flows. Groundwater levels were monitored during normal operations during two separate timeframes. During the second timeframe the City was able to pump Well 4 for 14 hours straight.

6.1 January Pumping Test

On January 20, 2016 a Shannon & Wilson representative measured the static water level in Boring B-1 and installed a pressure transducer. An effort was made to locate the historic test well near Well 4. No potential test wells were identified in the plowed area around the well house or within the well house. The top of Well 4 was evaluated for the deployment of a second pressure transducer. It was determined that it would take significant effort, and taking the well offline, to install a pressure transducer in the pumping well. Therefore groundwater levels were only monitored at one location (Boring B-1). A barologger was installed on the south side of the well house to allow compensation of the recordings in the pressure transducer to changes in atmospheric pressure.

The pressure transducer was allowed to record water levels until its memory was full (40,000 data points) on March 16, 2016. The pressure transducer and barologger were collected by City of Valdez personnel and downloaded. The downloaded data was emailed to Shannon & Wilson and, after the data was determined to not be corrupted, the pressure transducer and barologger were shipped to Shannon & Wilson.

The collected data was manipulated to show depth to groundwater. Chart 1 shows the entire dataset collected between January 20 and March 16, 2016. From this figure it is evident that water levels varied over a range of about 1.6 feet during the monitoring period. Chart 2 graphs the first 24 hours of observations during this monitoring and it is evident that the variations in water level observed on Chart 1 are not entirely due to pumping of Well 4. A cyclical pattern of drawdown and recharge is apparent on Chart 2 with an overall increasing depth to water. Based on this figure it appears that Well 4 typically operates for 60 to 90 minutes followed by a shutdown period of 2 to 4 hours. Longer shutdown periods are observed during the overnight hours. Chart 3 presents the data for the first week of monitoring from January 20 to 27, 2016. In this chart, the cycling of Well 4 and the overall change in aquifer water levels is observable.

6.2 May Pumping Test

On May 18, 2016 a Shannon & Wilson representative placed pressure transducers in Boring B-1 and Piezometers P-1 and P-2. A barologger was installed in Piezometer P-1, above the groundwater, to allow compensation of the recordings in the pressure transducer to changes in atmospheric pressure.

The pressure transducers were again allowed to record water levels until its memory was full. The pressure transducers and barologger were collected by City of Valdez personnel and downloaded. The downloaded data was emailed to Shannon & Wilson and, after the data was determined to not be corrupted, the pressure transducer and baralogger were shipped to Shannon & Wilson.

Once again the collected data was manipulated to show depth to groundwater. Chart 4 shows the entire dataset collected between May 18 and June 15, 2016. Similar pumping and recovery patterns are observed in the data. On May 25/26, 2016 the City was able to allow the well to recover for about 30 hours without pumping. The pump was then operated for 14 hours at 1,800 gpm. Chart 5 shows the drawdown observed during this pumping test. A maximum drawdown of about 1.7 feet was observed in Piezometer P-1 which is closest to Well 4. A similar drawdown curve, with less drawdown (0.23 feet maximum) was observed for Boring B-1. While drawdown was apparently measured in Piezometer P-2, due to the small amount and distance from the pumping well it is unclear if this drawdown was in response to the pumping at Well 4.

6.3 Aquifer Properties

A review of the pumping test data plotted on Chart 5 indicates that the test data appears reasonable and that problems with data collection were not encountered. Boundary conditions do not appear to have been encountered during pumping; however the pumping time was fairly short.

The data from the pumping test was evaluated in several ways. The data was first manually plotted to calculate initial aquifer transmissivity values using the Cooper-Jacob method. The data from the pumping test was imported into a commercial groundwater software program (Aqtesolv). This program was used to evaluate the data with several methods including the Cooper-Jacob (1946) and Neuman (1974) equations for an unconfined aquifer. The data was also evaluated for delayed-yield effects (common in highly stratified deposits) using the Tartakovsky-Neuman (2007) method. It was determined that the pumping test was not long enough for potential delayed-yield effects to be apparent.

The data from Piezometer P-1 and Boring B-1 were evaluated individually and together using the above methods. Based on this evaluation, we calculated the transmissivity of the aquifer to range from about 470,000 to 1,500,000 gallons per day per foot (gpd/ft) when modeled as an unconfined aquifer. The higher estimates are from the analysis of Boring B-1. Due to the small drawdown observed, we believe that the higher estimates are reflective of the upper portion of the aquifer and not the aquifer as a whole. Therefore we estimate the aquifer transmissivity to be on the order of 600,000 gpd/ft.

Based on the well log for Well 4 the well fully penetrates the aquifer. While the silty sand observed at 75 feet bgs will contribute water to the aquifer, the amount is relatively small compared to the recharge in the materials above this level at the rates and duration that the well is operated. Based on this, we estimate the aquifer thickness contributing to the flow as 60 feet. A hydraulic conductivity value of 0.5 centimeters per second (cm/s) was calculated for the aquifer. This is consistent with a clean, sandy gravel aquifer.

While we were not able to measure water levels in the pumping well we can make an estimate of the pumping water levels using the straight-line method applied to a distance-drawdown plot (Cooper-Jacob, 1946). The distance-drawdown is plotted on semi-log paper. A straight line is plotted between the drawdown in the observation wells and extended to intercept the radius of the pumping well. At the completion of the pumping test, and assuming an 80 percent well efficiency, the predicted drawdown within the well is 5.6 feet.

7.0 NUMERICAL MODELING

Based on the subsurface conditions described in the above sections, we constructed, calibrated, and ran a numerical model to estimate the impact the proposed pumping well on local groundwater conditions. The following subsections provide a description of the model setup and a summary of the modeling results. Detailed modeling documents are presented in Appendix B.

7.1 Modeling Approach

We used the USGS numerical groundwater flow code MODFLOW-2005 to simulate the groundwater flow system in the project area. MODFLOW is a three-dimensional, numerical computer model originally published by the U.S. Geological Survey (McDonald and Harbaugh, 1988) with updates in 2000 and 2005. MODFLOW is a robust model capable of simulating the diverse hydrologic conditions found in the project area. It is widely used and accepted by the groundwater modeling profession and is considered appropriate for this application. We used Groundwater Vistas (Version 6), a graphical interface program, as a pre- and post-processor to create and manage model input and output files for MODFLOW-2005 (Rumbaugh and Rumbaugh, 2007).

The spatial representation of the project area was initially constructed by defining the physical dimensions of the model domain and dividing it into a grid with distinct rows, columns, and layers. This division produces numerous cells that may be individually assigned specific attributes or properties that reflect the natural groundwater system. The groundwater flow system of the study area was numerically simulated to set the initial local aquifer conditions, and the initial conditions were then used to simulate the groundwater system under the proposed development scenarios.

7.2 Model Design

As shown in Figure B-1, we used a model domain measuring 10,000 feet (east-west) by 10,000 feet (north-south) to simulate the groundwater system in the vicinity of Valdez. Horizontally, the model grid consists of 352 rows and 373 columns and variable grid spacing with rows and columns ranging from 10 to 250 feet in width. We used the smallest width of 10 feet in the immediate project area to provide better resolutions for the evaluation of the local hydrogeology. The model grid is shown in Figure B-2. The model's upper surface was established by interpreting a 10-meter resolution digital elevation map (DEM) dataset for the area to the final model grid. Vertically, the model is about 75 feet thick in the project area but varies with topography. Figures B-3 and B-4 show a profile view of the model. Horizontal and vertical extents were chosen to be sufficiently large to capture elements of the groundwater flow system that might be affected by potential boundary effects.

7.3 Boundary Conditions

Boundary conditions are fixed values of hydraulic head (groundwater elevation) or groundwater flux (inflow/outflow rate) defined within or along the edges of the model domain. The boundary conditions used in the model include constant head boundaries, general-head boundaries, and drains (Figure B-1).

General-head boundaries (GHB) allow the water level elevation to be assigned in a cell; the water level is maintained in the cell by adding or removing water from the model from an unlimited source/sink using a specified conductance term. GHBs were used to represent areas where recharge may occur from Mineral Creek in the model. A constant head boundary (CHB) was used to represent the water in Port Valdez. We used CHB to represent the aquifer conditions that may exist beyond the model domain to the north. The addition of these boundary conditions supported the model calibration and resulted in a closer approximation of the observed groundwater conditions. Because of the uncertainty of the extent of the aquifer to the north, we evaluated the followings cases:

1. Unlimited aquifer – We constructed the model with a CHB on the north to represent the aquifer exists beyond the pumping influence zone at the at the north model boundary.

2. Limited aquifer – We constructed the model without a CHB on the north to represent the pumping influence zone reached the limit of the aquifer at the north model boundary.

7.4 Hydraulic Parameters

Hydraulic parameters used in the model include hydraulic conductivity and porosity. Hydraulic conductivity describes the ability of a soil to transmit water. For this evaluation, we used 0.46 cm/s (1,300 ft/day) based on the pumping test analysis and model calibration. We assumed the same horizontal hydraulic conductivity for all units in all directions (isotropic conditions). We also assumed anisotropic conditions for the vertical component of hydraulic conductivity with a 10:1 ratio of horizontal to vertical hydraulic conductivity. Aquifer porosity of 0.25 was used for the model. As discussed below, these values and assumptions appear to be reasonable based on calibration of the model to pumping water levels.

7.5 Model Calibration

Calibration is a process whereby the model results are compared to observed groundwater data and modifications are made to input parameters in order to get a better match to the data set. The numerical model was calibrated to the groundwater level data collected before and during the pumping test from May 23, 2016 to May 27, 2016. Figure B-5 in shows the observed versus modeled groundwater levels at Piezometer P-1. Overall, the modeled-observed piezometric level match is satisfactory for the purpose of this analysis.

7.6 Model Simulation

Using our calibrated model, we simulated several pumping scenarios. Because we are uncertain about the aquifer extent north of the site, we evaluated the scenarios for an unlimited aquifer and a limited aquifer as described in section 7.3. We used a transient state model to simulate the pumping impact based on the current pumping schedule at rate of 1,800 gpm for 1 hour on and 4 hours off. In order to evaluate the long term impact of the pumping, we also simulated steady state condition with constant pumping rate of 427 gpm by averaging the current transient state pumping over a day. Our modeling scenarios are as follows:

- **Baseline Scenario 1a –** Transient state pumping from the existing well at 1,800 gpm for 1 hour on and 4 hours off. Assume aquifer is continuous to the north.
- **Baseline Scenario 1b –** Transient state pumping from the existing well at 1,800 gpm for 1 hour on and 4 hours off. Assume aquifer is not continuous to the north.
- **Baseline Scenario 1c –** Steady state pumping from existing well at constant pumping rate of 427 gpm. Assume aquifer is continuous to the north.
- **Baseline Scenario 1d –** Steady state pumping from existing well at constant pumping rate of 427 gpm. Assume aquifer is not continuous to the north.

- **Production Scenario 2a** – Transient state pumping from existing well and proposed well at 1,800 gpm for 1 hour on and 4 hours off from each well. Assume aquifer is continuous to the north.
- **Production Scenario 2b** – Transient state pumping from existing well and proposed well at 1,800 gpm for 1 hour on and 4 hours off from each well. Assume aquifer is not continuous to the north.
- **Production Scenario 2c** – Steady state pumping from the existing and proposed wells at constant pumping rate of 427 gpm from each well. Assume aquifer is continuous to the north.
- **Production Scenario 2d** – Steady state pumping from the existing and proposed wells at constant pumping rate of 427 gpm from each well. Assume aquifer is not continuous to the north.

7.7 Analysis and Conclusions

We used our model to evaluate the impact of the pumping by comparing the maximum modeled drawdown at Boring B-1 and Piezometers P-1 and P-2. Groundwater modeling results show that drawdown ranged from 1.1 to 2.7 ft at Piezometer P-1 under the current existing well pumping schedule, when steady-state conditions are reached after 20 days of pumping. Drawdown from pumping from Well 4 and the proposed well at the current pumping schedule will increase the drawdown to between 1.4 and 3.2 ft, in Piezometer P-1. The model results also show that the steady state pumping with lower pumping rates would result in less drawdown in the aquifer. A third scenario was evaluated in which both wells were pumping at 1,800 and 3,600 gpm. Under the 'unlimited' scenario it appears that the aquifer can sustain both wells running at 1,800 gpm without excessive drawdown. A summary of the model output is included below and detail model set up and drawdown contours are shown Appendix B.

Scenario	Number of Pumping Wells	Pumping Rates (each well in gpm)	Pumping Schedule	Aquifer Extend to Northern Model Boundary	Maximum Drawdown (ft)		
					P-1	B-1	P-2
1a	1	1800	1 hr on, 4 hrs off	Unlimited	1.1	0.2	0.1
1b	1	1800	1 hr on, 4 hrs off	Limited	2.7	2.4	2.3
1c	1	427	Constant	Unlimited	0.7	0.2	0.1
1d	1	427	Constant	Limited	0.8	0.3	0.2
2a	2	1800	1 hr on, 4 hrs off	Unlimited	1.4	1.1	0.4
2b	2	1800	1 hr on, 4 hrs off	Limited	3.2	2.6	2.7
2c	2	427	Constant	Unlimited	0.9	0.7	0.4
2d	2	427	Constant	Limited	0.9	0.8	0.4
3a	2	1800	Constant	Unlimited	3.7	3.2	1.5
3b	2	3600	Constant	Unlimited	7.6	6.5	2.9

8.0 DISCUSSION

In Chart 1 it is evident that significant recharge events occurred twice during the monitoring of water levels. These events appeared to occur around January 26 and February 21. Weather observations (temperature and precipitation) are not yet available for this time period so it is unknown if water levels changed due to precipitation or snowmelt (or a combination). While this indicates that the aquifer is influenced by changes in surface water it does not necessarily mean that the aquifer should be considered groundwater under direct influence of surface water (GWUDISW).

An initial comparison of the subsurface conditions at the Boring B-1 indicates that the aquifer materials encountered would likely not be as productive as the conditions logged at Well 4. The Well 4 log did not identify the transition to denser, siltier material below 45 feet bgs. However further review of the well log and development summary indicates that the aquifer materials may be similar. The prior well log is not as descriptive as the log of Boring B-1 and the samples logged were disturbed. This prior sampling effort could easily underestimate the amount of fine sand and silt in the aquifer materials.

During development of Well 4 nearly four cubic yards of material was removed from around the well screen. This estimate is based on the two yards of gravel added to fill the depression around the well and the additional concrete that was required to create the well seal. We interpret this to indicate that the additional sand and fines in the formation near the lower portion of the well screen were removed to create a natural filter pack that is more like the shallower aquifer materials.

The results of the 14-hour pumping test were used to develop an estimate of aquifer properties. Based on this, test an aquifer thickness of 60 feet and a hydraulic conductivity of 0.5 cm/s was estimated. This hydraulic conductivity is consistent with the types of soil observed in Boring B-1. A calculated drawdown in Well 4 of 5.6 feet after 14 hours of pumping was estimated.

A numerical model was developed for the aquifer. Based on calibration of the model to the pumping test results the hydraulic conductivity value was modified to 0.46 cm/s. The model was used to predict expected drawdown in the aquifer if a second well was added on the school property. Based on the results of the model, it appears that not only is a second well possible, but that both wells may be able to be pumped at a steady state rate of 1,800 gpm. Based on the results of the model it appears that the northern boundary responds somewhere between the scenarios evaluated.

9.0 CONCLUSIONS/RECOMMENDATIONS

Based on nearly 4-months of water level measurements at Boring B-1 the current operation of Well 4 has a minimal impact on water levels in Boring B-1. If Well 4 is operated for longer periods of time in the future we would expect more significant impact to water levels in the vicinity of Boring B-1. Using the current pumping scenario, the model predicts that steady-state conditions are reached in the aquifer after 20 days with a maximum predicted drawdown of 2.4 feet at Boring B-1. Based on the water level measurements, the aquifer appears to respond rapidly to recharge events; however, based on the information available, we are unsure if the recharge events were precipitation or snow melt.

Based on our conclusion about the similarity of the aquifer between the two locations and the results of the numerical modeling, it appears that a production well located near Boring B-1 should be able to produce similar amounts of water as Well 4. To achieve this production a significant development effort would be needed and there is the possibility that the aquifer can't be developed enough to realize similar production. If operated simultaneously for longer periods of time than Well 4 is currently operated it is likely that additional interference (increased drawdown and potentially less production) will be observed. Based on the modeling conducted it appears that 0.5 feet of additional drawdown will be observed in the aquifer near the wells with two wells pumping under the current pumping schedule.

