associated
earth sciences
incorporated

RECEIVED

CITY OF MUKILTEO

FILE COPY

November 4, 2019
Project No. 20190080H001

Underwood Nelson Development
P.O. Box 1301
Seahurst, Washington 98062-1301

Attention: Mr. Greg S. Nelson, P.E.

Subject: Infiltration Assessment
Mukilteo Industrial Development (Nelson 43)
4301 78th Street SW
Mukilteo, Washington

Dear Mr. Nelson:

Associated Earth Sciences, Inc. (AESI) is pleased to present this letter-report providing the results of AESI's infiltration assessment for the proposed infiltration facility for the above-referenced site. The location of the subject site is shown on Figure 1, "Vicinity Map." A map showing the approximate locations of the explorations accomplished on the subject property is presented as Figure 2, "Site and Exploration Plan."

Our previous "Infiltration Feasibility" letter-report, dated May 8, 2019, included subsurface characterization derived from published resources, on-site exploration, and the installation of a groundwater monitoring well. In that letter-report, we documented the subsurface geology and groundwater conditions, and recommended this supplemental infiltration assessment. This current letter-report documents our subsurface exploration, in-situ infiltration testing, off-site reconnaissance, groundwater mounding analysis, and preliminary design infiltration rate recommendations.

PROJECT AND SITE DESCRIPTION

The project site is an undeveloped, forested property comprised of four Snohomish County parcels, 280410-003-001-00, -004-00, -005-00, and -006-00, totaling approximately 176,141 square feet (4.04 acres). The site is located in the northeast corner of the intersection of 44th Avenue West and 78th Street SW in Mukilteo, Washington, at address 4301 78th Street

SW. The property is bounded on the north by undeveloped, forested land, to the east by a church, to the west, across 44th Avenue West, by residential properties, and to the south, across 78th Street SW, by a maintenance shop and Mukilteo Public Works. The site slopes gently from southwest to northeast with elevations ranging from about 572 feet to 534 feet (North American Vertical Datum of 1988 [NAVD88]). Figure 1 shows the location of the site and Figure 2 shows the site and proposed development, including the explorations completed for this study.

SCOPE AND AUTHORIZATION

Our work was performed in general accordance with our scope of work dated April 18, 2019. This letter-report has been prepared for the exclusive use of Underwood Nelson Development and its agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our letter-report was prepared. AESI's observations, findings, and opinions are a means to identify and reduce the inherent risks to the owner. No other warranty, express or implied, is made.

INFILTRATION ASSESSMENT

As described in our May 8, 2019 letter-report AESI observed subsurface conditions in one exploration pit (EP-1) and one exploration boring (EB-1W), completed on March 20 and March 28, 2019, respectively. EP-1 was completed within the very dense till and was deepened on May 7, 2019, so that infiltration test IT-1 could be completed in the underlying outwash sediments. The approximate locations of the exploration pit (EP-1/IT-1) and the exploration boring/monitoring well (EB-1W) are shown on Figure 2, "Site and Exploration Plan."

Groundwater monitoring well EB-1W was previously installed in an exploration boring in March 2019. The monitoring well consists of a 2-inch-diameter polyvinyl chloride (PVC) Schedule 40 well casing with threaded connections. The lower 10 feet of the well is comprised of machine-slotted (0.020-inch slots) well screen to permit water inflow. The annular space around the well screen was backfilled with a clean, graded sand filter pack, and the upper portion of annulus was sealed with bentonite grout. An above-ground steel monument was placed over the top of the wellhead for protection in accordance with *Washington Administrative Code* (WAC) 173-160-420.

Monitoring well EB-1W is screened within the advance outwash, with the sand filter pack entirely within the advance outwash. Following well completion, the monitoring well was developed to remove fine-grained materials from the well screen and filter pack, to provide good hydraulic connection with the aquifer.

Groundwater Level Monitoring

Groundwater level monitoring in monitoring well EB-1W was initiated in May 2019. A pressure transducer/data logger was installed in EB-1W, which reads the water level on an hourly basis. The data logger is downloaded every 2 months, and manual water level measurements are collected at each site visit for data logger calibration. A hydrograph showing the groundwater elevations measured during the monitoring period is included as Figure 3. It should be noted that the groundwater elevations shown on Figure 3 are approximate, as the monitoring well has not been surveyed. The water level data is maintained on AESI's server. The wellhead elevation has not been surveyed and is estimated to be approximately 543 feet, based on Light Detection and Ranging (LIDAR) data (Figure 2). Groundwater levels fluctuate seasonally, in response to changes in season and amount of precipitation.

Infiltration Test Pit

The infiltration test pit was excavated with a subcontracted track-mounted excavator. Due to the difficult digging conditions encountered previously in exploration pit EP-1, infiltration test IT-1 was completed at a deeper interval in the same location as EP-1. The pit permitted direct, visual observation of subsurface conditions. Materials encountered in the exploration pit were studied and classified in the field by a hydrogeologist from our firm. After logging the exposed soils, the exploration was backfilled with the excavated soil and lightly tamped with the excavator bucket. Disturbed soil samples were selected from the pit, placed in moisture-tight containers, and transported to our laboratory for further visual classification and testing, as necessary. The exploration logs for all explorations completed for the project in Appendix A are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analyses. Laboratory grain-size analyses data are presented in Appendix B.

Infiltration Testing

The infiltration testing location was selected in order to obtain a preliminary design infiltration rate for the proposed infiltration system. The infiltration testing data summary sheet is included in Appendix C.

Infiltration test IT-1 was conducted at a depth of 16 feet below ground surface (bgs). Infiltration testing was conducted using a method consistent with the small-scale pilot infiltration test (PIT) referenced in Section 3.3.6 in the Washington State Department of Ecology's 2012 *Stormwater Management Manual for Western Washington*, as amended in December 2014 (SWMMWW). The test was conducted by discharging water into a flat-bottomed pit of known dimensions for a "soaking period," to allow the receptor soils in the immediate vicinity of the pit to become saturated. After completion of the soaking period, water was discharged into the pit at a rate sufficient to maintain a relatively constant head in the pit.

The water used for the testing was obtained from a nearby fire hydrant. During infiltration testing, water was discharged into the infiltration pit through a PVC pipe diffuser to minimize turbulence and scouring in the pit bottom. An electronic flow meter/totalizer was used to monitor the water discharge rate and total flow. An electronic water level tape was used to monitor the depth of water during testing.

The test depth, horizontal surface area, discharge time, total volume, head level, and field infiltration rate of the infiltration test are summarized in Table 1. The total discharge time for the test was about 7 hours. After initially adding water to the test pit at higher flow rates to establish head, the subsequent approximately 5 hours of testing was conducted at a relatively constant flow rate of just over 1 gallon per minute (gpm) to achieve a constant-head level of about 0.89 feet. The flow rate was adjusted periodically so that a relatively constant head could be achieved. Following completion of the constant-head test, the flow of water into the pit was discontinued and the rate of water level decline (falling head) in the pit was monitored for 40 minutes.

After falling-head data was collected, the infiltration test pit was deepened to observe subsurface conditions below the tested interval and to identify any soil layers that would restrict the downward flow of infiltrating water. The sediments were consistent with the material tested at 16 feet down to a depth of about 21 feet, at which point there was an interval of fine sand. Slight seepage was encountered at a depth of 18 feet bgs following the test. It should be noted that water conditions observed in the infiltration test pit below the depth of the infiltration test (16 feet bgs) are influenced by the water introduced during the test.

All infiltration test data was recorded by hand in the field and subsequently transferred to an electronic spreadsheet. Infiltration test data sheets are included in the Appendix C.

Table 1
Summary of Infiltration Test Parameters

Test No. and Depth	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Uncorrected Field Infiltration Rates	
					Constant-Head Test (inches/hour)	Falling-Head Test (inches/hour)
IT-1 at 16 feet	15	420	600	0.89	7.2	6.0

LABORATORY ANALYSES

Two laboratory grain-size analyses were performed on samples from EP-1/IT-1 in accordance with the *American Society for Testing and Materials* (ASTM) procedures on samples of the matrix material, with rocks over 3 inches in size excluded (Table 2). One sample was from a depth of 17 feet, and the second sample was from the bottom of the exploration pit (24.5 feet). The data are summarized in Table 2. The grain-size analyses test results (included in Appendix B) indicate that the soil at that interval correlate to "gravelly SAND, some silt," and "very sandy GRAVEL, trace silt," based on ASTM D-2487 Unified Soil Classification System (USCS). The respective silt contents as measured on the No. 200 sieve were 7 and 3 percent, for the 17- and 24.5-foot depths, respectively.

Table 2
Summary of Grain-Size Data

Exploration Number	Depth (feet)	Geologic Unit	USCS Soil Description	USDA Soil Texture*
EP-1/ IT-1	17	Advance Outwash	Gravelly SAND, some silt (SP-SM)	SAND
EP-1/ IT-1	24.5	Advance Outwash	Very sandy GRAVEL, trace silt (GP)	SAND

USCS = Unified Soil Classification System
USDA = U.S. Department of Agriculture
* No hydrometers were performed. USDA soil texture range reflects possible range assuming fines consist entirely of silt to entirely of clay.

SITE CONDITIONS

The following text sections describe current site conditions, including regional and local topography, regional geology, local soils, regional hydrogeology, and local groundwater. Our sources of information include: 1) a geologic map titled *Distribution and Description of Geologic Units in the Mukilteo Quadrangle, Washington*, by James P. Minard, dated 1982 (Minard, 1982), 2) *The Ground-Water System and Ground-Water Quality in Western Snohomish County, Washington* (Thomas et al., 1997), and 3) *Ground-Water Resources of Snohomish County, Washington* (Newcomb, 1952).

Regional and Local Topography

The project site is situated on a till-mantled upland about 0.8 miles east of Puget Sound. Grades slope downward to the east-northeast in the site vicinity. The site slopes gently to the east-northeast with approximately 38 feet of grade change over roughly 600 feet from the southwest to northeast corners of the site.

Subsurface Conditions

Subsurface conditions at the project site were inferred from the field explorations accomplished for this study, field exploration completed for our May 8, 2019 letter-report, visual reconnaissance of the site and selected off-site areas, our experience in the area, and review of selected applicable geologic literature.

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix A. The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field.

Published Geologic Map

A review of the *Distribution and Description of Geologic Units in the Mukilteo Quadrangle, Washington*, by James P. Minard, dated 1982 (Minard, 1982), indicates that the surficial sediments underlying the property are Vashon lodgement till. Our interpretation of the sediments encountered in our explorations is in general agreement with the regional geologic mapping.

Regional Geology

Minard, 1982 indicates that the project site is underlain by Vashon lodgement till (Qvt), and shows exposures of Vashon advance outwash (Qva) underlying the Qvt approximately 800 feet east of the site, in Japanese Gulch.