Accurate well performance data is an important component of a long-term well monitoring plan that includes regular monitoring and periodic maintenance/rehabilitation. Water level measurements and pumping rates should be determined and logged as frequently as possible so well performance can be tracked over time allowing potential pump problems to be identified early on. Currently there is no monitoring of the water levels in Well 4. The water levels in the well should also be compared to the predicted water level of 5.6 feet after 14 hours of pumping. This will allow a calculation of well efficiency.

Specific capacity (flow rate divided by drawdown) is a good indicator for determining when routine maintenance may be needed. Shannon & Wilson suggests that the specific capacity be monitored at least monthly during operation, and a simple database be established to record the information. An initial baseline specific capacity should be estimated while pumping at the normal production rate. When the specific capacity has declined by 10-percent, Shannon & Wilson recommends that a more thorough analysis be performed to determine the cause of the decline and develop options for regaining or reducing additional losses in specific capacity.

10.0 CLOSURE/LIMITATIONS

This report was prepared for the exclusive use of our client and their representatives for evaluating the site as it relates to the geotechnical aspects discussed herein. The analyses and conclusions contained in this report are based on site conditions as they presently exist. It is assumed that the exploratory borings are representative of the subsurface conditions throughout the site, i.e., the subsurface conditions everywhere are not significantly different from those disclosed by the explorations. Groundwater levels and recharge vary by season and from year to year. The available water in the aquifer could vary substantially from what was observed during this study.

If, during construction, subsurface conditions different from those encountered in these explorations are observed or appear to be present, Shannon & Wilson, Inc. should be advised at once so that these conditions can be reviewed and recommendations can be reconsidered where necessary. If there is a substantial lapse of time between the submittal of this report and the start of work at the site, or if conditions have changed due to natural causes or construction operations at or adjacent to the site, it is recommended that this report be reviewed to determine the applicability of the conclusions considering the changed conditions and time lapse.

Shannon & Wilson has prepared the attachments in Appendix C *Important Information About Your Geotechnical/Environmental Report* to assist you and others in understanding the use and limitations of the reports.

Copies of documents that may be relied upon by our client are limited to the printed copies (also known as hard copies) that are signed or sealed by Shannon & Wilson with a wet, blue ink signature. Files provided in electronic media format are furnished solely for the convenience of the client. Any conclusion or information obtained or derived from such electronic files shall be at the user's sole risk. If there is a discrepancy between the electronic files and the hard copies, or you question the authenticity of the report please contact the undersigned.

We appreciate this opportunity to be of service. Please contact the undersigned at (907) 561-2120 with questions or comments concerning the contents of this report.

SHANNON & WILSON, INC.

Stafford Glashan, P.E.
Senior Engineer

SJG:KLB

CHART 1 - DEPTH TO GROUNDWATER (January 20 to March 16, 2016)

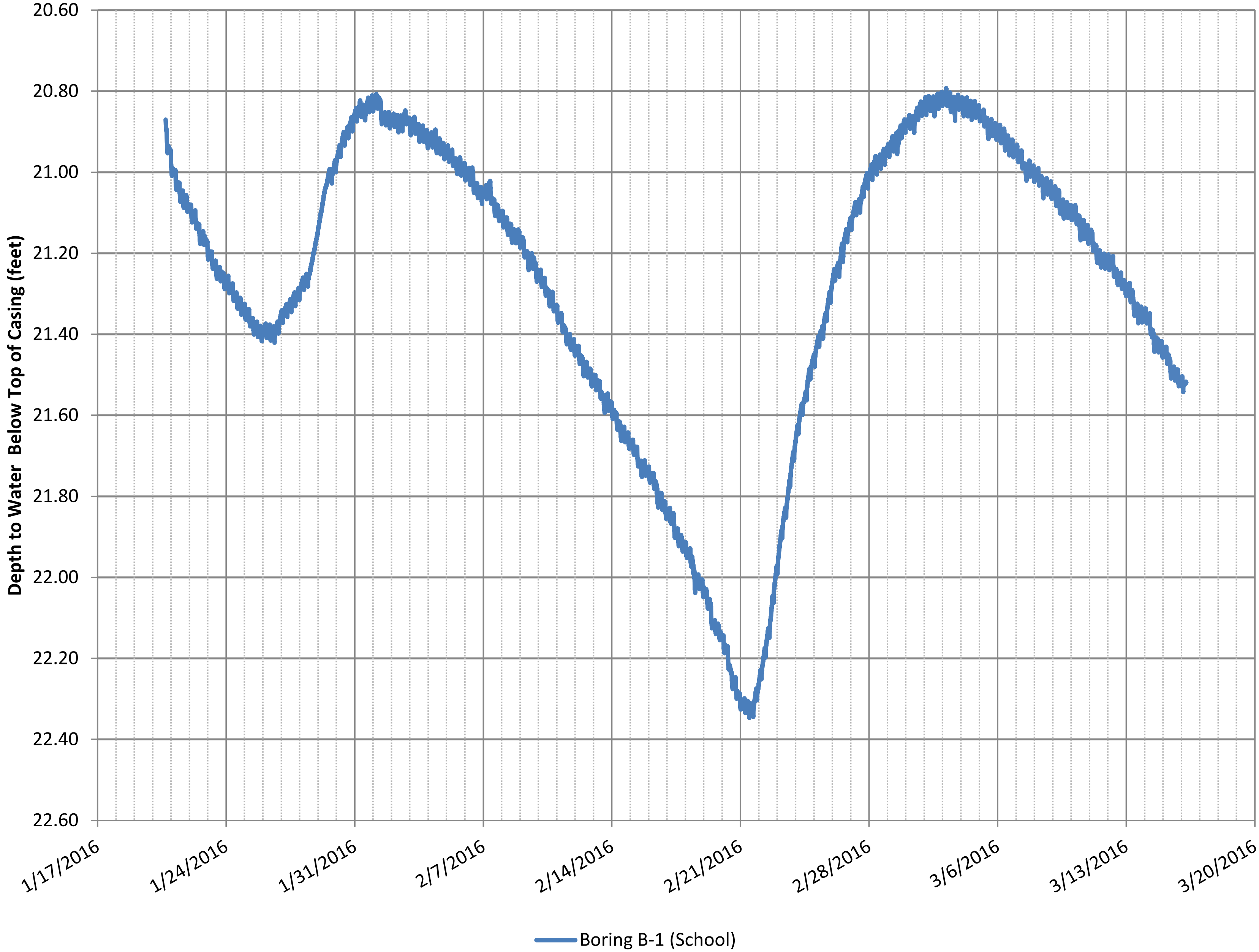


CHART 2 - DEPTH TO GROUNDWATER (January 20, 2016)

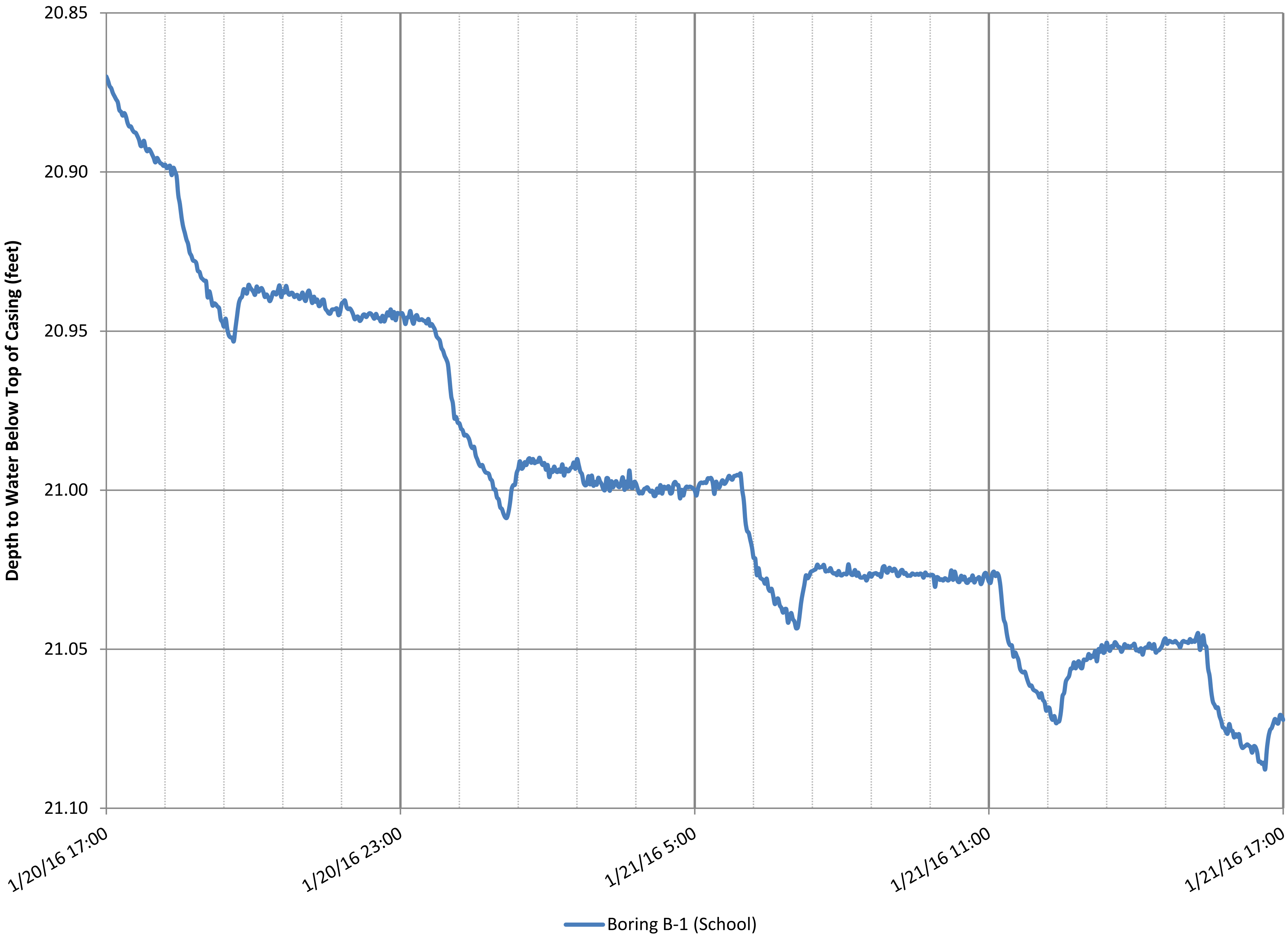


CHART 3 - DEPTH TO GROUNDWATER (January 20 to 27, 2016)

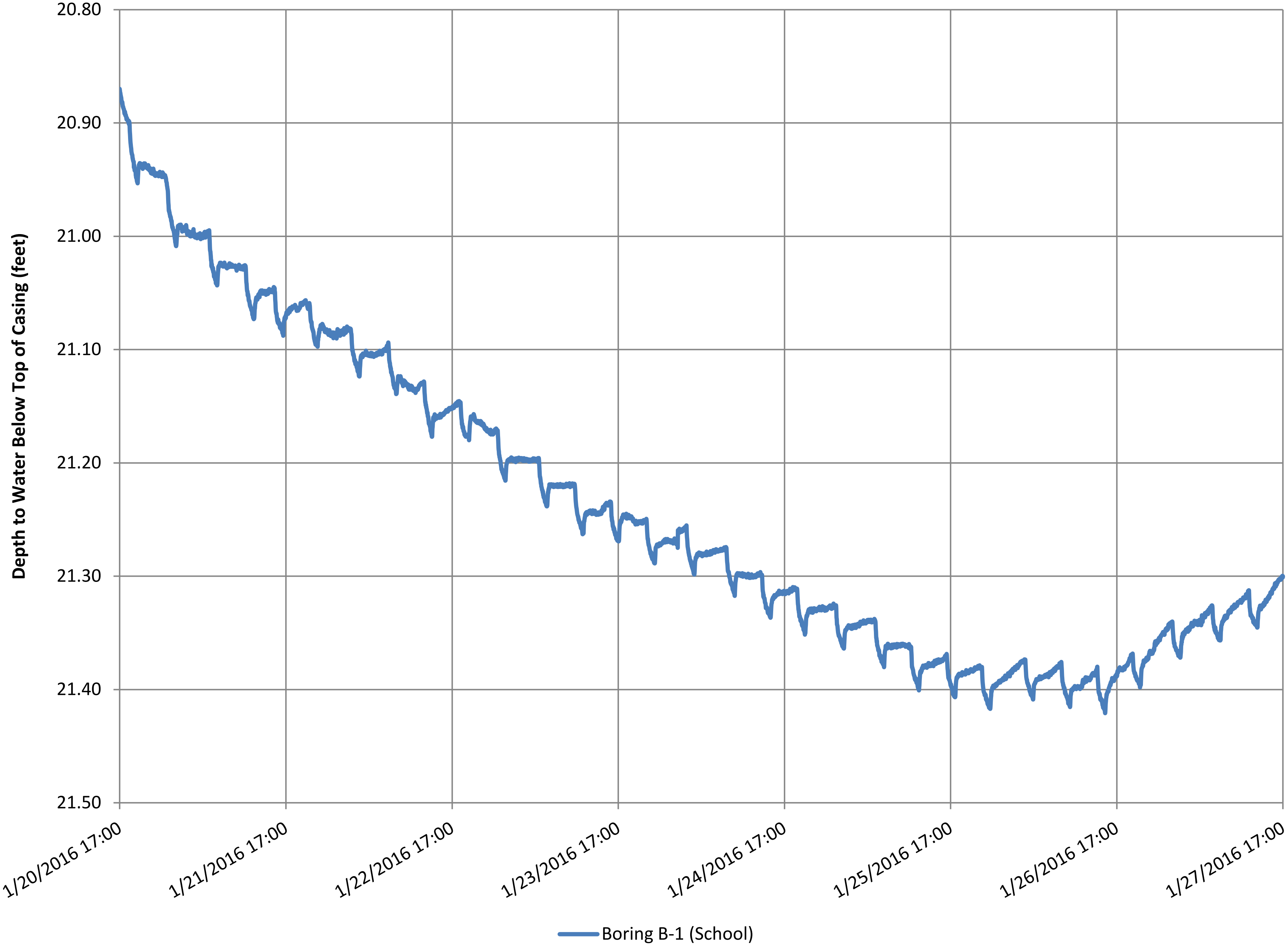


CHART 4 - DEPTH TO GROUNDWATER (May 18 to June 15, 2016)