Lodgement till was deposited at the base of an active continental glacier during the Vashon Stade of the Fraser Glaciation approximately 15,000 years ago and was subsequently compacted to a very dense condition by the weight of the overlying glacial ice. Lodgement till typically comprises a very dense, unsorted mixture of silts, sands, gravels, cobbles, and boulders. Thicknesses can range from a few feet to several tens of feet. Lodgement till exhibits a very low permeability, typically about 1 inch per month, and is commonly used in earth berm applications to detain surface water.

The lodgement till is underlain by Vashon advance outwash in the site vicinity. Advance outwash sediments were deposited as outwash from rivers flowing from the base of the southward-advancing glacial front during the Vashon Stade of the Fraser Glaciation. The high relative density of the advance outwash is due to its consolidation by the massive weight of glacial ice that overrode the sediments subsequent to their deposition. Advance outwash typically comprises a dense to very dense, well-sorted mixture of fine to coarse sands, gravelly sands, or sandy gravels. Thicknesses can range from several feet to one hundred feet or more. The advance outwash is generally permeable and where unsaturated, is commonly used for stormwater infiltration. Based on Minard, 1982, the top of the Vashon advance outwash is exposed at the ground surface to the east of the site, immediately beneath the lodgement till beginning at elevations around 500 feet NAVD88.

Pre-Fraser deposits of sands, silts, and clays underlie the advance outwash. Based on the regional geologic map, the pre-Fraser deposits are exposed at lower elevations approximately 1,800 feet west of the site at approximate elevations in the range of 400 to 430 feet NAVD88.

Site Stratigraphy

Exploration boring EB-1W and exploration pit EP-1/IT-1 encountered approximately 13 and 13.5 feet of lodgement till, respectively, overlying advance outwash. In EP-1/IT-1, the advance outwash extended below the base of the exploration, at 24.5 feet bgs, and in EB-1W, the advance outwash extended to a depth of 50 feet bgs (approximately 493 feet NAVD88). Sediments interpreted to represent pre-Fraser-aged glacial till extended below the bottom of EB-1W at 55.4 feet bgs. These findings are generally consistent with the regional geologic maps, and the top of the advance outwash was encountered at approximate elevation 530 feet in our explorations. The following paragraphs describe our stratigraphic observations. Depths and approximate elevations of the geologic units and groundwater are included in Table 3. The exploration logs contained in Appendix A provide additional subsurface information.

Lodgement Till: Sediments interpreted to be lodgement till were encountered just below a surficial layer of forest duff in EP-1/IT-1 and EB-1W, and extended to depths of 13.5 and 13 feet bgs, respectively. This deposit consisted of dense to very dense, unsorted, silty, gravelly sands. Lodgement till typically possesses high strength and low compressibility, and has a very low permeability due to its relative high density and high content of fine-grained material.

Advance Outwash: Advance outwash was encountered underlying the glacial till at a depth of about 13.5 and 13 feet bgs in EP-1/IT-1 and EB-1W, respectively, and consisted of dense to very dense, fine sand with variable amounts of silt and gravel. The advance outwash was generally stratified, varying from trace to some silt. The advance outwash deposit extended below the base of EP-1/IT-1, and to around 50 feet bgs in EB-1W. Advance outwash sand is typically relatively permeable and is the proposed receptor for the infiltration of treated stormwater runoff at the site.

Pre-Fraser Till: Sediments comprised of unsorted, grayish brown to dark gray, silty fine sand, trace gravel were encountered in EB-1W, beginning at a depth of 50 feet bgs and extending beyond the termination of the boring (55.5 feet bgs). These sediments were interpreted to represent pre-Fraser lodgement till sediments.

Table 3
Exploration Summary

Exploration	Approx. GSE	Depth to GW	Approx. GW Elevation	Depth Below Ground Surface (ft)					Approximate Elevation (ft NAVD88)				
				Top of Forest Duff	Top of Qvt	Top of Qva	Top of Qpf	Bottom of Explor.	Top of Forest Duff	Top of Qvt	Top of Qva	Top of Qpf	Bottom of Explor.
EB-1W	543	42.9	500	0	1	13	50	55.5	543	542	530	493	487.5
EP-1/IT-1	542	--	--	0	1	13.5	--	24.5	542	541	528.5	--	517.5

Note: Elevations interpolated from site topography.
GSE = ground surface elevation
GW = groundwater
Qvt = Vashon lodgement till
Qva = Vashon advance outwash
Qpf = Pre-Fraser sediments
ft = feet
-- = not encountered
NAVD88 = North American Vertical Datum of 1988
Depth to groundwater on March 29, 2019, after well development.

Regional Hydrogeology

The regional hydrogeology of the project area is described in Thomas et al., 1997 and Newcomb, 1952. The project area is located in the Intercity Plateau which is underlain by Vashon till, Vashon advance outwash and older sands and silts. Water supply wells in the vicinity of the site appear to obtain water from the Vashon till, Vashon advance outwash, and undifferentiated sediments lying beneath the Vashon advance outwash. Based on well records and potentiometric surface maps in Thomas et al., 1997 and Newcomb, 1952, the water levels in the advance outwash aquifer appear to generally follow topography, and decrease to the north and east in the vicinity of the site.

Project Hydrogeology

A thin interval of seepage was encountered in EP-1 at a depth of 3.5 feet. This seepage is interpreted to represent interflow, which commonly accumulates at the base of the weathered Vashon lodgement till, immediately above the low-permeability unweathered till.

The monitoring well is completed in the shallowest regional aquifer beneath the site, which is interpreted to be the advance outwash aquifer. The water level in EB-1W after well development was approximately 43 feet bgs, or approximately 500 feet NAVD88. The saturated thickness of the Qva aquifer beneath the site is about 7 feet, based on EB-1W. According to Newcomb, 1952, and Thomas et al., 1997, the regional water table is laterally extensive and flows to the north-northwest in the vicinity of the site.

INFILTRATION DESIGN CONCEPT

The infiltration facility design will include a cast-in-place vault with the base of the vault set within the Vashon lodgement till sediments. The till beneath the vault footprint will be excavated down to expose the upper surface of the advance outwash. From the upper advance outwash, a trench or series of pit drains will be extended deep into the advance outwash. The trenches and subgrade beneath the vault will be backfilled with clean, free-draining import material. The base of the trench or pit drains will be maintained at approximately 10 feet above the groundwater table.

In its natural condition (without installed trench or drains) the advance outwash is horizontally stratified. Stratification will reduce the effective infiltration rate.

The deep trench or pit drains will allow the treated stormwater runoff to bypass the lower-permeability stratification within the advance outwash and access more of the formation for treated stormwater disposal. This results in significantly higher effective infiltration rates.

DESIGN INFILTRATION RATE DETERMINATION

Basis for Unfactored Infiltration Rates

Infiltration rates can be determined through either in-situ infiltration testing or grain-size analysis as described in Section 3.3.6 of the 2014 SWMMWW. Both methods were used to evaluate infiltration rates at this site. The PIT method was used to determine a preliminary design infiltration rate at the proposed subgrade elevation of the infiltration facility. The grain-size method was used to evaluate a preliminary design infiltration rate from deeper in the subsurface to account for the installation of deep trench or pit drain elements. The small-scale PIT was used as a basis for the facility subgrade infiltration rate. The uncorrected field-calculated constant-head infiltration rate was determined to be 7.2 inches per hour (in/hr) (Table 4).

The grain-size analysis method was used to assess the infiltration potential of the advance outwash at depths consistent with the proposed infiltration trench or pit drains beneath the infiltration vault. Using the Massmann equations as described in Section 3.3.6 of the SWMMWW and the grain-size analysis results for the sediment sample obtained from 24.5 feet bgs in IT-1, an infiltration rate of 161 in/hr was derived. Based on AESI's experience, the Massmann equations overstate infiltration rates. We developed a series of equations in-house, which are more conservative, and have been shown to predict infiltration rates with a higher level of confidence than Massmann. The infiltration rate yielded by our in-house method was 12 in/hr.

Corrected Infiltration Rates

Table 3.3.1 in the SWMMWW was used to determine appropriate correction factors to be applied to the field-based and grain-size-based infiltration rates. The design infiltration rates were derived using the correction factors for site variability and number of locations tested (CF_v), test method (CF_t) and degree of influent control to prevent siltation and bio-buildup (CF_m), per the following formula:

$$\text{Total Correction Factor } CF_T = CF_v \times CF_t \times CF_m$$

Correction factor CF_v accounts for the number of locations tested and the value selected depends on the level of uncertainty that adverse subsurface conditions may occur. The range for correction factors for CF_v is 0.33 to 1.0. A correction factor of 1.0 was used for this analysis since both the deep boring and exploration pit indicated similar subsurface characteristics.

The CF_t correction factor accounts for the test method. The value for CF_t is 0.5 for the small scale PIT. The value of CF_t is 0.4 for the grain-size method.

The value for CF_m, degree of influent control is 0.9.

Table 4 shows the correction factors applied to the PIT completed at 16 feet bgs, and the grain-size analysis results of the sample collected at 24.5 feet.

Table 4
Correction Factors and Preliminary Design Infiltration Rates

Test No.	Field or Grain Size Infiltration Rate (in/hr)	CF_v	CF_t	CF_m	Preliminary Design Infiltration Rate (in/hr)
IT-1	7.2	1.0	0.5	0.9	**3.2**
IT-1/24.5'	12	1.0	0.4	0.9	**4.3**

CF_v = site variability and number of locations tested
CF_t = test method
CF_m = degree of influent control to prevent siltation and bio-buildup
in/hr = inches per hour

GROUNDWATER MOUNDING ANALYSIS

A groundwater mounding analysis was completed to simulate the maximum groundwater mound height and compare it to the design high water elevation (DHWE) in the proposed infiltration facility. Groundwater mounding can occur when water is introduced into an infiltration facility at a higher rate than can be conveyed from the area beneath the facility. The introduced water can "mound" on the groundwater table or on a less-permeable silty interbed within the receptor sand and gravel during a storm event. When the storm event is over and water is not being introduced into the system, the mound will dissipate.

The MODRET computer program was used to model potential groundwater mounding beneath the proposed infiltration facility under two design time series. Infiltration system civil design details and stormwater inflow hydrographs were provided by Navix Engineering (Navix). The facility size was based on 2.0 in/hr. Table D-1 in Appendix D provides a summary of the input parameters used in the mounding analysis, and the basis for the parameters used. MODRET input parameters, stormwater hydrographs, and results are included in Appendix D.

The results of the MODRET simulation indicate that the modeled infiltration facility will have the capacity to infiltrate the stormwater runoff routed to the facility during the design storm time series hydrographs provided by Navix, without reaching the DHWE. Under the peak flow hydrograph, the maximum groundwater mound elevation was below the facility bottom elevation of 540.0 feet, and under the maximum volume hydrograph, the groundwater mound reached a maximum elevation of 548.8 feet. These elevations are below the DHWE of 553.15 feet.

OFF-SITE RECONNAISSANCE

According to an email to Spencer Humphrey (Navix) from Jennifer Adams (Surface Water Programs Manager for the City of Mukilteo) on January 29, 2019, the project discharges to an off-site Category II depressional wetland with no discernable outlet. Ms. Adams suggested that Navix confer with a hydrogeologist to determine the "existing hydrologic performance" for the wetland. AESI completed an off-site reconnaissance on June 25, 2019, in the vicinity of an area mapped as a wetland, beginning approximately 400 feet northeast of the proposed infiltration facility (Figure 1). We were provided an excerpt of the Mukilteo Geographic Information System (GIS) data, showing a surface water flow path emanating from the adjacent parcel to the east of the subject property, and flowing north toward a surface water pond within Japanese Gulch Park. The GIS map depicts the flow path continuing downstream to the north from the pond.

The wetland is identified as beginning south of the pond. Our visual observations of the area south of the pond indicated healthy, green undergrowth including fireweed and blackberries. We did not observe any surface water or incised channeling, or indications of groundwater seepage south of the pond.

We observed the pond as indicated on the GIS map. The water appears stagnant, with no visible inlet. No springs or seepage were observed in the vicinity of the pond at the time of our field reconnaissance.

We observed the area to the north of the pond. We did not observe any surface flow, however we did observe faint traces of surface moisture, consisting of bare soil in the topographic low near the flow path indicated on the GIS map. No distinct discharge point from the pond was observed at the time of our field reconnaissance.

RECOMMENDATIONS AND CONCLUSIONS

Based on our off-site reconnaissance, subsurface exploration, modeling, and geologic interpretations, we conclude infiltration of treated stormwater runoff is feasible in the northeast corner of the site and is considered suitable for the proposed infiltration facility, in our opinion. The modeled facility information was provided by Navix, and is approximately 20 x 60 feet long, by 15.5 feet deep, with a storage volume of 18,600 cubic feet. Based on the results of our infiltration study, we recommend a design infiltration rate of 2 in/hr, provided the recommendations in this section are incorporated in the design.

General Considerations for Infiltration

Long-term performance of infiltration facilities is improved by providing clean turbid-free water to the facility. Therefore, we recommend that all stormwater runoff be routed through treatment systems prior to entering the infiltration facility.

Preliminary Infiltration Facility Construction Considerations

The currently-proposed infiltration facility design includes a vault whose base is founded in Vashon lodgement till. We recommend that the infiltration facility bottom area be overexcavated a minimum of 2 feet into the underlying Vashon advance outwash unit. Based on our explorations, the advance outwash begins at approximately elevation 530 feet in the vicinity of the proposed vault.

We recommend that infiltration trenches or pit drains be excavated from the base of the overexcavation, to an approximate depth of 20 feet below overexcavation subgrade, or approximate elevation 510 feet. The bottoms of the trenches must be a minimum of 5 feet above the seasonal high groundwater elevation. We anticipate in the proposed vault design, there could be one trench extending the length of the vault, or if individual pit drains are employed, they should be placed with a minimum 25-foot spacing, edge-to-edge. Trenches and pit drains can be a minimum of 4 feet wide. Compaction of the infiltration subgrade with wheeled vehicles or excessive tracked vehicles should be avoided. After the infiltration trenches are installed, the infiltration subgrade should be scarified a minimum of 8 inches, prior to the placement of additional import materials.

Infiltration Facility Considerations

The following sections discuss the general configuration and design recommendations for construction of the infiltration facility. Specifications for the gravel backfill for trench drains, 4x8 sand, and filter sand are provided in Appendix E.

- Sand Filter Layers: Two successive layers of sand filter media shall be placed across the infiltration facility footprint and over the top of the infiltration trench backfill media. The sand filter layers should consist of a minimum 12-inch layer of 4x8 coarse sand overlying the gravel backfill, and a minimum 12-inch layer of filter sand overlying the 4x8 sand. Inclusion of the sand filter layers will provide additional filtration of suspended particles that may remain in the stormwater. See Tables E-2 and E-3 for specifications.

  Care must be taken to ensure the gravel backfill and sand products are clean and free of fines. Stockpiled backfill materials must be protected from site soils and run-on from silt-contaminated surfaces. Fines contaminated backfill materials cannot be used in the sand filters and will be rejected by AESI.

- Due to natural variability of the subsurface conditions, the potential for field adjustments should be anticipated based on actual conditions encountered during construction. Depending on the season the infiltration facility is excavated, perched water above and within the Vashon lodgement till sediments should be anticipated. The contractor should be prepared to handle the perched water.

- Energy dissipation elements must be provided inside the infiltration facility at the inlet(s). The energy dissipation is essential to prevent the erosion of the filter sand in the facility. Energy dissipation strategies may include walls, level spreaders, quarry spall blankets, or other means. Energy dissipation strategies must be sized to be effective for peak flow events. If spall blankets are selected, it is advisable to place the spall on filter fabric to prevent comingling of spall and the underlying sand.

- In AESI's experience, permanent wet pond elements incorporated in the stormwater infiltration design can be sources of filter contamination by aquatic flora or fauna. Therefore, we recommend minimizing permanent wet facilities in the stormwater treatment/infiltration train.

- Piezometers: Vertical pipes consisting of solid and machine-slotted, 2-inch-diameter Schedule 80 PVC with threaded connections will extend from ground surface to the bottoms of the infiltration trenches and will consist of 10 feet of machine-slotted well screen with 0.020-inch-diameter openings and solid 2-inch-diameter PVC pipe. The piezometers facilitate as-built performance verification testing, and potential long-term or future performance monitoring.

- Gravel Backfill: The infiltration trenches shall be backfilled with washed pea gravel, per the specification in Table E-1. The backfill shall extend from the bottoms of the infiltration trenches to the infiltration facility subgrade.

General Guidelines for On-Line Status and Maintenance

In order to maximize future performance of the stormwater infiltration system, the following recommendations are provided:

- All stormwater *must* be pre-treated to remove suspended sediments, nutrients, and contaminants. Lack of proper pre-treatment could result in sediment entering the backfill media and/or formation, loss of system performance, and deterioration of groundwater quality.

The site must be fully stabilized prior to routing stormwater to the infiltration facility. Full stabilization shall include the following:

1. All planned earthwork must be complete.
2. Site stabilization must be complete:
    a. All permanent groundcover in place.
    b. Areas around the infiltration facility must be completed slightly above grade or otherwise completed so that manhole structures cannot collect surface water runoff.
    c. No exposed topsoil.
    d. Hydroseeded areas must have established growth sufficient to fix topsoil in place.
    e. No visible sediment transport by stormwater during rain events.
    f. Catch-basin filter socks should no longer be needed and shall be removed.
3. Hard surfaces such as paving and sidewalks must be cleaned with no visible sediment or substances that could be transported by stormwater.
4. All stormwater collection system components must be cleaned and inspected:
    a. All catch basins, manholes, and similar structures shall be cleaned by rinsing and vacuuming to remove visible sediment.
    b. All stormwater pipes shall be jetted to remove visible sediment.
5. AESI shall be notified that construction is complete, and shall be allowed to install long-term monitoring components such as water level loggers before water is routed to the infiltration facility.
6. The Owner, civil engineer, and AESI must be notified that the above items have been completed, and must concur that the above items have been satisfactorily completed.
7. Written authorization must be provided from the Owner, civil engineer, and AESI to the contractor that water may be routed to the infiltration facility.
8. Following the first substantial rain event after the infiltration facility is brought on-line, the system shall be visually inspected. The contractor shall contact the Owner, civil

engineer, and AESI to attend the inspection, and shall open inspection ports, catch basins, manholes, and other structures as needed to allow visual inspection.

9. No stormwater shall be discharged to the wells until the turbidity **prior** to treatment by the stormwater pretreatment device is less than 25 nephelometric turbidity units (NTUs).

CLOSURE

We appreciate the opportunity to be of service to you on this project. Should you have any questions regarding this letter-report or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

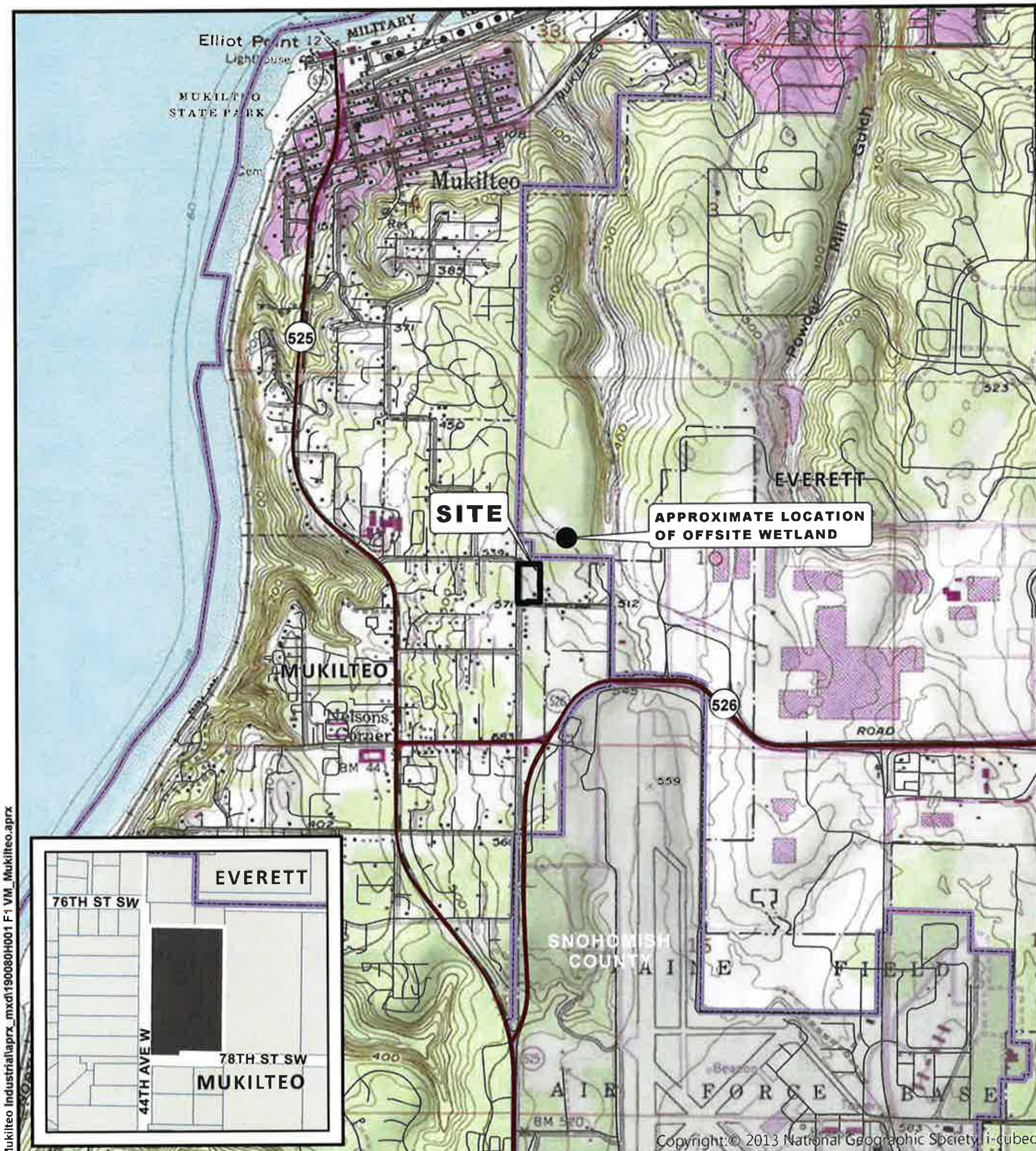
Sincerely,
ASSOCIATED EARTH SCIENCES, INC.
Kirkland, Washington