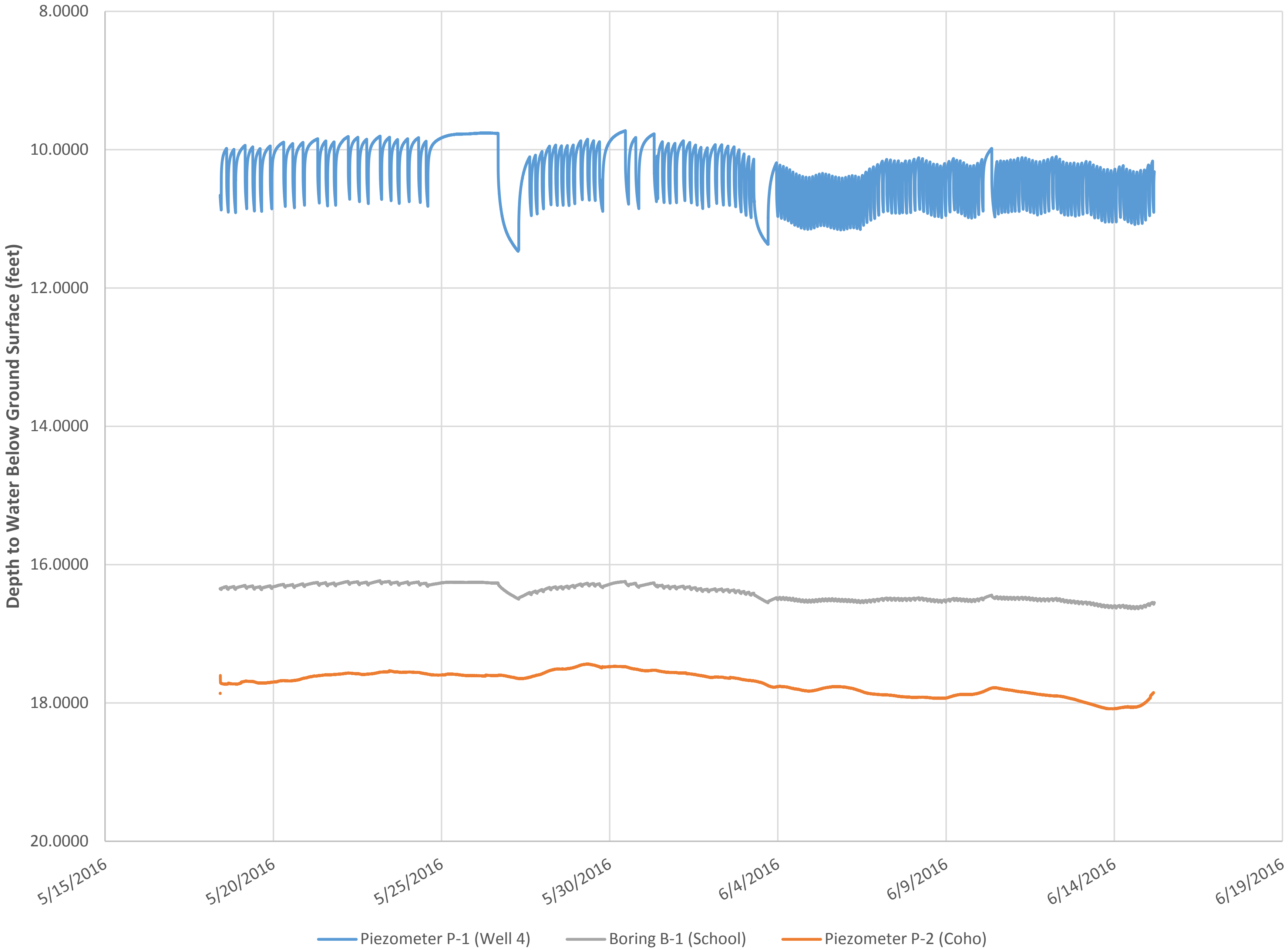
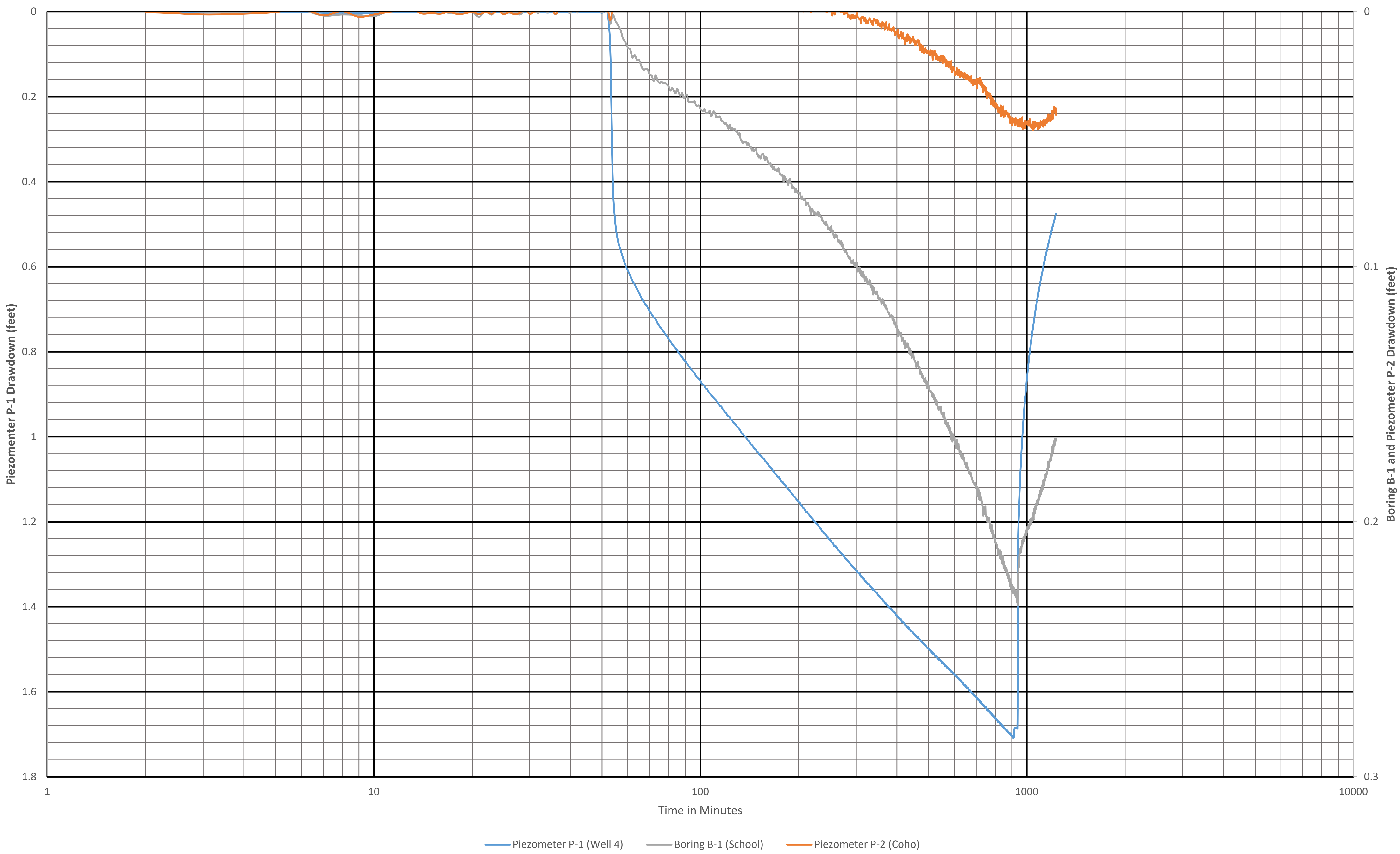
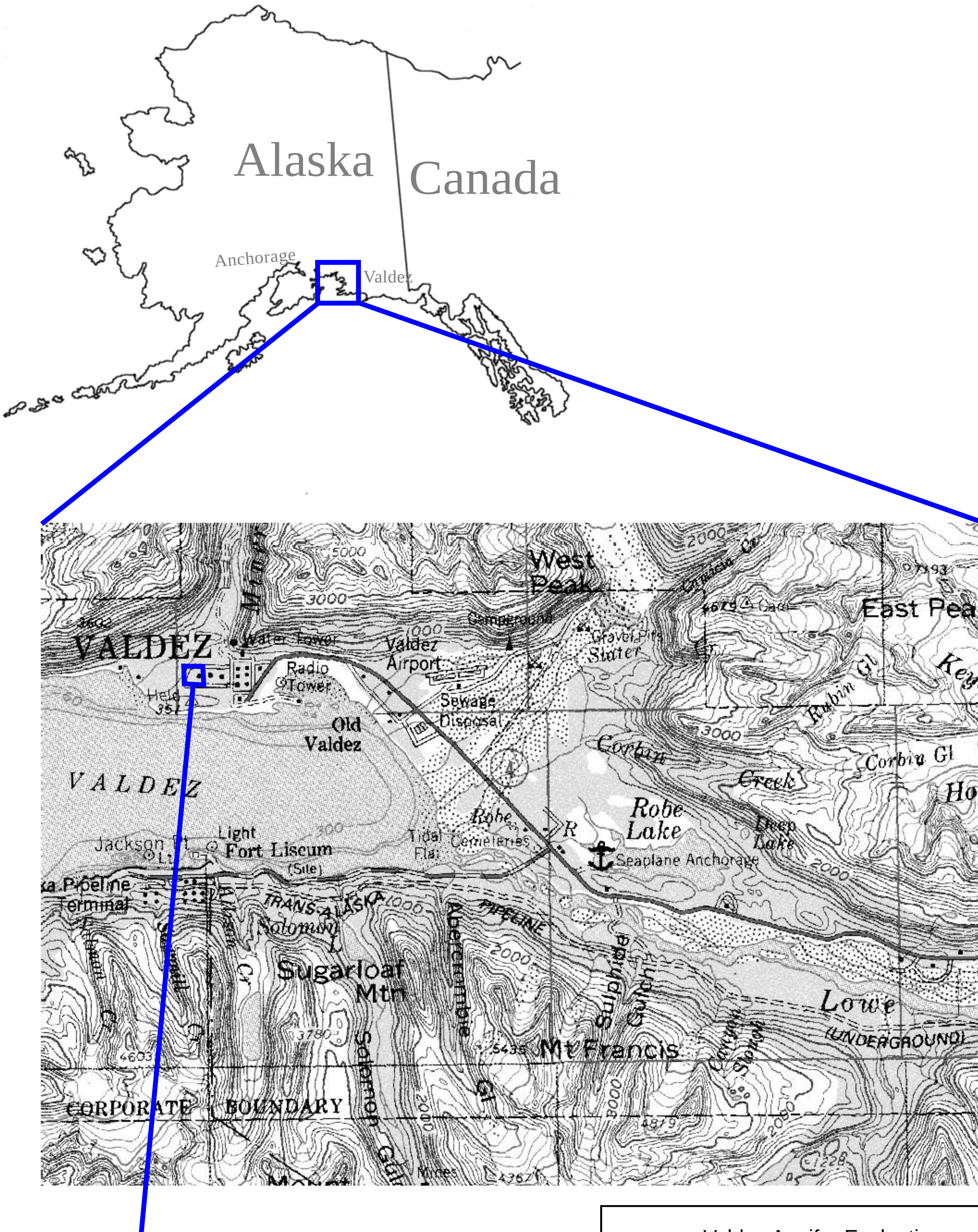


CHART 5 - MAY 26, 2016 PUMPING TEST





Approximate Location of Project

Base map taken from USGS
Map Valdez C-5 SW Quadrangle
Not to Scale

Valdez Aquifer Evaluation
Valdez, Alaska

VICINITY MAP

August 2016

32-1-02498

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FIG. 1

LEGEND

B-I — Approximate Location of Boring B-1, Advanced by Shannon & Wilson, October 2015 / May 2016

NOTES

1. Basemap imagery (June 2007) provided by Google Earth Pro, reproduced by permission granted by Google Earth™ Mapping Service.

0 150 300 600
APPROXIMATE SCALE IN FEET

Valdez Aquifer Evaluation
Valdez, Alaska

SITE PLAN

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FIG. 2

APPENDIX A

BORING LOGS AND LABORATORY TEST RESULTS

FIGURES

Shannon & Wilson, Inc. (S&W), uses a soil identification system modified from the Unified Soil Classification System (USCS). Elements of the USCS and other definitions are provided on this and the following pages. Soil descriptions are based on visual-manual procedures (ASTM D2488) and laboratory testing procedures (ASTM D2487), if performed.

S&W INORGANIC SOIL CONSTITUENT DEFINITIONS

CONSTITUENT[2]	FINE-GRAINED SOILS (50% or more fines)[1]	COARSE-GRAINED SOILS (less than 50% fines)[1]
Major	***Silt, Lean Clay, Elastic Silt,*** or ***Fat Clay***[3]	***Sand*** or ***Gravel***[4]
Modifying (Secondary) Precedes major constituent	30% or more coarse-grained: ***Sandy*** or ***Gravelly***[4]	More than 12% fine-grained: ***Silty*** or ***Clayey***[3]
Minor Follows major constituent	15% to 30% coarse-grained: ***with Sand*** or ***with Gravel***[4]	5% to 12% fine-grained: ***with Silt*** or ***with Clay***[3]
	30% or more total coarse-grained *and* lesser coarse-grained constituent is 15% or more: ***with Sand*** or ***with Gravel***[5]	15% or more of a second coarse-grained constituent: ***with Sand*** or ***with Gravel***[5]

[1]All percentages are by weight of total specimen passing a 3-inch sieve.
[2]The order of terms is: *Modifying Major with Minor*.
[3]Determined based on behavior.
[4]Determined based on which constituent comprises a larger percentage.
[5]Whichever is the lesser constituent.

MOISTURE CONTENT TERMS

Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, from below water table

STANDARD PENETRATION TEST (SPT) SPECIFICATIONS

Hammer:	140 pounds with a 30-inch free fall. Rope on 6- to 10-inch-diam. cathead 2-1/4 rope turns, > 100 rpm NOTE: If automatic hammers are used, blow counts shown on boring logs should be adjusted to account for efficiency of hammer.
Sampler:	10 to 30 inches long Shoe I.D. = 1.375 inches Barrel I.D. = 1.5 inches Barrel O.D. = 2 inches
N-Value:	Sum blow counts for second and third 6-inch increments. Refusal: 50 blows for 6 inches or less; 10 blows for 0 inches.

NOTE: Penetration resistances (N-values) shown on boring logs are as recorded in the field and have not been corrected for hammer efficiency, overburden, or other factors.

PARTICLE SIZE DEFINITIONS

DESCRIPTION	SIEVE NUMBER AND/OR APPROXIMATE SIZE
FINES	< #200 (0.075 mm = 0.003 in.)
SAND	
Fine	#200 to #40 (0.075 to 0.4 mm; 0.003 to 0.02 in.)
Medium	#40 to #10 (0.4 to 2 mm; 0.02 to 0.08 in.)
Coarse	#10 to #4 (2 to 4.75 mm; 0.08 to 0.187 in.)
GRAVEL	
Fine	#4 to 3/4 in. (4.75 to 19 mm; 0.187 to 0.75 in.)
Coarse	3/4 to 3 in. (19 to 76 mm)
COBBLES	3 to 12 in. (76 to 305 mm)
BOULDERS	> 12 in. (305 mm)

RELATIVE DENSITY / CONSISTENCY

COHESIONLESS SOILS		COHESIVE SOILS	
N, SPT, BLOWS/FT.	RELATIVE DENSITY	N, SPT, BLOWS/FT.	RELATIVE CONSISTENCY
< 4	Very loose	< 2	Very soft
4 - 10	Loose	2 - 4	Soft
10 - 30	Medium dense	4 - 8	Medium stiff
30 - 50	Dense	8 - 15	Stiff
> 50	Very dense	15 - 30	Very stiff
		> 30	Hard

WELL AND BACKFILL SYMBOLS

Bentonite Cement Grout	Surface Cement Seal
Bentonite Grout	Asphalt or Cap
Bentonite Chips	Slough
Silica Sand	Inclinometer or Non-perforated Casing
Perforated or Screened Casing	Vibrating Wire Piezometer

PERCENTAGES TERMS [1, 2]

Trace	< 5%
Few	5 to 10%
Little	15 to 25%
Some	30 to 45%
Mostly	50 to 100%

[1]Gravel, sand, and fines estimated by mass. Other constituents, such as organics, cobbles, and boulders, estimated by volume.

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SOIL DESCRIPTION AND LOG KEY

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FIG. A-1
Sheet 1 of 3

2013_BORING_CLASS1 02498 VALDEZ GROUNDWATER.GPJ SWNEW.GDT 7/29/16

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)
(Modified From USACE Tech Memo 3-357, ASTM D2487, and ASTM D2488)

MAJOR DIVISIONS			GROUP/GRAPHIC SYMBOL	TYPICAL IDENTIFICATIONS
COARSE-GRAINED SOILS *(more than 50% retained on No. 200 sieve)*	Gravels *(more than 50% of coarse fraction retained on No. 4 sieve)*	Gravel *(less than 5% fines)*	GW	Well-Graded Gravel; Well-Graded Gravel with Sand
			GP	Poorly Graded Gravel; Poorly Graded Gravel with Sand
		Silty or Clayey Gravel *(more than 12% fines)*	GM	Silty Gravel; Silty Gravel with Sand
			GC	Clayey Gravel; Clayey Gravel with Sand
	Sands *(50% or more of coarse fraction passes the No. 4 sieve)*	Sand *(less than 5% fines)*	SW	Well-Graded Sand; Well-Graded Sand with Gravel
			SP	Poorly Graded Sand; Poorly Graded Sand with Gravel
		Silty or Clayey Sand *(more than 12% fines)*	SM	Silty Sand; Silty Sand with Gravel
			SC	Clayey Sand; Clayey Sand with Gravel
FINE-GRAINED SOILS *(50% or more passes the No. 200 sieve)*	Silts and Clays *(liquid limit less than 50)*	Inorganic	ML	Silt; Silt with Sand or Gravel; Sandy or Gravelly Silt
			CL	Lean Clay; Lean Clay with Sand or Gravel; Sandy or Gravelly Lean Clay
		Organic	OL	Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly Organic Silt or Clay
	Silts and Clays *(liquid limit 50 or more)*	Inorganic	MH	Elastic Silt; Elastic Silt with Sand or Gravel; Sandy or Gravelly Elastic Silt
			CH	Fat Clay; Fat Clay with Sand or Gravel; Sandy or Gravelly Fat Clay
		Organic	OH	Organic Silt or Clay; Organic Silt or Clay with Sand or Gravel; Sandy or Gravelly Organic Silt or Clay
HIGHLY-ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor		PT	Peat or other highly organic soils (see ASTM D4427)

NOTE: No. 4 size = 4.75 mm = 0.187 in.; No. 200 size = 0.075 mm = 0.003 in.