11-4-2019 11/4/19

Stanley S. Thompson, L.G., L.Hg.
Senior Project Geologist/Hydrogeologist

Curtis J. Koger, L.G., L.E.G., L.Hg.
Senior Principal Geologist/Hydrogeologist

Attachments:	Figure 1:	Vicinity Map
	Figure 2:	Site and Exploration Plan
	Figure 3:	MW-1 Hydrograph
	Appendix A:	Exploration Logs
	Appendix B:	Grain-Size Analyses
	Appendix C:	Infiltration Testing Data
	Appendix D:	Groundwater Mounding Analysis
	Appendix E:	Backfill Specifications



DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NATIONAL GEOGRAPHIC SOCIETY 2013
SNOHOMISH CO: STREETS, CITY LIMITS, PARCELS, 2/19
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 1000 2000
FEET

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

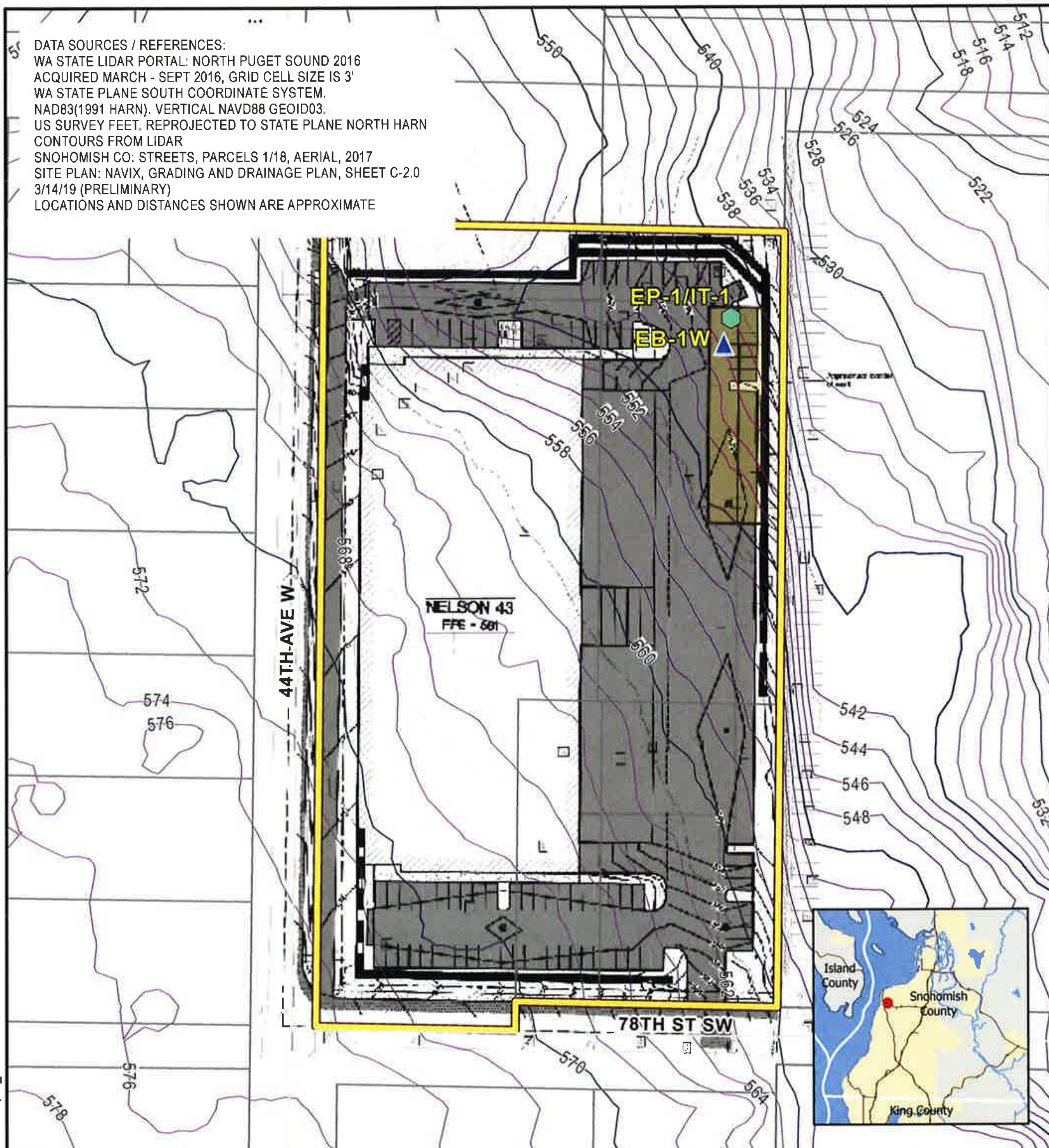
associated earth sciences incorporated

VICINITY MAP

MUKILTEO INDUSTRIAL DEVELOPMENT
MUKILTEO, WASHINGTON

PROJ NO.	DATE:	FIGURE:
190080H001	5/19	1

Document Path: G:\GIS_Projects\aaY2019\190080 Mukilteo Industrial\aprx_mxd\190080H001 F1 VM_Mukilteo.aprx



▭	SITE
▲	MONITORING WELL
⬢	INFILTRATION TEST
▭	PROPOSED VAULT
∿	CONTOUR 10 FT
∿	CONTOUR 2 FT
▭	PARCEL

N

0 — 100 Feet

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

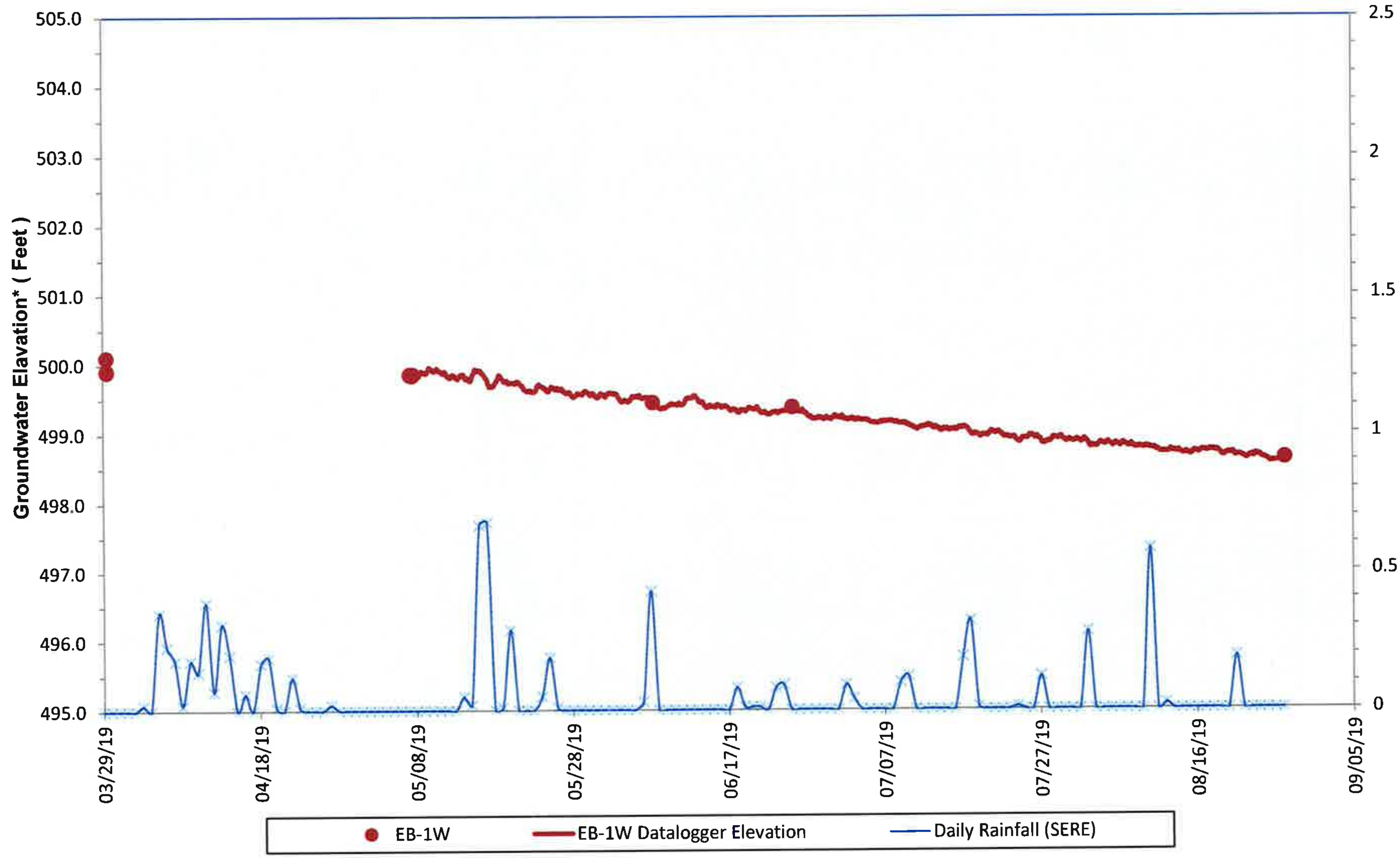
associated earth sciences incorporated

EXISTING SITE AND EXPLORATION PLAN

MUKILTEO INDUSTRIAL DEVELOPMENT
MUKILTEO, WASHINGTON

PROJ NO.	DATE:	FIGURE:
190080H001	7/19	2

Path: G:\GIS_Projects\aaY2019\190080 Mukilteo Industrial\aprx_mxd\190080H001



Note: Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect

* Groundwater elevations are approximate, as the well has not been surveyed.

EB-1W Groundwater Hydrograph
Mukilteo Industrial (Nelson 43)
Mukilteo, Washington

Figure 3
Date 10/2019
Proj. No. 190080H001

Associated Earth Sciences, Inc.

APPENDIX A

Exploration Logs

Major Divisions			Group Symbol	Description
Coarse-Grained Soils - More than 50%[1] Retained on No. 200 Sieve	Gravels - More than 50%[1] of Coarse Fraction Retained on No. 4 Sieve	≤5% Fines[5]	GW	Well-graded gravel and gravel with sand, little to no fines
			GP	Poorly-graded gravel and gravel with sand, little to no fines
		≥12% Fines[5]	GM	Silty gravel and silty gravel with sand
			GC	Clayey gravel and clayey gravel with sand
	Sands - 50%[1] or More of Coarse Fraction Passes No. 4 Sieve	≤5% Fines[5]	SW	Well-graded sand and sand with gravel, little to no fines
			SP	Poorly-graded sand and sand with gravel, little to no fines
		≥12% Fines[5]	SM	Silty sand and silty sand with gravel
			SC	Clayey sand and clayey sand with gravel
Fine-Grained Soils - 50%[1] or More Passes No. 200 Sieve	Silts and Clays Liquid Limit Less than 50		ML	Silt, sandy silt, gravelly silt, silt with sand or gravel
			CL	Clay of low to medium plasticity; silty, sandy, or gravelly clay, lean clay
			OL	Organic clay or silt of low plasticity
	Silts and Clays Liquid Limit 50 or More		MH	Elastic silt, clayey silt, silt with micaceous or diatomaceous fine sand or silt
			CH	Clay of high plasticity, sandy or gravelly clay, fat clay with sand or gravel
			OH	Organic clay or silt of medium to high plasticity
Highly Organic Soils			PT	Peat, muck and other highly organic soils

Terms Describing Relative Density and Consistency

	Density	SPT[2] blows/foot
Coarse-Grained Soils	Very Loose	0 to 4
	Loose	4 to 10
	Medium Dense	10 to 30
	Dense	30 to 50
	Very Dense	>50

	Consistency	SPT[2] blows/foot
Fine-Grained Soils	Very Soft	0 to 2
	Soft	2 to 4
	Medium Stiff	4 to 8
	Stiff	8 to 15
	Very Stiff	15 to 30
	Hard	>30

Test Symbols

G = Grain Size
M = Moisture Content
A = Atterberg Limits
C = Chemical
DD = Dry Density
K = Permeability

Component Definitions

Descriptive Term	Size Range and Sieve Number
Boulders	Larger than 12"
Cobbles	3" to 12"
Gravel	3" to No. 4 (4.75 mm)
Coarse Gravel	3" to 3/4"
Fine Gravel	3/4" to No. 4 (4.75 mm)
Sand	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse Sand	No. 4 (4.75 mm) to No. 10 (2.00 mm)
Medium Sand	No. 10 (2.00 mm) to No. 40 (0.425 mm)
Fine Sand	No. 40 (0.425 mm) to No. 200 (0.075 mm)
Silt and Clay	Smaller than No. 200 (0.075 mm)

[3] Estimated Percentage

Component	Percentage by Weight
Trace	<5
Some	5 to <12
Modifier (silty, sandy, gravelly)	12 to <30
Very *modifier* (silty, sandy, gravelly)	30 to <50

Moisture Content

Dry - Absence of moisture, dusty, dry to the touch
Slightly Moist - Perceptible moisture
Moist - Damp but no visible water
Very Moist - Water visible but not free draining
Wet - Visible free water, usually from below water table

Symbols

Sampler Type

Blows/6" or portion of 6"

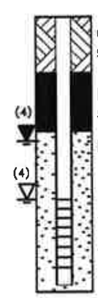
2.0" OD Split-Spoon Sampler (SPT)

Bulk sample

Grab Sample

Sampler Type Description

3.0" OD Split-Spoon Sampler
3.25" OD Split-Spoon Ring Sampler
3.0" OD Thin-Wall Tube Sampler (including Shelby tube)
Portion not recovered



Cement grout surface seal
Bentonite seal
Filter pack with blank casing section
Screened casing or Hydrotip with filter pack
End cap

(1) Percentage by dry weight
(2) (SPT) Standard Penetration Test (ASTM D-1586)
(3) In General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
(4) Depth of ground water
▼ ATD = At time of drilling
▽ Static water level (date)
(5) Combined USCS symbols used for fines between 5% and 12%

Classifications of soils in this report are based on visual field and/or laboratory observations, which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field or laboratory testing unless presented herein. Visual-manual and/or laboratory classification methods of ASTM D-2487 and D-2488 were used as an identification guide for the Unified Soil Classification System.

blocks \ dwg \ log_key.dwg LAYOUT: Layout 4 -2014 Qty Chng

associated earth sciences incorporated

EXPLORATION LOG KEY

FIGURE A1

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
190080H001	EB-1W	1 of 2

Project Name	Mukilteo Industrial	Location	Mukilteo, WA
Elevation (Top of Well Casing)	~546	Surface Elevation (ft)	543 (LiDAR Contours)
Water Level Elevation	500	Date Start/Finish	3/28/19,3/28/19
Drilling/Equipment	ADT	Hole Diameter (in)	8 inches
Hammer Weight/Drop	140# / 30"		

Depth (ft)	WELL CONSTRUCTION	Blows/6"	DESCRIPTION
0	Above ground steel locking monument Concrete 0 to 2 feet		**Forest Duff** **Vashon Lodgment Till** Loose to medium dense, moist, brown, silty, fine SAND, some fine to coarse gravel, trace cobbles, trace organics (rootlets); weathered (SM). Becomes dense, brownish gray.
5	3/8-inch Bentonite chips 2 to 6 feet	8 26 41	Moist, brownish gray grading to gray, silty, fine SAND, trace gravel; unsorted (SM).
10		20 36 50/4"	Dark gray, moist, silty, fine SAND, trace gravel (SM).
15		50 50/2"	**Vashon Advance Outwash** Driller notes increased drill rate. Moist, gray, gravelly, well graded SAND, trace silt; unsorted (SW).
20	Bentonite grout 6 to 30 feet 2-inch I.D. Sch 40 PVC casing -3 to 40 feet	17 34 37	Moist, brownish gray, gravelly, medium SAND, some silt; increased gravel in lower 4 inches to gravelly, SAND; stratified (SP/SM). Driller notes drills more gravelly.
25		35 50/5"	Upper 2 inches: very moist, brownish gray, gravelly, medium to coarse SAND, trace silt (SP). Mid 3 inches: moist, tan, fine to coarse SAND, some silt, trace gravel (SP). Lower 4 inches: slightly moist, tannish gray, fine to coarse SAND, some gravel, trace to some silt; stratified (SW/SM). Driller notes increased larger gravel; stratified.
30	3/8-inch Bentonite chips 30 to 37 feet	8 32 37	Upper 8 inches: moist, brownish gray, gravelly, fine to medium SAND, some silt (SP). Lower 6 inches: moist, tannish gray, fine SAND, trace silt, trace gravel (SP).
35	10/20 filter sand 37 to 50 feet	37 41 50/5"	Moist, brownish gray, sandy, GRAVEL, trace to some silt; multiple broken larger pieces of gravel in sampler (GP).

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level (3/29/19)
Water Level at time of drilling (ATD)

Logged by: SST
Approved by: CJK

associated earth sciences incorporated

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
190080H001	EB-1W	2 of 2

Project Name: Mukilteo Industrial
Elevation (Top of Well Casing): ~546
Water Level Elevation: 500
Drilling/Equipment: ADT
Hammer Weight/Drop: 140# / 30"

Location: Mukilteo, WA
Surface Elevation (ft): 543 (LiDAR Contours)
Date Start/Finish: 3/28/19,3/28/19
Hole Diameter (in): 8 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
				20 50/3"		Moist to very moist, brown, sandy, GRAVEL, some silt; cuttings and broken gravel in sampler suggest fine to coarse gravel (GM/GW).
45		2-inch I.D. Sch 40 PVC well screen 0.020-inch slot width 40 to 50 feet		21 24 37		Wet, grayish brown, medium to coarse sandy, GRAVEL, some silt; grades siltier in lower 4 inches of sampler (SP/SM).
50		Native slough and 10/20 filter sand 50 to 55 feet		30 50/2"		**Pre-Fraser Till** Driller notes change in drilling action, more dense, less coarse gravel at 50 feet. Moist, grayish brown with slight orange mottling, silty, fine SAND, some gravel; unsorted (SM).
55				50/5"		Moist, dark gray, silty, fine SAND, trace gravel; unsorted (SM). Boring terminated at 55.4 feet Well completed at 50 feet on 3/28/19. Groundwater encountered at 43 feet ATD and at 42.9 on 3/29/19.
		Well tag # BKU 938				
60						
65						
70						
75						

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level (3/29/19)
Water Level at time of drilling (ATD)

Logged by: SST
Approved by: CJK

LOG OF EXPLORATION PIT NO. EP-1/IT-1

Depth (ft)

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

DESCRIPTION

Elev: ~542 ft

Forest Duff / Topsoil - 8 inches

Vashon Lodgment Till

Loose to medium dense, very moist, brown to reddish brown, silty, fine SAND, some fine to coarse gravel, trace cobbles, trace organics; unsorted; weathered; (SM).

Very dense, moist, gray, silty, fine SAND, trace gravel, trace cobbles; unsorted; unweathered (SM).

Dense, moist, gray, silty, fine SAND, trace gravel; unsorted (SM).

Vashon Advance Outwash

Dense, moist, gray, gravelly, fine to coarse SAND, some silt; stratified (SM/SW).
Dense, moist, gray, medium to coarse SAND, fine to coarse gravel, trace silt; stratified (SP).

Dense, very moist, gray, gravelly, fine to medium SAND, some silt; stratified (SP/SM).

Dense, very moist, gray, fine SAND, trace silt, trace fine gravel; partially cemented; stratified (SP).
Dense, very moist, gray, gravelly, fine to coarse SAND, trace silt; stratified (SP).

Dense, very moist, gray, very sandy, GRAVEL, some silt; stratified (GP).

Bottom of exploration pit at depth 24.5 feet
Minor seepage at 3.5 feet (interflow) and slight seepage at 18 feet. Slight caving at 18 feet. Infiltration test performed at 16 feet. Moisture below 16 feet inferred to be wetted by water from infiltration test.