NOTES

1. Dual symbols *(symbols separated by a hyphen, i.e., SP-SM, Sand with Silt)* are used for soils with between 5% and 12% fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart. Graphics shown on the logs for these soil types are a combination of the two graphic symbols (e.g., SP and SM).

2. Borderline symbols *(symbols separated by a slash, i.e., CL/ML, Lean Clay to Silt; SP-SM/SM, Sand with Silt to Silty Sand)* indicate that the soil properties are close to the defining boundary between two groups.

Valdez Aquifer Evaluation
Valdez, Alaska

SOIL DESCRIPTION AND LOG KEY

August 2016 32-1-02498

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FIG. A-1
Sheet 2 of 3

GRADATION TERMS

Poorly Graded	Narrow range of grain sizes present or, within the range of grain sizes present, one or more sizes are missing (Gap Graded). Meets criteria in ASTM D2487, if tested.
Well-Graded	Full range and even distribution of grain sizes present. Meets criteria in ASTM D2487, if tested.

CEMENTATION TERMS[1]

Weak	Crumbles or breaks with handling or slight finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

PLASTICITY[2]

DESCRIPTION	VISUAL-MANUAL CRITERIA	APPROX. PLASITICTY INDEX RANGE
Nonplastic	A 1/8-in. thread cannot be rolled at any water content.	< 4
Low	A thread can barely be rolled and a lump cannot be formed when drier than the plastic limit.	4 to 10
Medium	A thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. A lump crumbles when drier than the plastic limit.	10 to 20
High	It take considerable time rolling and kneading to reach the plastic limit. A thread can be rerolled several times after reaching the plastic limit. A lump can be formed without crumbling when drier than the plastic limit.	> 20

ADDITIONAL TERMS

Mottled	Irregular patches of different colors.
Bioturbated	Soil disturbance or mixing by plants or animals.
Diamict	Nonsorted sediment; sand and gravel in silt and/or clay matrix.
Cuttings	Material brought to surface by drilling.
Slough	Material that caved from sides of borehole.
Sheared	Disturbed texture, mix of strengths.

PARTICLE ANGULARITY AND SHAPE TERMS[1]

Angular	Sharp edges and unpolished planar surfaces.
Subangular	Similar to angular, but with rounded edges.
Subrounded	Nearly planar sides with well-rounded edges.
Rounded	Smoothly curved sides with no edges.
Flat	Width/thickness ratio > 3.
Elongated	Length/width ratio > 3.

[1]Reprinted, with permission, from ASTM D2488 - 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.
[2]Adapted, with permission, from ASTM D2488 - 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.

ACRONYMS AND ABBREVIATIONS

ATD	At Time of Drilling
Diam.	Diameter
Elev.	Elevation
ft.	Feet
FeO	Iron Oxide
gal.	Gallons
Horiz.	Horizontal
HSA	Hollow Stem Auger
I.D.	Inside Diameter
in.	Inches
lbs.	Pounds
MgO	Magnesium Oxide
mm	Millimeter
MnO	Manganese Oxide
NA	Not Applicable or Not Available
NP	Nonplastic
O.D.	Outside Diameter
OW	Observation Well
pcf	Pounds per Cubic Foot
PID	Photo-Ionization Detector
PMT	Pressuremeter Test
ppm	Parts per Million
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
rpm	Rotations per Minute
SPT	Standard Penetration Test
USCS	Unified Soil Classification System
q_u	Unconfined Compressive Strength
VWP	Vibrating Wire Piezometer
Vert.	Vertical
WOH	Weight of Hammer
WOR	Weight of Rods
Wt.	Weight

STRUCTURE TERMS[1]

Interbedded	Alternating layers of varying material or color with layers at least 1/4-inch thick; singular: bed.
Laminated	Alternating layers of varying material or color with layers less than 1/4-inch thick; singular: lamination.
Fissured	Breaks along definite planes or fractures with little resistance.
Slickensided	Fracture planes appear polished or glossy; sometimes striated.
Blocky	Cohesive soil that can be broken down into small angular lumps that resist further breakdown.
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay.
Homogeneous	Same color and appearance throughout.

Valdez Aquifer Evaluation
Valdez, Alaska

SOIL DESCRIPTION AND LOG KEY

August 2016 32-1-02498

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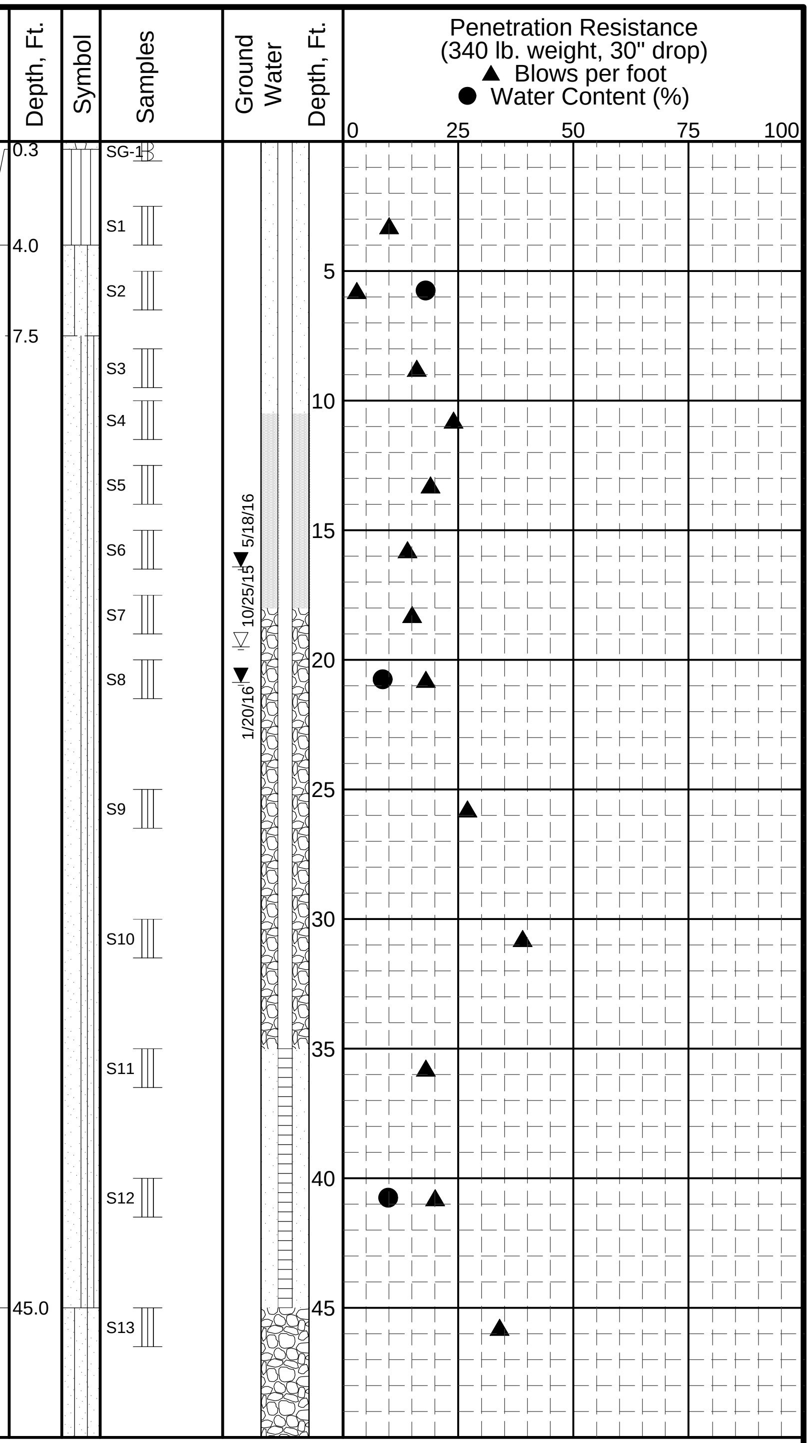
FIG. A-1
Sheet 3 of 3

2013_BORING_CLASS3 02498 VALDEZ GROUNDWATER.GPJ SWNEW.GDT 7/29/16

MATERIAL DESCRIPTION

Approx. Elevation:

Depth, Ft.	Material Description
0.3	Organic Mat, Roots, leaves, detritus.
4.0	Loose, gray *Silt with Gravel (ML)*; moist; trace fine roots.
7.5	Loose, gray, *Sandy Silt (ML) to Silty Sand (SM)*; moist. S2: 1% Gravel, 57% Sand, 42% Fines
45.0	Medium dense to dense, gray, *Well Graded Sand with Silt and Gravel (SP-SM)*; moist to wet. S8: 40% Gravel, 53% Sand, 6% Fines. S12: 31% Gravel, 62% Sand, 7% Fines
	Medium dense to dense, gray, *Silty Sand with Gravel* (SM); wet



CONTINUED NEXT PAGE

LEGEND

- * Sample Not Recovered
- Grab Sample
- 3" O.D. Split Spoon Sample
- Ground Water Level At Time Of Drilling
- Static Water Level
- Blank Casing, Annular Seal
- Blank Section, Cuttings Backfill
- Slotted Section, Cuttings Backfill
- VWP Ground Water Level

● Water Content (%)

Plastic Limit |—●—| Liquid Limit

Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

Valdez Aquifer Evaluation
Valdez, Alaska

LOG OF BORING B-1

August 2016 32-1-02498

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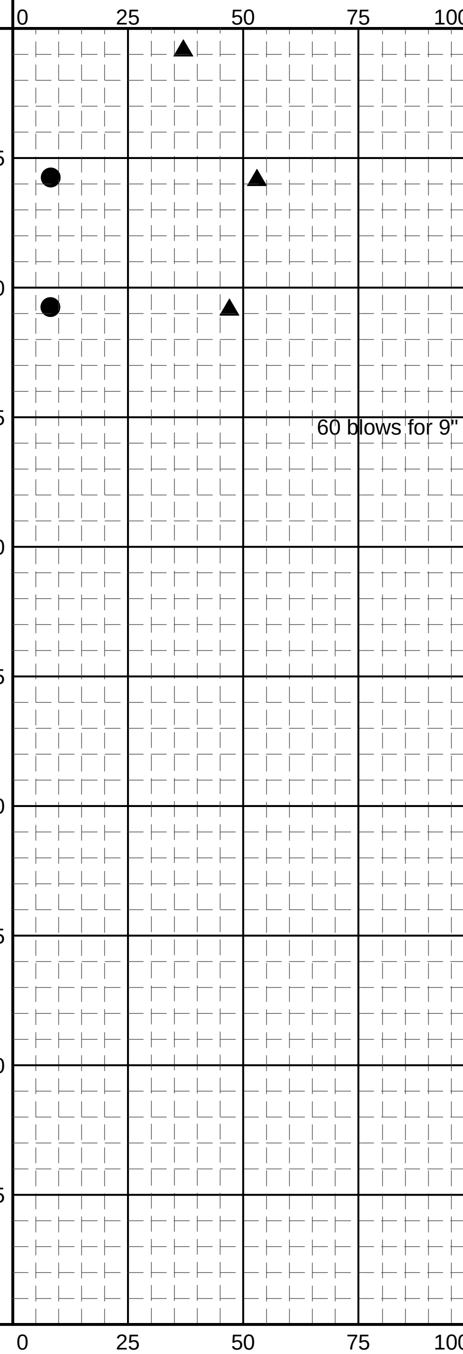
FIG. A-2
Sheet 1 of 2

REV 3 - Approved for Submittal

MATERIAL DESCRIPTION Approx. Elevation:	Depth, Ft.	Symbol	Samples	Ground Water	Depth, Ft.
Medium dense to dense, gray, *Silty Sand with Gravel* (SM); wet S15: 36% Gravel, 42% Sand, 22% Fines			S14 S15		55
Dense, gray, *Poorly-Graded Gravel with Silt and Sand* (GP-GM); wet S16: 48% Gravel, 41% Sand, 10% Fines	57.5		S16 S17		60 65
Bottom of Boring Boring Completed 10/25/15	65.8				70 75 80 85 90 95

Penetration Resistance
(340 lb. weight, 30" drop)
▲ Blows per foot
● Water Content (%)



● Water Content (%)
Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

LEGEND

- * Sample Not Recovered
- Grab Sample
- 3" O.D. Split Spoon Sample
- Ground Water Level At Time Of Drilling
- Static Water Level
- Blank Casing, Annular Seal
- Blank Section, Cuttings Backfill
- Slotted Section, Cuttings Backfill
- VWP Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

Valdez Aquifer Evaluation
Valdez, Alaska

LOG OF BORING B-1

August 2016 32-1-02498

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FIG. A-2
Sheet 2 of 2

REV 3 - Approved for Submittal

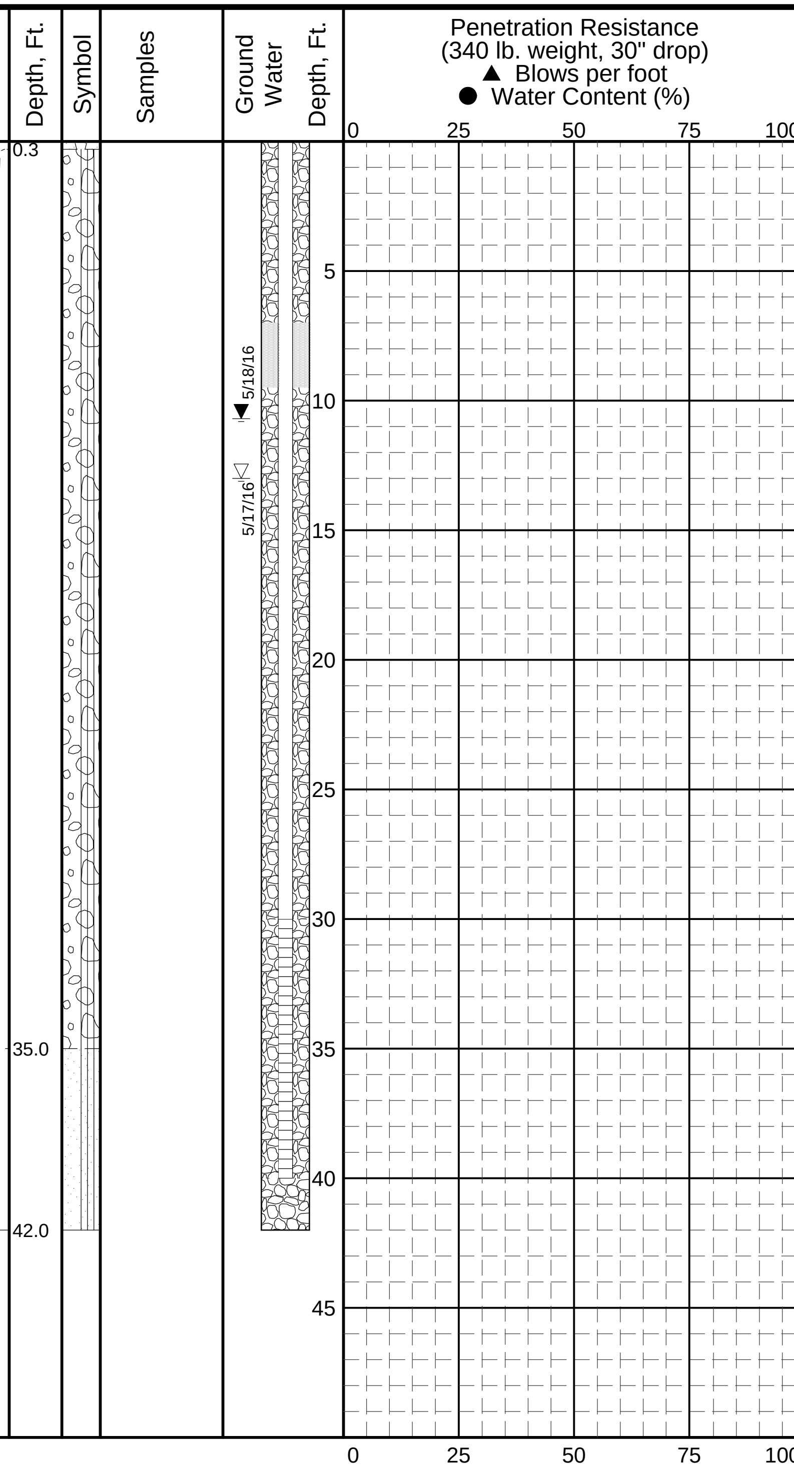
GEOTECHNICAL LOG 02498 VALDEZ GROUNDWATER.GPJ S&W GEO1.GDT 8/1/16

MATERIAL DESCRIPTION

Approx. Elevation:

Depth, Ft.	Material Description
0.3	Organic Mat
35.0	Dark gray, *Gravel with Silt and Sand (GP-GM)* to *Silty Gravel with Sand (GM)*; moist to wet; few cobbles
42.0	Dark gray, *Sand with Silt and Gravel (SP-SM)* grading to *Silty Sand with Gravel (SM)*; wet

Bottom of Boring
Boring Completed 5/17/16



LEGEND

- * Sample Not Recovered
- Grab Sample
- 3" O.D. Split Spoon Sample
- Ground Water Level At Time Of Drilling
- Static Water Level
- Blank Casing, Annular Seal
- Blank Section, Cuttings Backfill
- Slotted Section, Cuttings Backfill

● Water Content (%)
Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

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LOG OF PIEZOMETER P-1

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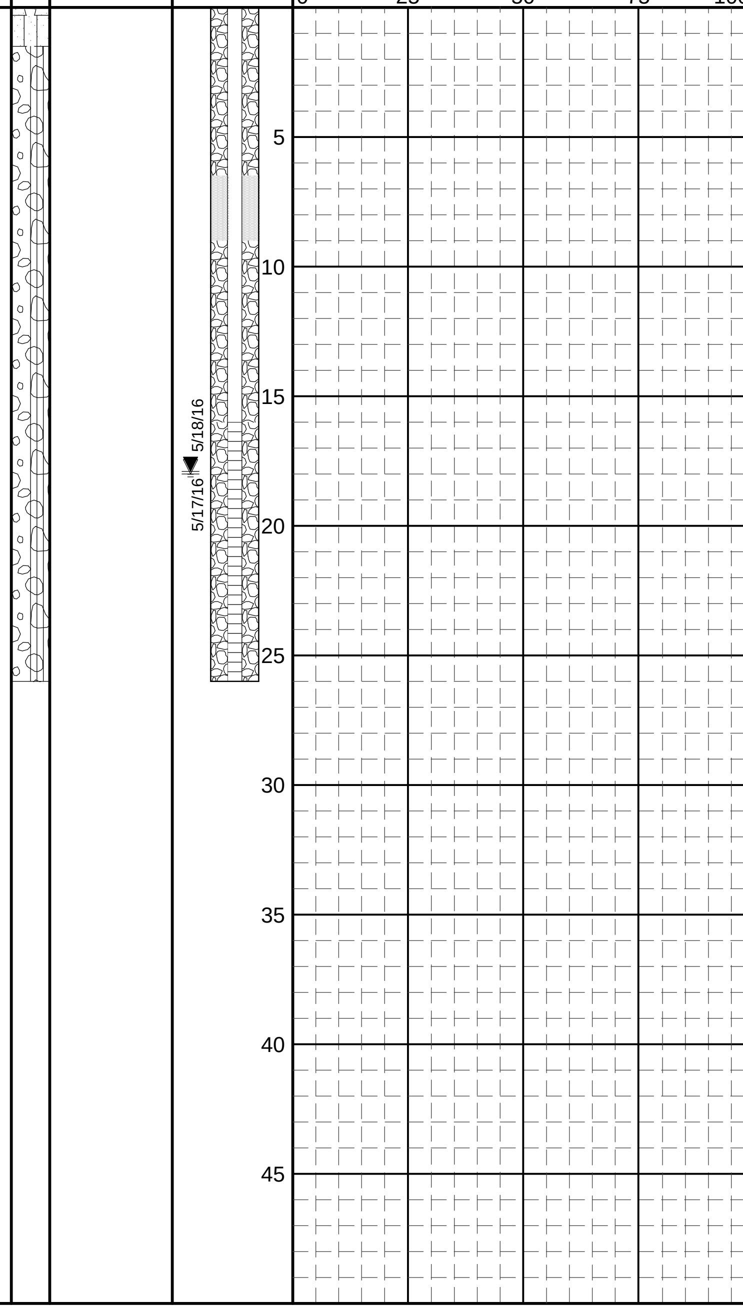
FIG. A-3

REV 3 - Approved for Submittal

MATERIAL DESCRIPTION	Depth, Ft.	Symbol	Samples	Ground Water	Depth, Ft.	Penetration Resistance (340 lb. weight, 30" drop) ▲ Blows per foot ● Water Content (%)
Approx. Elevation:						0 25 50 75 100
Organic Mat	0.3					
Dark gray to brown, *Silty Sand with Gravel (SM)*; moist	1.5					
Dark gray, *Gravel with Silt and Sand (GP-GM)* to *Silty Gravel with Sand (GM)*; moist to wet; few to little cobbles	26.0			5/18/16 5/17/16	5 10 15 20 25	
Bottom of Boring Boring Completed 5/17/16					30 35 40 45	



LEGEND

* Sample Not Recovered
Grab Sample
3" O.D. Split Spoon Sample
Ground Water Level At Time Of Drilling
Static Water Level
Blank Casing, Annular Seal
Blank Section, Cuttings Backfill
Slotted Section, Cuttings Backfill

● Water Content (%)
Plastic Limit — ● — Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

Valdez Aquifer Evaluation
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LOG OF PIEZOMETER P-2

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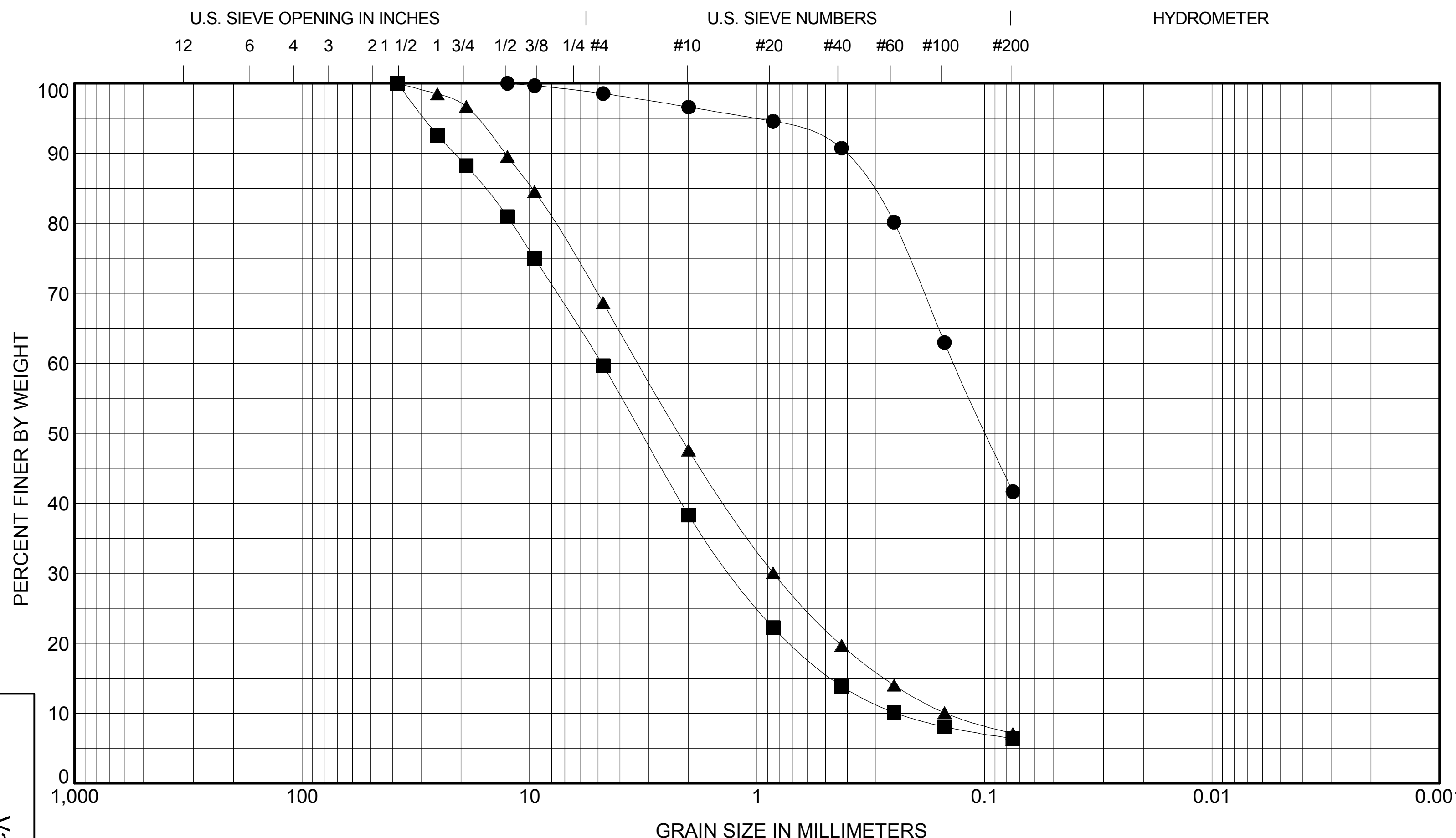
FIG. A-4



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Sample		Depth, Ft	Classification	LL	PL	PI	Cc	Cu
●	**B-1 S2**	**5.0 - 6.5**	**Silty Sand (SM)**					
■	**B-1 S8**	**20.0 - 21.5**	**Well-Graded Sand with Silt and Gravel (SW-SM)**				**1.4**	**19.9**
▲	**B-1 S12**	**40.0 - 41.5**	**Well-Graded Sand with Silt and Gravel (SW-SM)**				**1.5**	**22.6**

Sample		Depth, Ft	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**B-1 S2**	**5.0 - 6.5**	**12.5**	**0.14**			**1**	**57**	**42**	
■	**B-1 S8**	**20.0 - 21.5**	**38.1**	**4.82**	**1.28**	**0.24**	**40**	**53**	**6**	
▲	**B-1 S12**	**40.0 - 41.5**	**38.1**	**3.33**	**0.85**	**0.15**	**31**	**62**	**7**	

Valdez Aquifer Evaluation
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GRAIN SIZE CLASSIFICATION

August 2016

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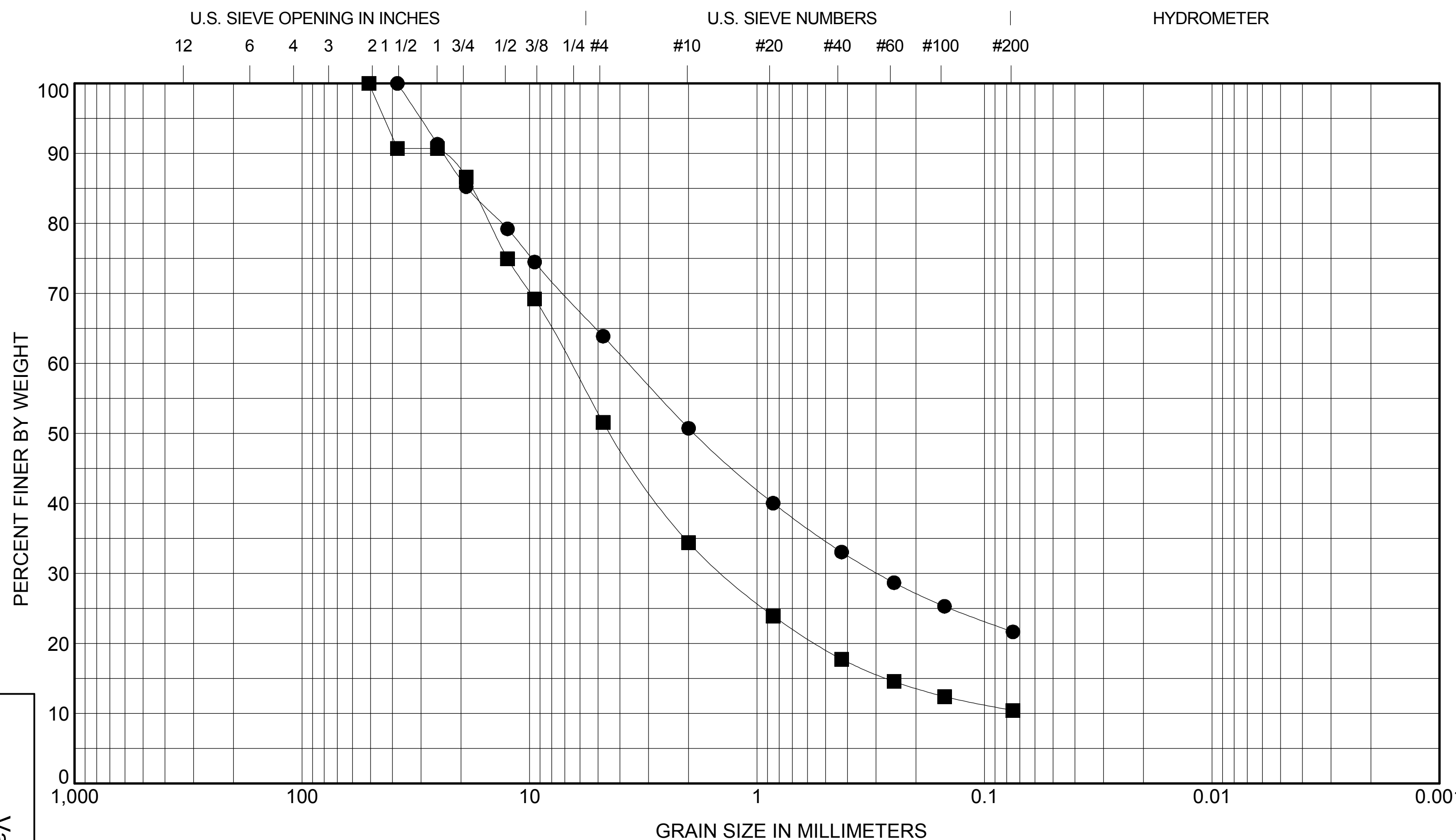
FIG. A-5
Sheet 1 of 2



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Sample	Depth, Ft	Classification	LL	PL	PI	Cc	Cu
●	**B-1 S15**	**55.0 - 56.5**	**Silty Sand with Gravel (SM)**					
■	**B-1 S16**	**60.0 - 61.5**	**Pooly-Graded Gravel with Silt and Sand (GP-GM)**				**4.5**	**102.2**

	Sample	Depth, Ft	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**B-1 S15**	**55.0 - 56.5**	**38.1**	**3.68**	**0.29**		**36**	**42**	**22**	
■	**B-1 S16**	**60.0 - 61.5**	**50.8**	**6.62**	**1.39**		**48**	**41**	**10**	