Mukilteo Industrial
Mukilteo, WA

associated earth sciences incorporated

Logged by: SST
Approved by: CJK

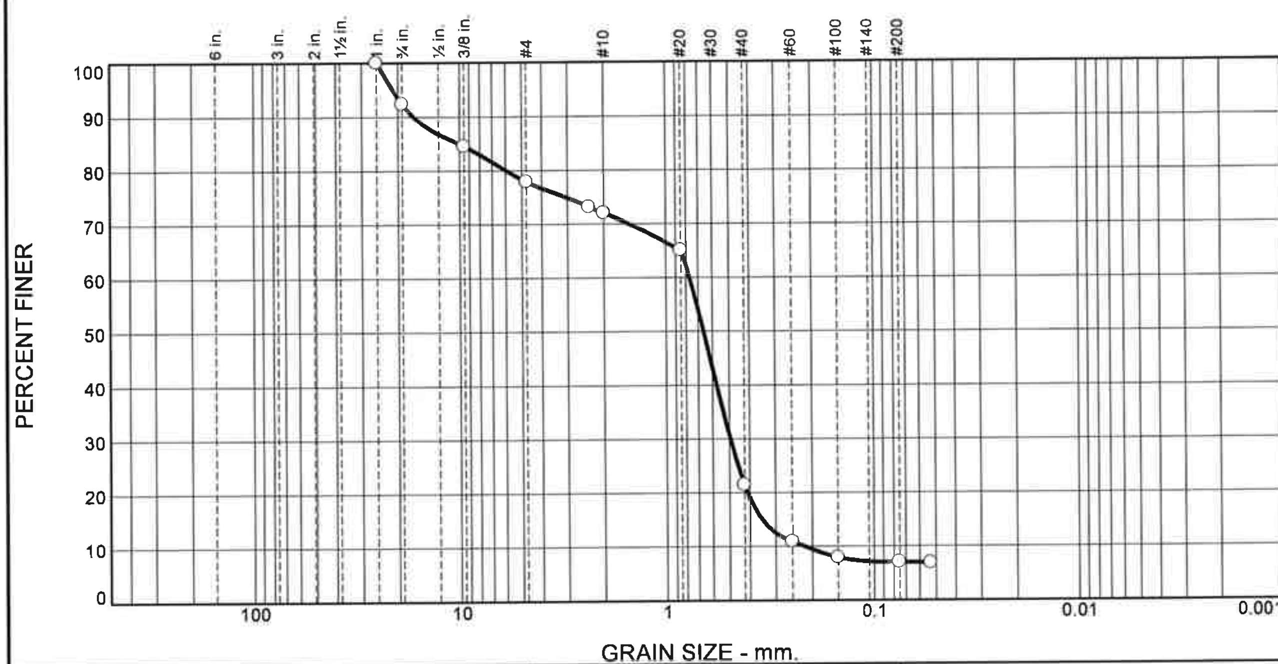
Project No. 190080H001

3/20/19

APPENDIX B

Grain-Size Analyses

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	7.7	14.4	5.9	50.5	14.5	7.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1	100.0		
.75	92.3		
.375	84.5		
#4	77.9		
#8	73.2		
#10	72.0		
#20	65.0		
#40	21.5		
#60	11.0		
#100	7.9		
#200	7.0		
#270	6.9		

* (no specification provided)

Material Description

Gravelly SAND Some Silt

Atterberg Limits (ASTM D 4318)

PL= np **LL=** nv **PI=**

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 16.8194 D_{85}= 10.1305 D_{60}= 0.7702
D_{50}= 0.6592 D_{30}= 0.4948 D_{15}= 0.3502
D_{10}= 0.2174 C_u= 3.54 C_c= 1.46

Remarks

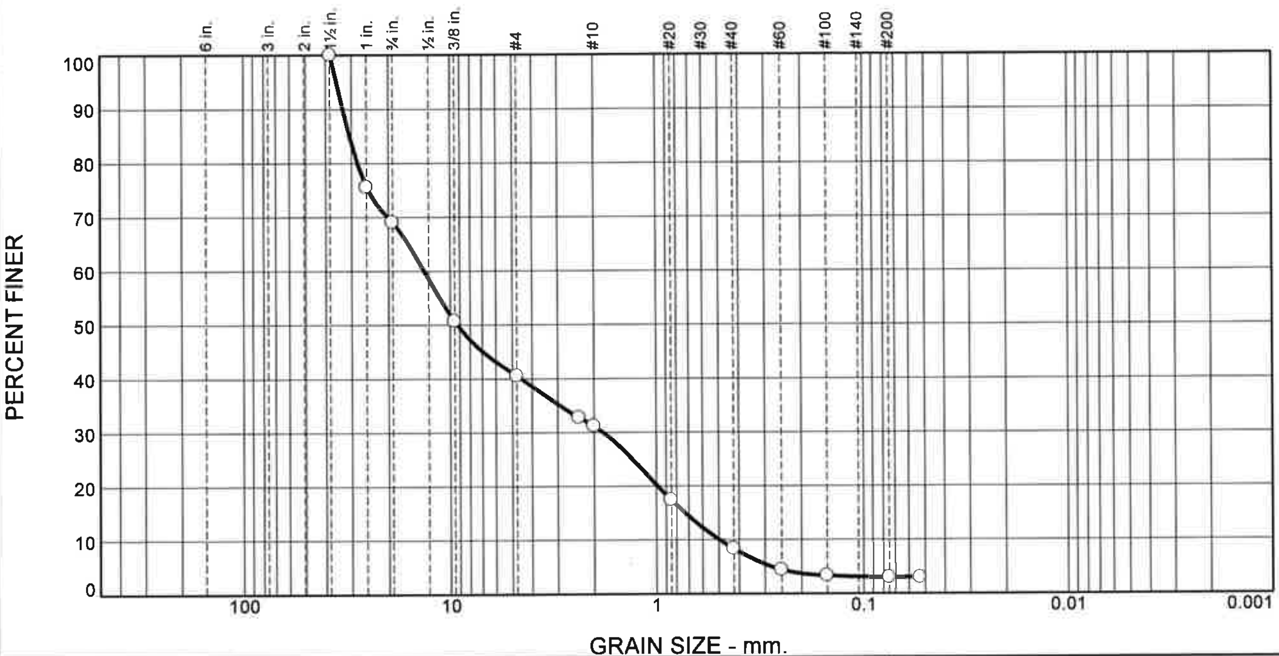
Date Received: 5-8-19 **Date Tested:** 5-8-19
Tested By: AM
Checked By: CJK
Title:

Location: Onsite **Date Sampled:** 5-8-19
Sample Number: IT-1 **Depth:** 17'

associated earth sciences incorporated

Client: Underwood Nelson Development
Project: Mukilteo Industrial
Project No: 190080 H001 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	31.0	28.5	9.3	22.8	5.4	3.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	75.6		
.75	69.0		
.375	50.7		
#4	40.5		
#8	32.8		
#10	31.2		
#20	17.4		
#40	8.4		
#60	4.4		
#100	3.3		
#200	3.0		
#270	3.0		

* (no specification provided)

Material Description

Very Sandy GRAVEL Trace Silt

Atterberg Limits (ASTM D 4318)

PL= np **LL=** nv **PI=**

Classification

USCS (D 2487)= GP **AASHTO (M 145)=** A-1-a

Coefficients

D_{90}= 33.0641 D_{85}= 30.6132 D_{60}= 13.3694
D_{50}= 9.2325 D_{30}= 1.8066 D_{15}= 0.7289
D_{10}= 0.4963 C_u= 26.94 C_c= 0.49

Remarks

Date Received: 5-8-19 **Date Tested:** 5-8-19

Tested By: AM

Checked By: CJK

Title:

Location: Onsite
Sample Number: IT-1 **Depth:** 24.5'
Date Sampled: 5-8-19

associated earth sciences incorporated

Client: Underwood Nelson Development
Project: Mukilteo Industrial
Project No: 190080 H001 **Figure**

APPENDIX C

Infiltration Testing Data

Project Name:	Mukilteo Industrial	Water Source:	4,000-gal water truck
Project Number:	190080H001	Meter:	NW Excavating low flow
Date:	5/7/2019	Pit Area (sq. feet):	15
Weather:	clear, 60's	Ring Area (sq. feet):	n/a
Test No.:	IT-1	Test Depth (feet):	16 feet
Performed By:	SST	Receptor Soils:	Advance Outwash

Time	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
8:40	1.77	0	0	Flow on
8:47	4.28	0	13.74	Increase flow from 1.82 gpm
8:52	4.32	0.12	31.33	
8:56	4.16	0.24	48.44	
9:03	4.16	0.4	77.08	
9:13	2.46	0.67	120.37	Decrease flow from 4.40 gpm
9:22	1.51	0.76	143.92	Decrease flow from 2.60 gpm
9:33	1.56	0.77	161.66	
9:42	1.22	0.79	176.3	Decrease flow from 1.64 gpm
10:00	1.36	0.79	199.92	
10:16	1.18	0.81	221.82	Decrease flow from 1.45 gpm
10:30	1.29	0.81	239.24	
10:44	1.28	0.82	256.58	
11:00	1.29	0.84	277.3	
11:15	1.31	0.86	296.61	
11:30	1.16	0.88	317.06	Decrease flow from 1.43 gpm
11:45	1.14	0.88	334.3	
12:00	1.12	0.88	351.35	
12:15	0.91	0.87	368.36	Increase flow from 0.88 gpm
12:45	1.21	0.82	397.14	
13:00	1.23	0.81	413.1	Increase flow from 1.00 gpm
13:15	1.19	0.82	429.39	Increase flow from 1.00 gpm
13:30	1.2	0.84	447.89	
13:45	1.23	0.84	465.94	
14:00	1.06	0.85	484.06	Decrease flow from 1.22 gpm
14:15	1.16	0.87	502.21	
14:20	1.18	0.87	507.96	
14:25	1.18	0.87	513.81	
14:30	1.14	0.87	519.61	
14:35	1.16	0.87	525.37	
14:40	1.12	0.87	531.23	
14:45	1.13	0.87	536.94	
14:50	1.13	0.88	542.71	
14:55	1.18	0.88	548.44	
15:00	1.2	0.88	554.22	
15:05	1.16	0.88	560	
15:10	1.13	0.88	565.74	
15:15	1.13	0.89	571.52	
15:20	1.13	0.89	577.35	
15:25	1.14	0.89	583.02	Flow off
15:30	1.18	0.89	588.8	
15:35	1.16	0.89	594.67	
15:40	0	0.89	600.58	Flow off; decrease from 1.12 gpm
15:43	0	0.88		
15:49	0	0.83		

Project Name:	Mukilteo Industrial	**Water Source:**	4,000-gal water truck
Project Number:	190080H001	**Meter:**	NW Excavating low flow
Date:	5/7/2019	**Pit Area (sq. feet):**	15
Weather:	clear, 60's	**Ring Area (sq. feet):**	n/a
Test No.:	IT-1	**Test Depth (feet):**	16 feet
Performed By:	SST	**Receptor Soils:**	Advance Outwash

Time	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
15:54	0	0.78		
16:00	0	0.72		
16:06	0	0.68		
16:12	0	0.63		
16:20	0	0.57		

Average Infiltration Rate (in/hr) during last hour of inflow:	7.2
Average Infiltration Rate (in/hr) during falling head:	6.0