Valdez Aquifer Evaluation
Valdez, Alaska

GRAIN SIZE CLASSIFICATION

August 2016

32-1-02498

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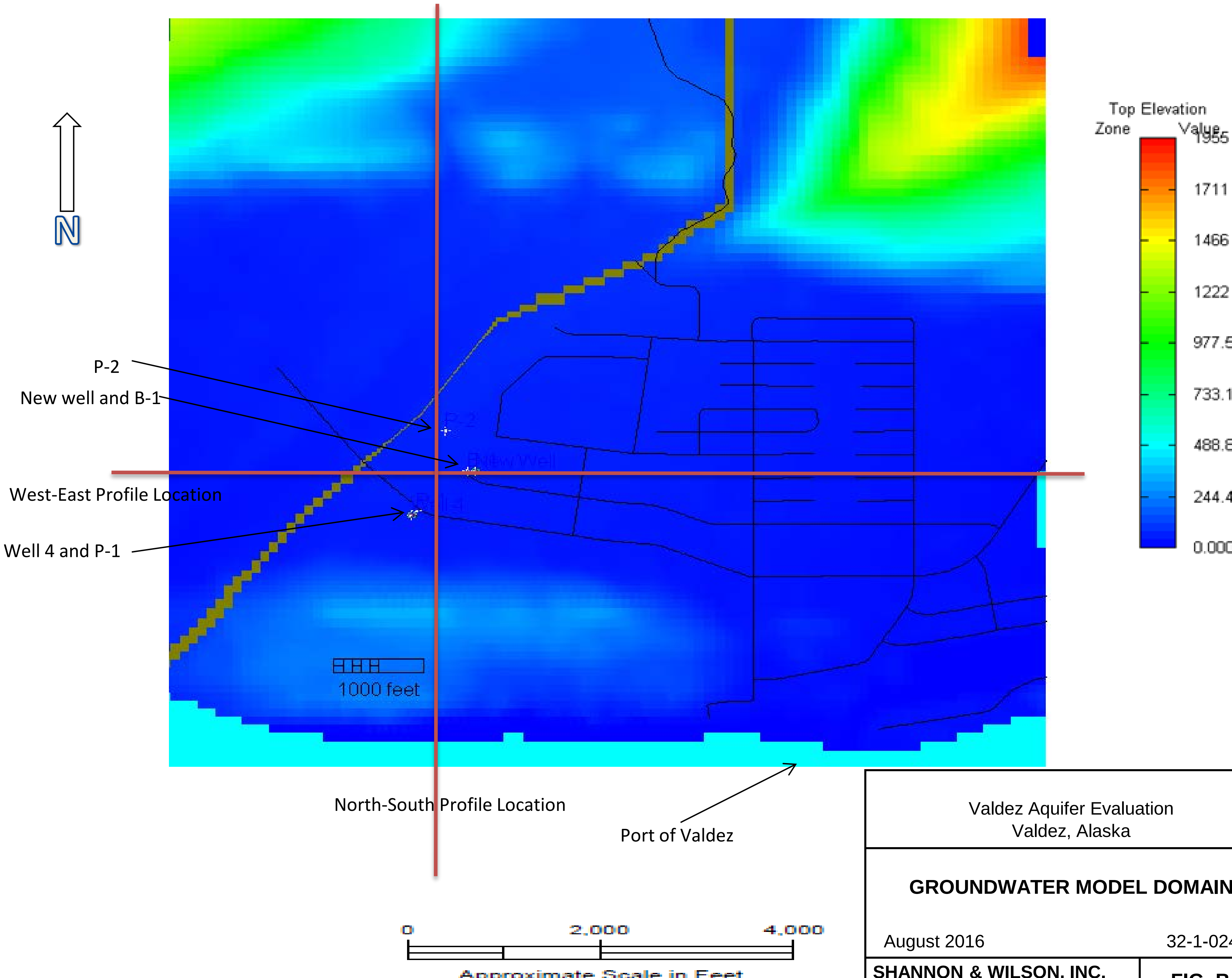
FIG. A-5
Sheet 2 of 2

APPENDIX B

GROUNDWATER MODEL DETAILS

FIGURES



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GROUNDWATER MODEL DOMAIN

August 2016 | 32-1-02498

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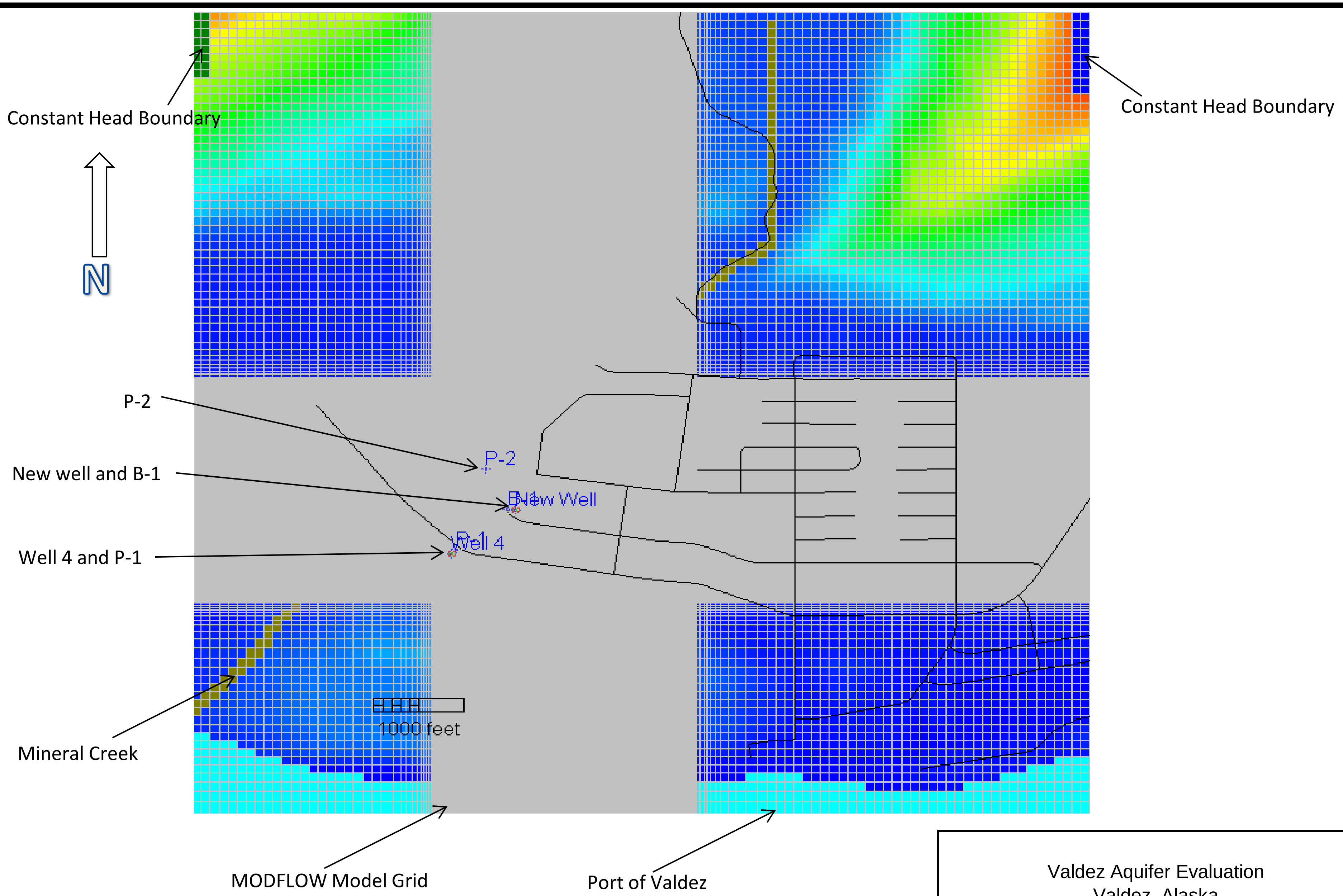
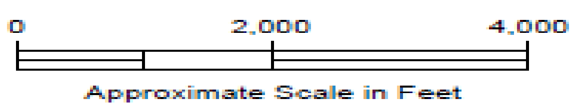
FIG. B-1





Valdez Aquifer Evaluation
Valdez, Alaska

GROUNDWATER MODEL GRID & BOUNDARY CONDITIONS

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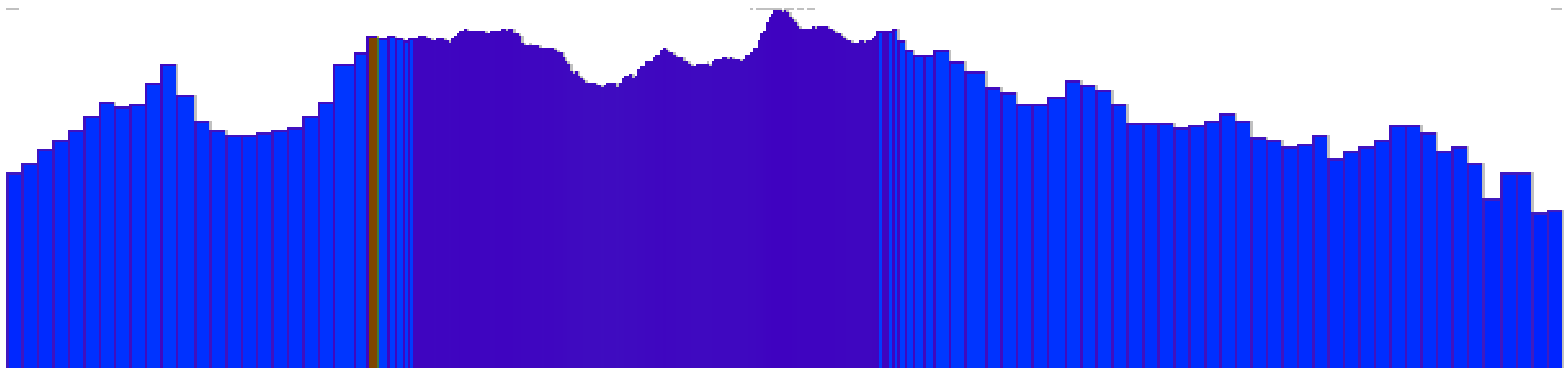
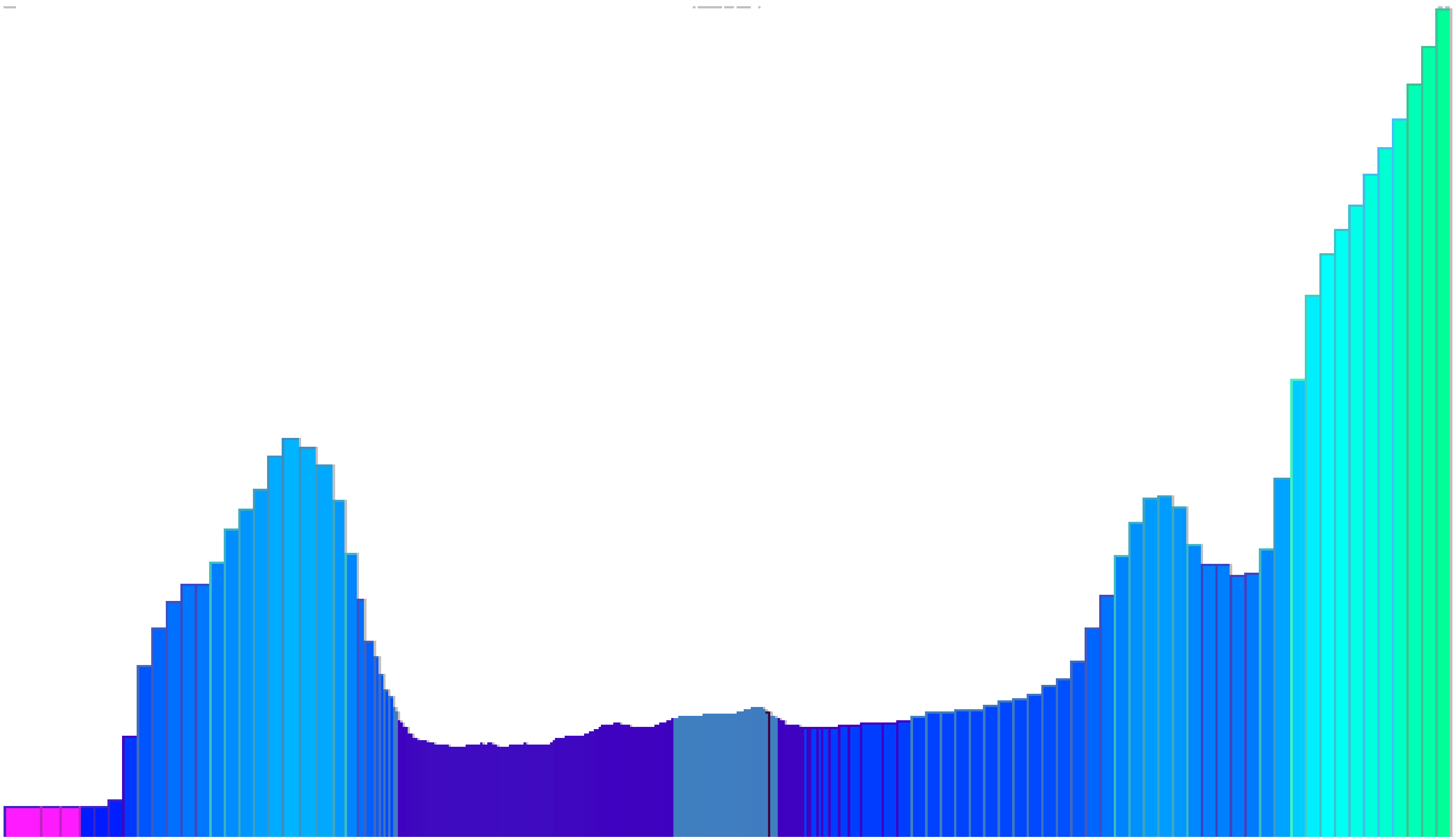
FIG. B-2



Note
Vertical exaggeration = 30

Valdez Aquifer Evaluation Valdez, Alaska	
GROUNDWATER MODEL **Profile (West-East)**	
August 2016	32-1-02498
SHANNON & WILSON, INC. Geotechnical and Environmental Consultants	**FIG. B-3**



Note
Vertical exaggeration = 10

Valdez Aquifer Evaluation
Valdez, Alaska

GROUNDWATER MODEL
Profile (North-South)

August 2016

32-1-02498

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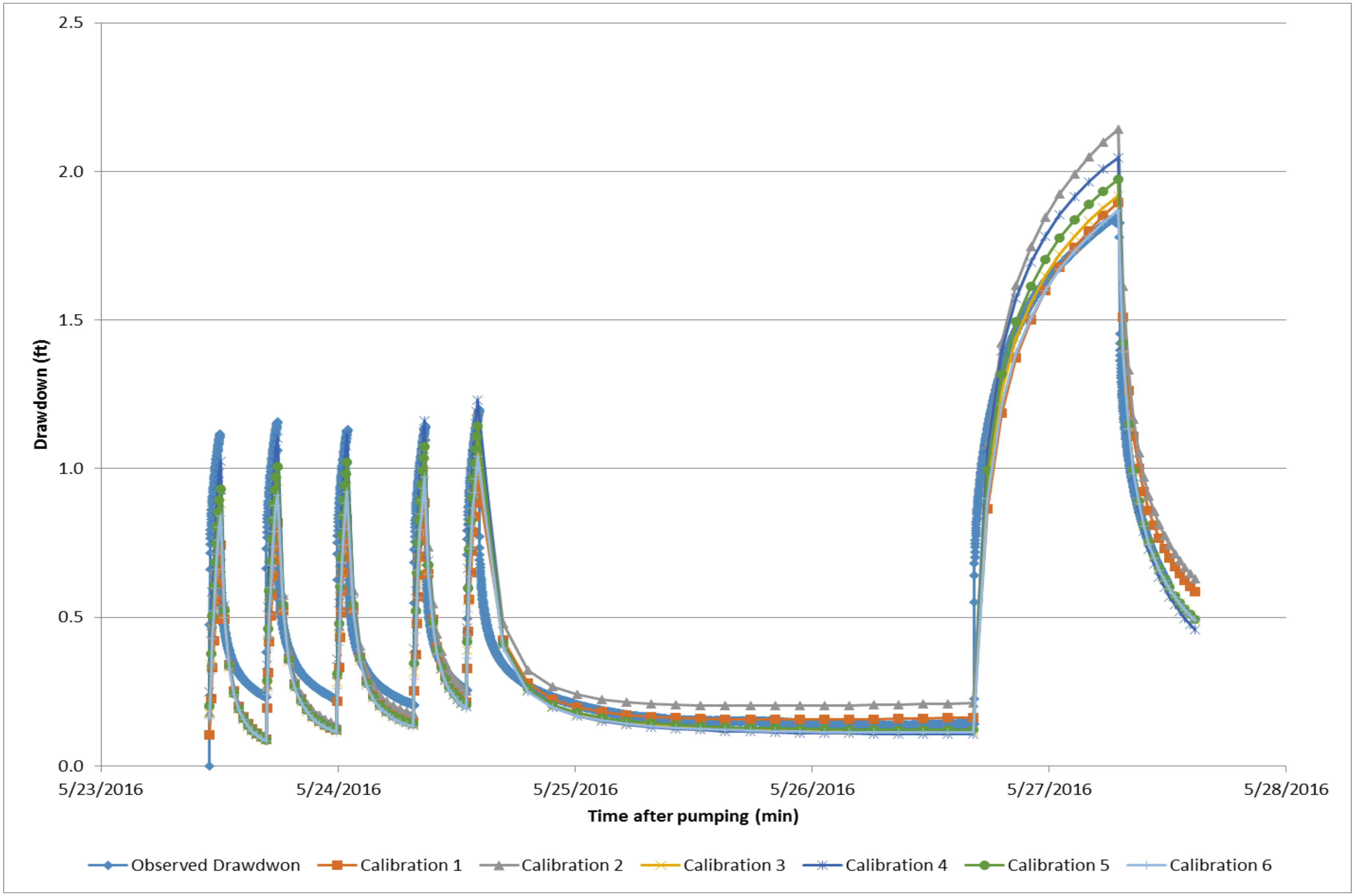
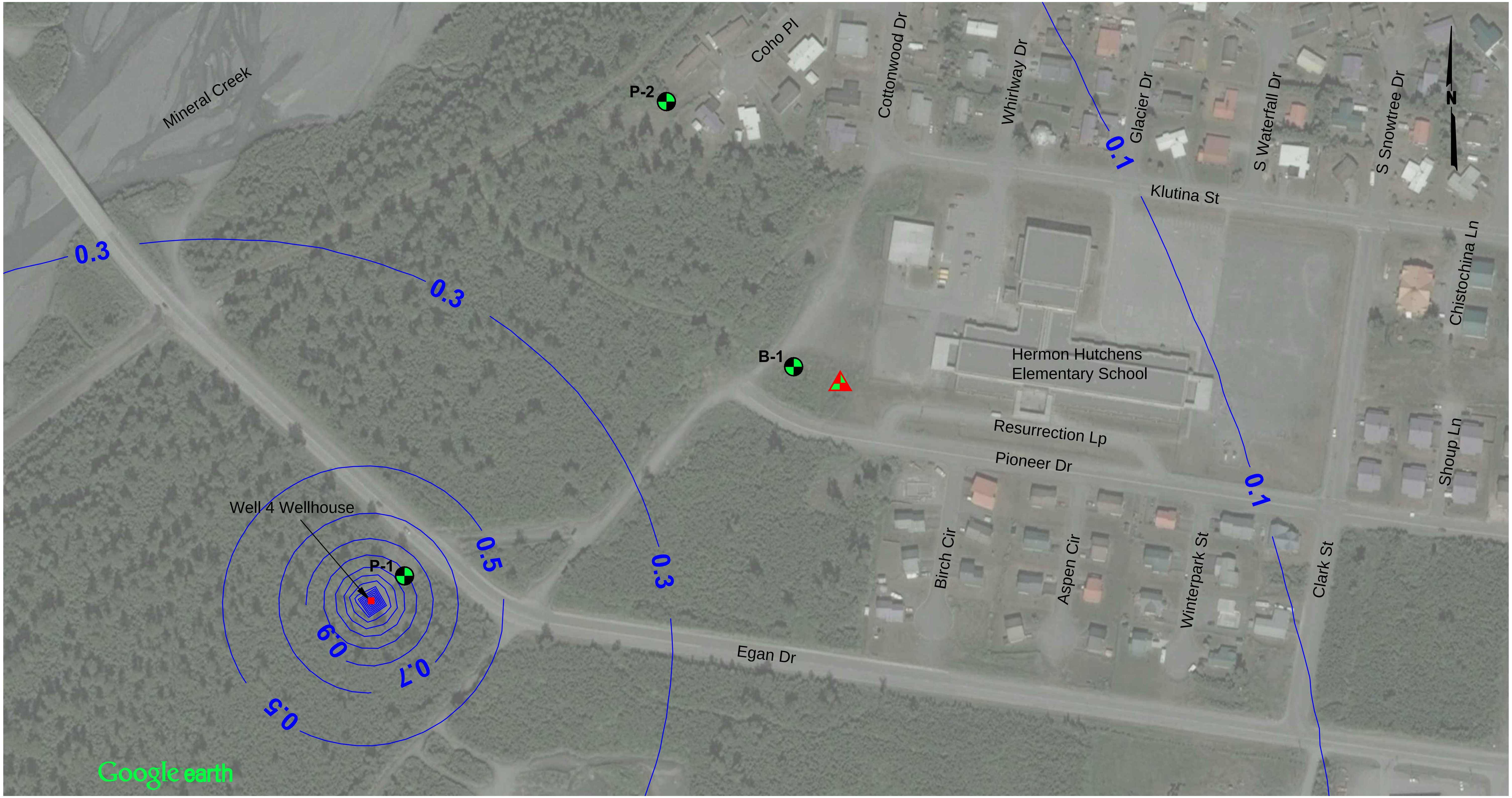
FIG. B-4



Valdez Aquifer Evaluation Valdez, Alaska	
GROUNDWATER MODEL CALIBRATION August 2016 32-1-02498	
SHANNON & WILSON, INC. Geotechnical and Environmental Consultants	**FIG. B-5**



0 200 400

Scale in Feet
Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

1. Refer to Section 7.7 of report text for pumping scenario details.
2. Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

Valdez Aquifer Evaluation
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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 1A

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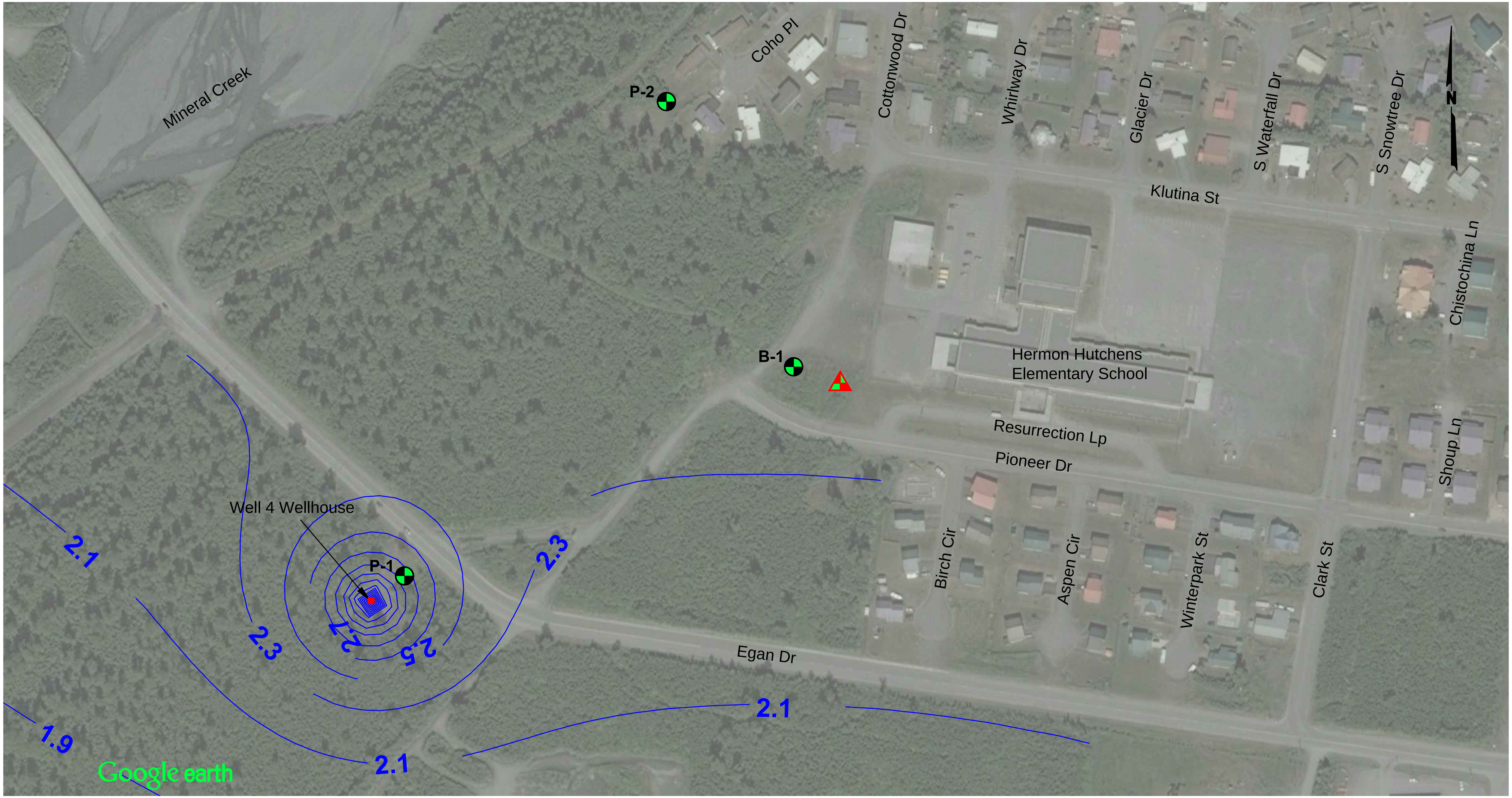
FIG. B-6



0 200 400

Scale in Feet
Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

Proposed Pumping Well

Existing Pumping Well

B-1 Existing Boring

NOTES

1. Refer to Section 7.7 of report text for pumping scenario details.
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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 1B

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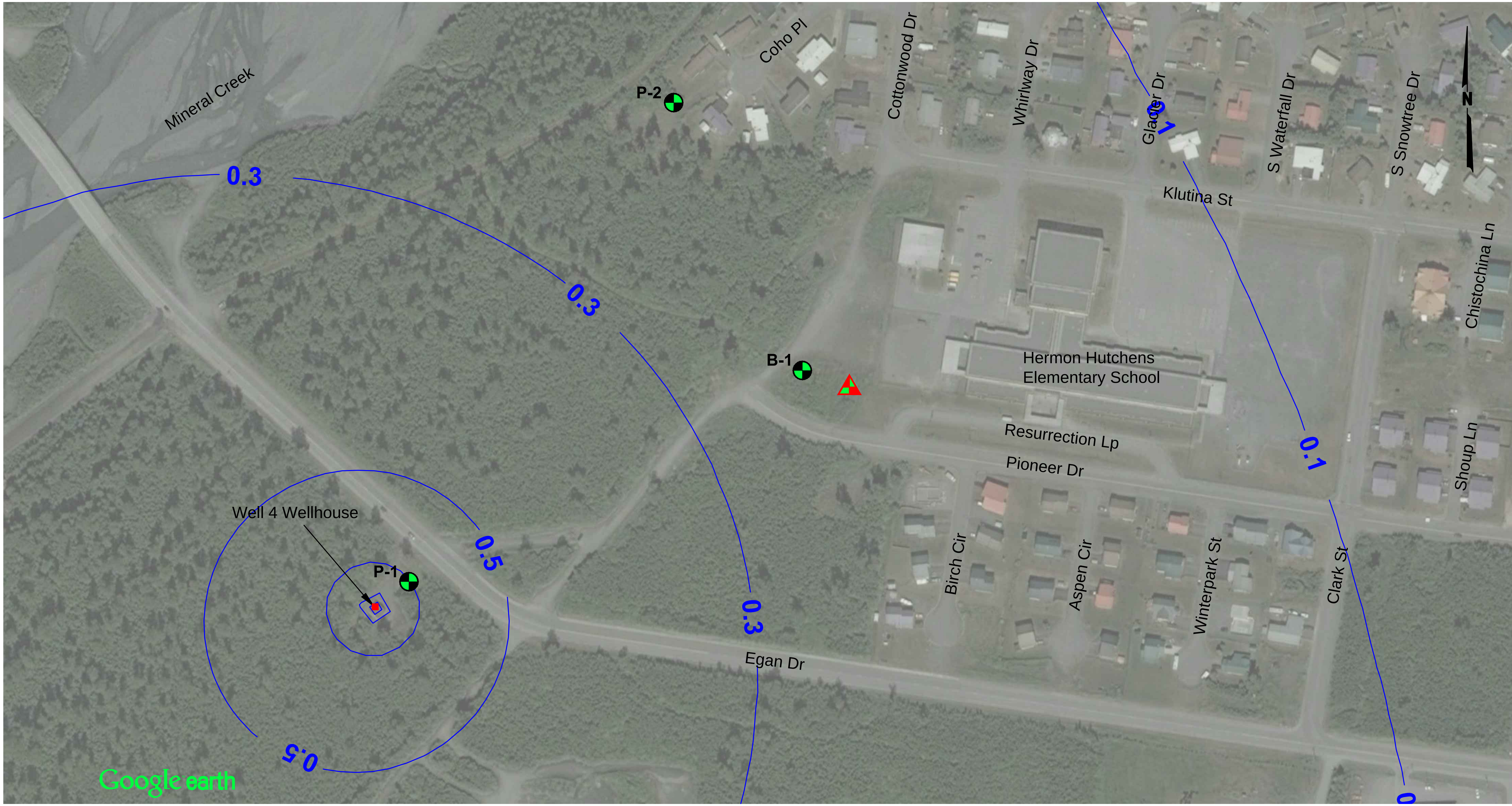
FIG. B-7



0 200 400

Scale in Feet
Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

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Valdez, Alaska

GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 1C

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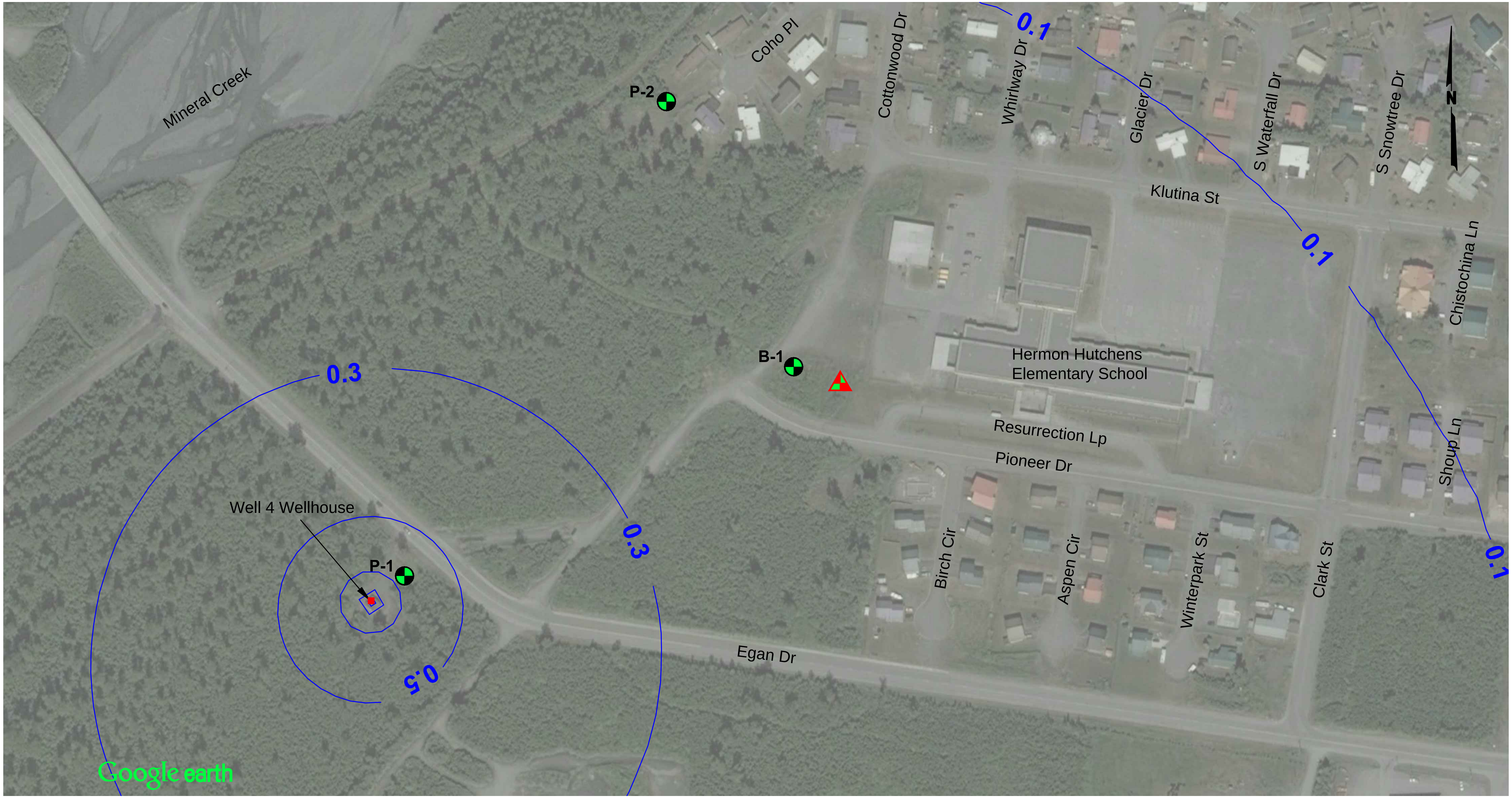
FIG. B-8