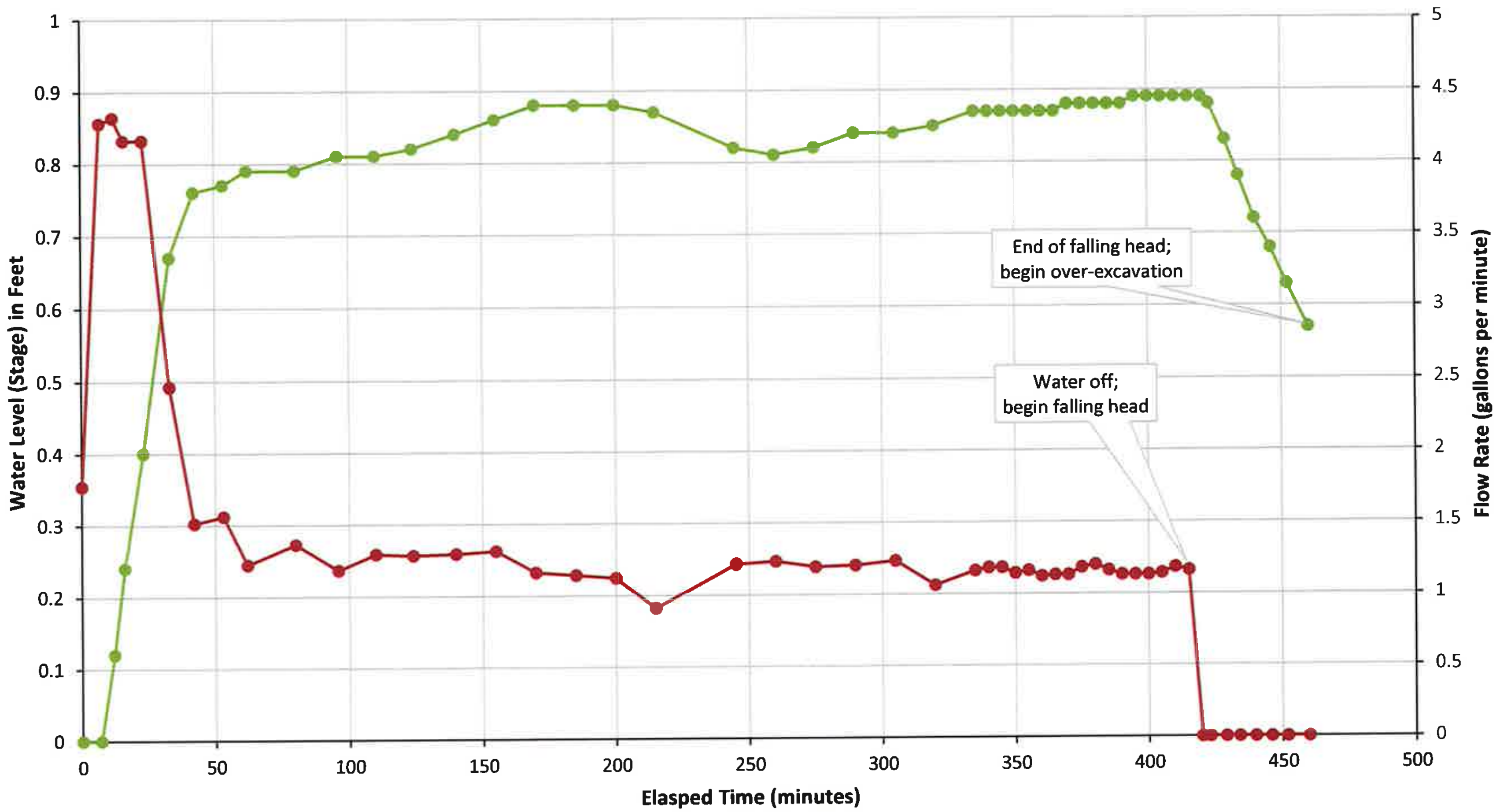
Note:

Meter zeroed at start of test.

Shut down flow at 15:40

Calculated infiltration rate accounts for change in storage during course of test.

Field Infiltration Test Data
Stage (feet) on Left Axis; Flow Rate (gpm) on Right Axis vs Elasped Time (minutes)



Notes:
Test conducted on 5/7/2019 at a depth of 16 feet below existing grade. Total volume of water used was 600 gallons.
Geologic unit tested was Advance outwash (Qva).
Constant head infiltration Rate during last of hour of inflow = 7.2 in/hr.
Falling head infiltration rate = 6.0 in/hr

APPENDIX D

Groundwater Mounding Analysis

APPENDIX D
GROUNDWATER MOUNDING ANALYSIS

The groundwater mounding analysis was completed to simulate the maximum groundwater mound height and compare it to the design high water elevation (DHWE) in the proposed infiltration facility. Groundwater mounding can occur when water is introduced into an infiltration facility at a higher rate than can be conveyed from the area beneath the facility. The introduced water can "mound" on the groundwater table or on a less-permeable silty interbed within the receptor sand and gravel during a storm event. When the storm event is over and water is not being introduced into the system, the mound will dissipate. The mounding analysis is used to simulate the maximum groundwater mound beneath the facility during a design storm series.

The MODRET computer program was used to model potential groundwater mounding beneath the proposed infiltration facility under two design time series. Infiltration system civil design details and stormwater inflow hydrographs were provided by Navix Engineering (Navix), the project civil engineer. The MODRET program utilizes the Greene Ampt method for unsaturated conditions and the U.S. Geological Survey MODFLOW model for saturated conditions.

The soil and groundwater input parameters used in the MODRET evaluation were consistent with field/laboratory data and applicable published hydrogeologic literature. The model input parameters are included in this Appendix and an explanation of the basis for all parameters used is included in Table D-1. The civil design and hydrogeologic conceptual model are described below.

Civil Design and Proposed Stormwater Inflow Hydrographs

One infiltration vault is proposed for the project, located near the northeast corner of the site. According to Navix, an open-bottom vault is currently proposed to mitigate stormwater runoff. This section describes the civil design elements facility.

Current preliminary sizing of the infiltration facility indicates it will be approximately 18,600 cubic feet of storage with dimensions of 60 feet long by 20 feet wide. The vault height between bottom and the design high water elevation will be 15.5 feet. The facility is designed with three orifices at different elevations to meet discharge compliance.

Navix provided two stormwater hydrographs for the facility: one from a period which includes the highest flow rate (peak flow) and one from a period of maximum volume, derived from the Western Washington Hydrology Model, 2012 (WWHM2012) surface water model. In Navix's analyses, from the simulated rainfall data, the period of the peak flow hydrograph is November 18 to December 18, 2007, with the peak flow occurring on December 3, 2007. The 30-day date range with the maximum volume is December 29, 1996 to January 27, 1997. Prints of the spreadsheet pages containing the hydrographs provided by Navix are included in this Appendix.

Navix's design includes three flow control orifices, as shown in Table D-2. MODRET can only model a facility with one orifice, so the lower orifice was selected. This orifice was selected because it is located at the facility bottom elevation and would thus activate immediately upon water accumulating in the facility.

Navix also provided facility elevation and volume parameters for the infiltration facility in an email dated June 20, 2019, and also provided a preliminary Stormwater Drainage Report, dated September 27, 2019. The facility parameters are included in Table D-1.

Hydrogeologic Conceptual Model and Aquifer Parameters

Infiltration test IT-1 was conducted at a depth of 16 feet below ground surface (bgs) (approximate elevation 226 feet) in the facility footprint. The tested constant-head infiltration rate was 7.2 inches per hour (in/hr) as described in the "Infiltration Testing" section of this letter-report.

Because the infiltration system design will include a deep trench or drains, as described in the "Infiltration Design Concept" section of this letter-report, the hydraulic conductivities used in the mounding analysis are based on grain-size analyses of the sample obtained from 24.5 feet bgs (approximate elevation 526 feet).

The constant-head infiltration rate is considered analogous to saturated vertical hydraulic conductivity (Kvs). The model requires input of two hydraulic conductivity values: saturated horizontal hydraulic conductivity (Khs) and unsaturated vertical hydraulic conductivity (Kvu). To derive a value for Khs, we use a relationship of Khs = 3 times the Kvs. This value is generally considered conservative, within the range of published hydraulic conductivity ratio values for sediments deposited by flowing water, and is required by jurisdictions such as King County (in Section 5.2.1 of King County's *Surface Water Design Manual*, 2016). Kvu is assumed to be two-thirds the value of Kvs (Andreyev and Wiseman, 1989).

The infiltration design includes a facility bottom elevation of 537.65 feet.

The bottom of the aquifer was modeled as 493 feet, based on the base of the advance outwash observed in EB-1W. The maximum groundwater elevation observed during the limited monitoring program was approximately 500 feet. We anticipate seasonal high groundwater elevations will be higher, so a groundwater elevation of 503 feet was used in the model. Table D-1 presents the model input values for the infiltration facility and the basis for these values.

The proposed infiltration facility lies approximately 400 feet southwest of an off-site area mapped as a wetland. An additional analysis was performed for the facility, to estimate potential influence on the wetland as a result of infiltration. Based on our analysis, the temporary maximum simulated design storm head rise at the western edge of the wetland was about 0.4 feet or less. No significant adverse impacts to wetland hydrology have been identified.

Groundwater Mounding Analysis Results

The results of the MODRET simulation are included in this Appendix and indicate that under the scenarios using the grain-size analysis-derived infiltration rate as a basis for hydraulic conductivity, the modeled infiltration facility will have the capacity to infiltrate the stormwater runoff routed to the facility during the design storm time series hydrographs provided by Navix, without reaching the DHWE. Under the peak flow hydrograph, the maximum groundwater mound elevation was below the facility bottom elevation of 537.65 feet, and under the maximum volume hydrograph, the groundwater mound reached a maximum elevation of 548.4 feet. These elevations are below the DHWE of 553.15 feet.

REFERENCES

Andreyev, N.E. and Wiseman, L.P., 1989, Stormwater retention pond infiltration analysis in unconfined aquifers: Prepared for Southwest Florida Water Management District, Brooksville, Florida.

King County Department of Natural Resources and Parks, 2016, Surface water design manual: April 24, 2016.

Table D-1
MODRET Input Parameter Summary

Parameter	Value	Basis
Parameters Provided by Civil Engineer		
Facility Bottom Area (square feet)	1,200	Navix.
Facility Volume Between Bottom and DHWE (ft^3)	18,600	Navix.
Facility Length to Width Ratio	3.0	Navix.
Elevation of Starting Water Level (ft)	537.65	Facility bottom elevation (Navix).
Elevation of Facility Bottom (ft)	537.65	Navix.
DHWE (ft)	553.15	Navix.
Average Effective Storage Coefficient of Facility/Exfiltration Trench	1.0	Navix (vault is 100 percent void space).
Design Infiltration Rate Used for Vault Design (in/hr)	2.0	Navix.
Parameters Derived by AESI		
Elevation of Effective Aquifer Base	493	EB-1W Base of Qva.
Elevation of Seasonal High Groundwater Table	503	Approximately 3 feet above groundwater encountered in EB-1W.
Storage Coefficient of Soil for Unsaturated Analysis	0.25	AESI - Within range of published values for the soil types present.
Unsaturated Vertical Hydraulic Conductivity (Kvu) (ft/day)	25.8	Rate accounts for permeable backfill in vertical drains/trench. Incorporates the Washington State Department of Ecology Stormwater Management Manual for Western Washington (SWMMWW) corrected rate obtained from grain-size method at 24.5 feet below ground surface (bgs). See text.
Saturated Horizontal Hydraulic Conductivity (Khs) (ft/day)	25.8	3 x Khs, based on SWMMWW corrected rate obtained from grain-size method at 24.5 feet bgs. See text.
Storage Coefficient of Soil for Saturated Analysis	0.25	AESI - Within range of published values for the soil types present.
Model Default Parameters		
Factor of Safety	2	Standard value.
Time Increment During Storm Event (hours)	24	Increments match hydrograph time steps.
Time Increment After Storm Event (hours)	24	Increments match hydrograph time steps.
Total Number of Increments After Storm Event	6	Program default.

Navix = civil engineer, Navix Engineering; DHWE = design high water elevation; ft^3 = cubic feet; ft = feet; in/hr = inches per hour; ft/day = feet per day; in = inch;

Table D-2
Flow Control Orifice Information

Orifice #	Diameter (inches)	Orifice area (square inch)	Height from Bottom (feet)	Elevation
1	0.688	0.371	0	540
2	1.031	0.835	10.5	550.5
3	0.656	0.338	12.27	552.27

MODRET

SUMMARY OF UNSATURATED & SATURATED INPUT PARAMETERS

PROJECT NAME : Nelson 43 Peak Flow
HYDROGRAPH RUNOFF DATA USED
UNSATURATED ANALYSIS INCLUDED

Pond Bottom Area	1,200.00 ft^2
Pond Volume between Bottom & DHWL	18,600.00 ft^3
Pond Length to Width Ratio (L/W)	3.00
Elevation of Effective Aquifer Base	493.00 ft
Elevation of Seasonal High Groundwater Table	503.00 ft
Elevation of Starting Water Level	537.65 ft
Elevation of Pond Bottom	537.65 ft
Is there overflow ?	Y
Avg. Effective Storage Coefficient of Soil for Unsaturated Analysis	0.25
Unsaturated Vertical Hydraulic Conductivity	25.80 ft/d
Factor of Safety	2.00
Saturated Horizontal Hydraulic Conductivity	25.80 ft/d
Avg. Effective Storage Coefficient of Soil for Saturated Analysis	0.25
Avg. Effective Storage Coefficient of Pond/Exfiltration Trench	1.00
Time Increment During Storm Event	24.00 hrs
Time Increment After Storm Event	24.00 hrs
Total Number of Increments After Storm Event	6.00

Runoff Hydrograph File Name: Nelson 43_Peak Flow.prn

Time of Peak Runoff: 384.00 hrs

Rate of Peak Runoff: 0.44 cfs

Hydraulic Control Features:

	Top	Bottom	Left	Right
Groundwater Control Features - Y/N	N	N	N	N
Distance to Edge of Pond	0.00	0.00	0.00	0.00
Elevation of Water Level	0.00	0.00	0.00	0.00
Impervious Barrier - Y/N	N	N	N	N
Elevation of Barrier Bottom	0.00	0.00	0.00	0.00

Analysis Date: 10/10/2019

MODRET

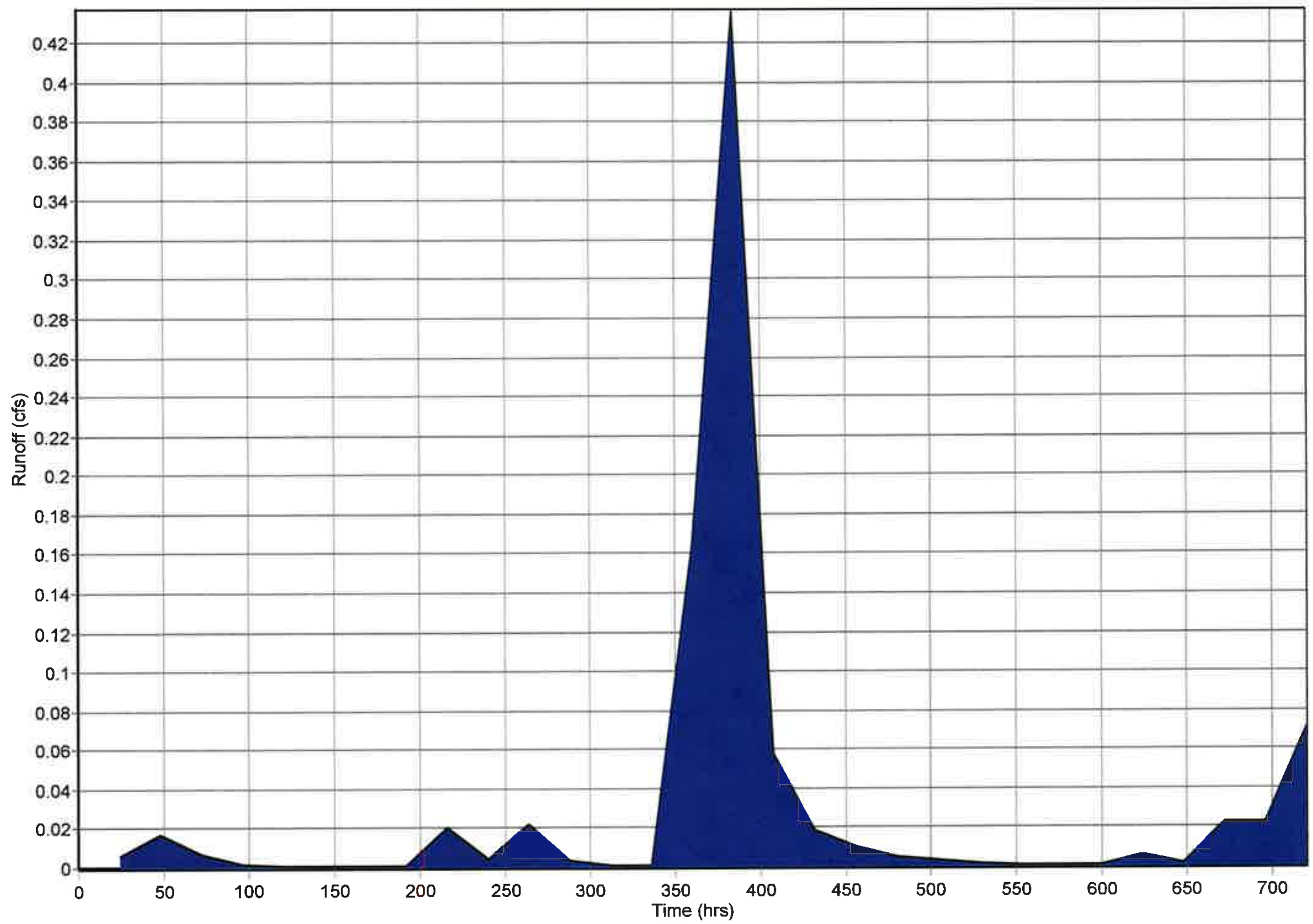
ELEVATION VS OVERFLOW RELATIONSHIP

PROJECT NAME : Nelson 43 Peak Flow
ORIFICE STRUCTURE TYPE

Centerline Elevation of Orifice	540.00 ft
Area of Orifice	0.37 in
Coefficient of Discharge	4.98
Orifice Flow Exponent	0.50
Number of Identical Orifices	1.00
Design High Water Level Elevation	553.15 ft

Analysis Date: 10/10/2019

HYDROGRAPH : Nelson 43 Peak Flow



Qpeak: 0.4370 cfs Time of peak: 384.0 hrs Vtotal: 75,902 ft^3

MODRET

SUMMARY OF RESULTS

PROJECT NAME : Nelson 43 Peak Flow

CUMULATIVE TIME (hrs)	WATER ELEVATION (feet)	INSTANTANEOUS INFILTRATION RATE (cfs)	AVERAGE INFILTRATION RATE (cfs)	CUMULATIVE OVERFLOW (ft^3)
00.00 - 0.00	503.000	0.000 *		
			0.00000	
0.00	503.000	0.10758		
			0.04608	
384.00	537.650	-0.01542		0.00
			-0.01927	
408.00	537.650	0.00962		0.00
			0.03850	
432.00	537.650	0.02650		0.00
			0.01450	
456.00	537.650	0.01100		0.00
			0.00750	
480.00	537.650	0.00575		0.00
			0.00400	
504.00	537.650	0.00325		0.00
			0.00250	
528.00	537.650	0.00200		0.00
			0.00150	
552.00	537.650	0.00125		0.00
			0.00100	
576.00	537.650	0.00100		0.00
			0.00100	
600.00	537.650	0.00225		0.00
			0.00350	
624.00	537.650	0.00375		0.00
			0.00400	
648.00	537.650	0.00825		0.00
			0.01250	
672.00	537.650	0.01775		0.00

Analysis Date: 10/10/2019

MODRET

SUMMARY OF RESULTS

PROJECT NAME : Nelson 43 Peak Flow

CUMULATIVE TIME (hrs)	WATER ELEVATION (feet)	INSTANTANEOUS INFILTRATION RATE (cfs)	AVERAGE INFILTRATION RATE (cfs)	CUMULATIVE OVERFLOW (ft^3)
			0.02300	
696.00	537.650	0.03500		0.00
			0.04700	
720.00	537.650	0.02350		0.00
			0.00000	
744.00	537.650	0.00000		0.00
			0.00000	
768.00	537.650	0.00000		0.00
			0.00000	
792.00	537.650	0.00000		0.00
			0.00000	
816.00	537.650	0.00000		0.00
			0.00000	
840.00	537.650	0.00000		0.00
			0.00000	
864.00	537.650			0.00

Maximum Water Elevation: 537.650 feet @ 384.00 hours Recovery @ 0.000 hours
* Time increment when there is no runoff
Maximum Infiltration Rate: 3.384 ft/day

Analysis Date: 10/10/2019

MODRET

SUMMARY OF UNSATURATED & SATURATED INPUT PARAMETERS

PROJECT NAME : Nelson 43 Max Volume
HYDROGRAPH RUNOFF DATA USED
UNSATURATED ANALYSIS INCLUDED

Pond Bottom Area	1,200.00 ft^2
Pond Volume between Bottom & DHWL	18,600.00 ft^3
Pond Length to Width Ratio (L/W)	3.00
Elevation of Effective Aquifer Base	