0 200 400

Scale in Feet

Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 1D

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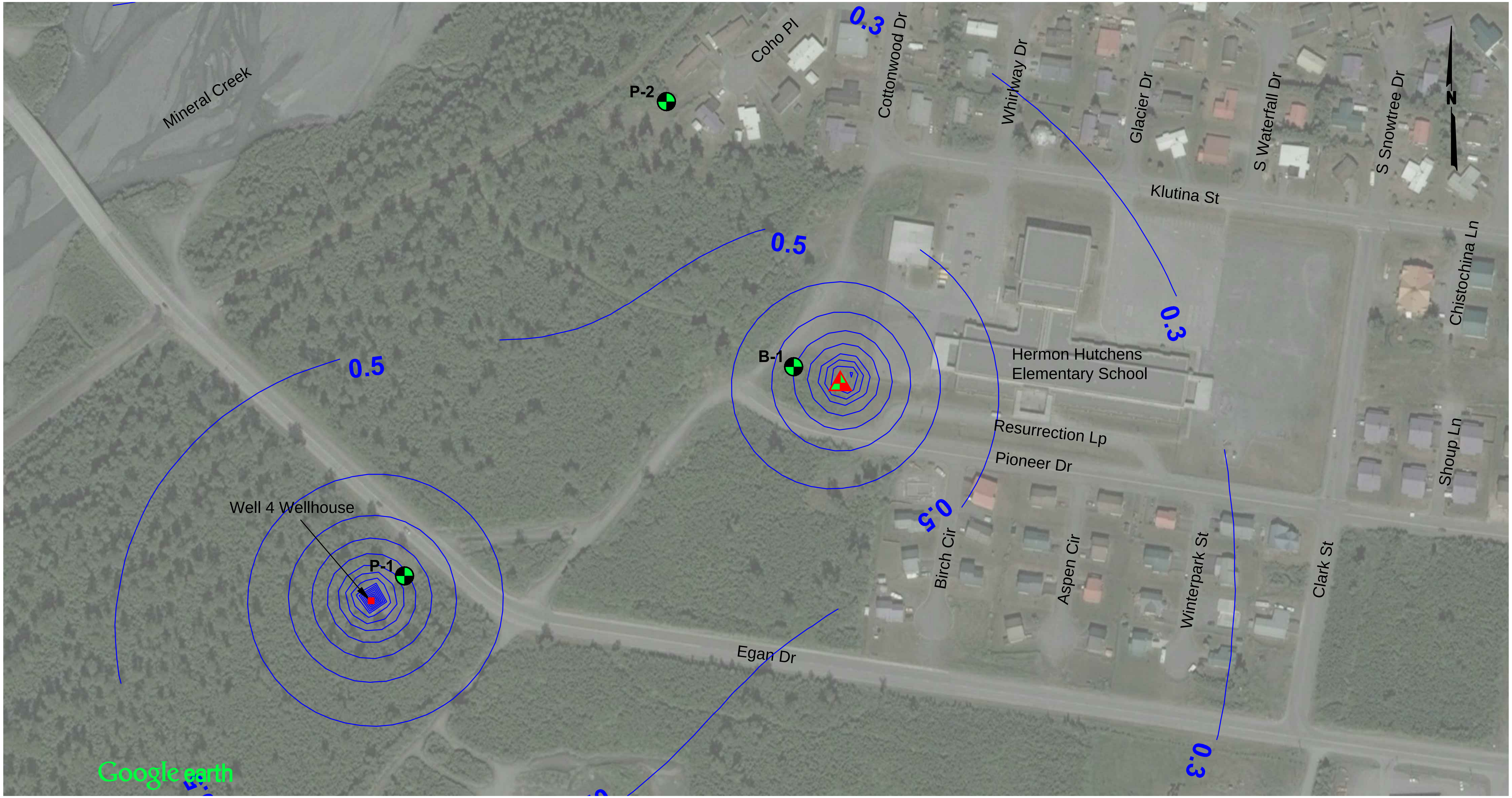
FIG. B-9



0 200 400

Scale in Feet
Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 2A

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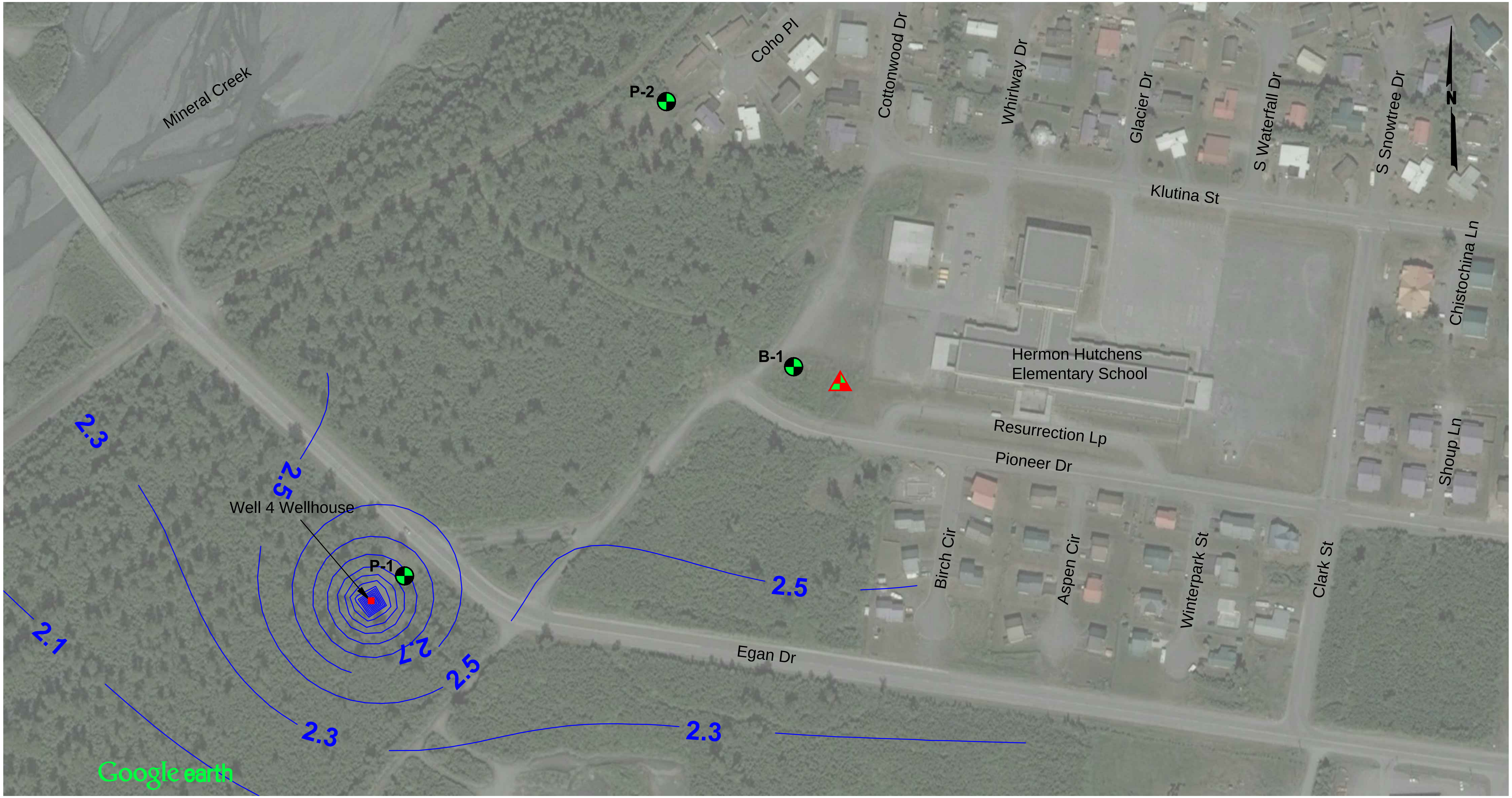
FIG. B-10

Filename: I:\FileServer\Geotech Jobs Working\Anchorage Jobs\32-1-02400 thru 32-1-02499\02490 to 02499\02498 Valdez Aquifer Evaluation\Report\Phase II Report\App B drawings\32-1-02498-001 Groundwater Model Plans.dwg Layout: 2a



0 200 400

Scale in Feet

Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

1. Refer to Section 7.7 of report text for pumping scenario details.
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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 2B

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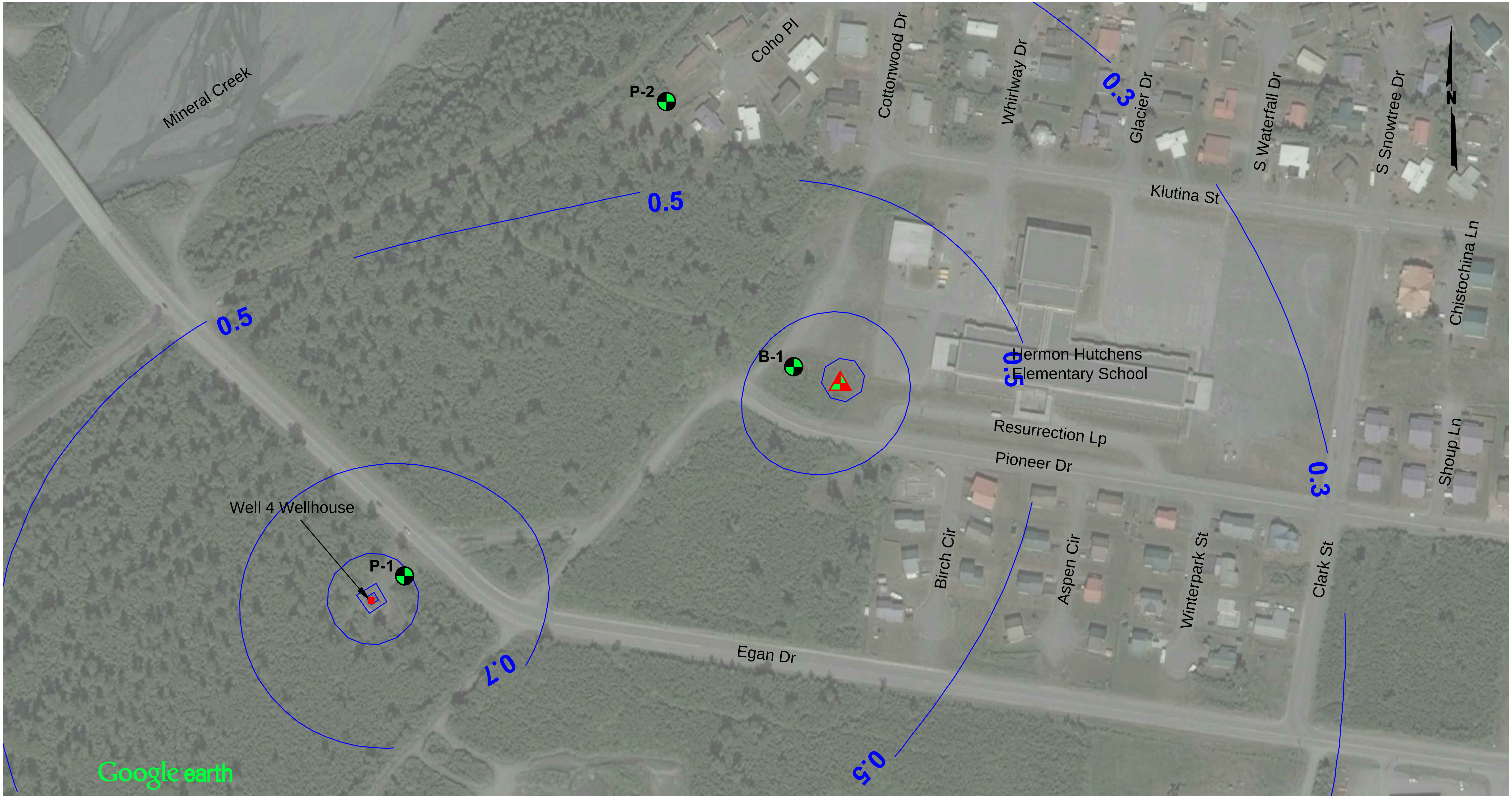
FIG. B-11



0 200 400

Scale in Feet
Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

- Proposed Pumping Well
- Existing Pumping Well
- B-1 Existing Boring

NOTES

1. Refer to Section 7.7 of report text for pumping scenario details.
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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 2C

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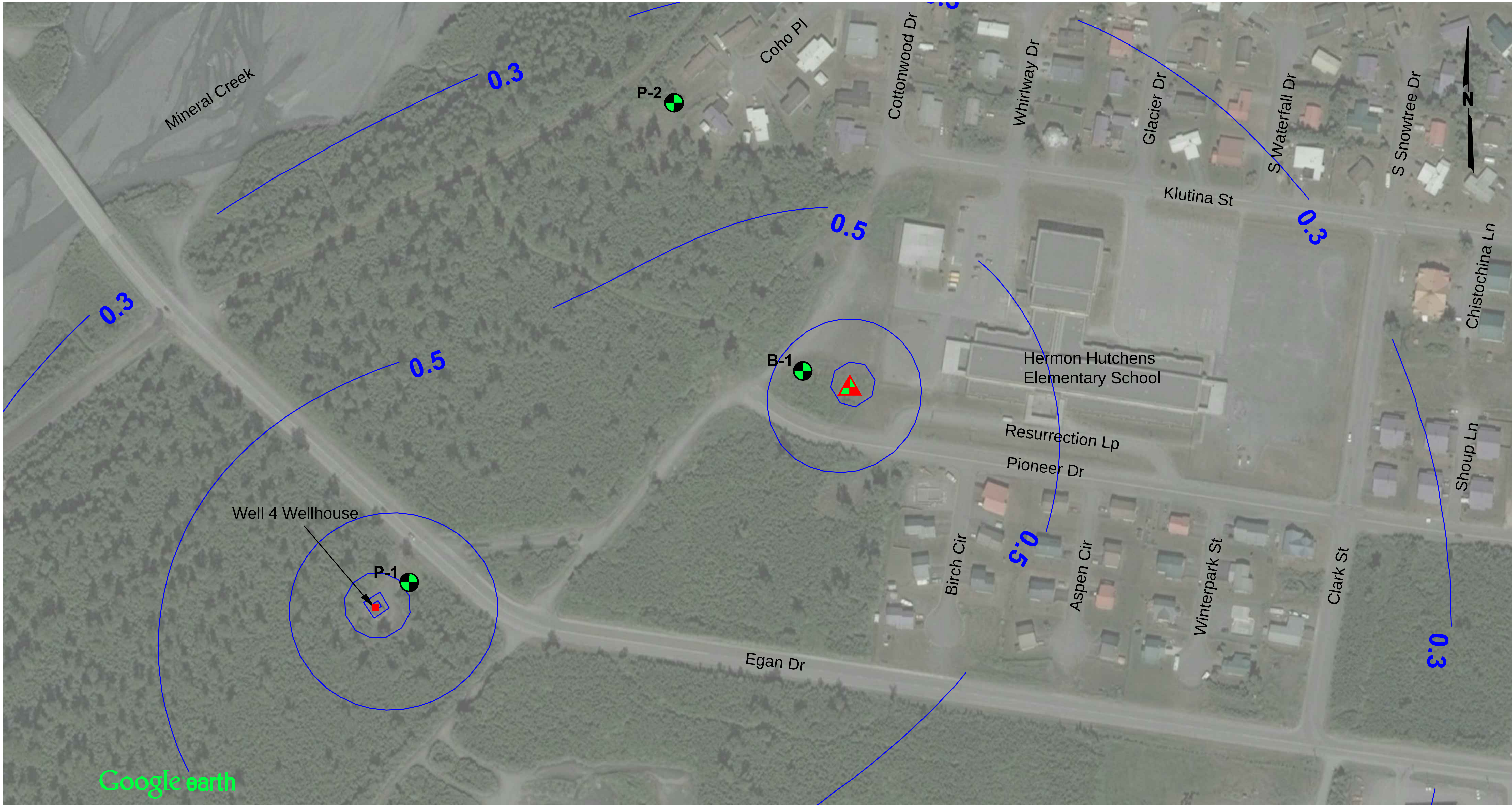
FIG. B-12

Filename: I:\FileServer\Geotech Jobs Working\Anchorage Jobs\32-1-02400 thru 32-1-02499\02490 to 02499\02498 Valdez Aquifer Evaluation\Report\Phase II Report\App B drawings\32-1-02498-001 Groundwater Model Plans.dwg Layout: 2c



0 200 400

Scale in Feet

Groundwater Contour Interval = 0.2 Feet

LEGEND

Exploration Designation and Approximate Location

Proposed Pumping Well

Existing Pumping Well

B-1 Existing Boring

NOTES

1. Refer to Section 7.7 of report text for pumping scenario details.

2. Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

Valdez Aquifer Evaluation
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GROUNDWATER DRAWDOWN FOR PUMPING SCENARIO 2D

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FIG. B-13

APPENDIX C

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

Important Information About Your Geotechnical/Environmental Report

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors, which were considered in the development of the report, have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland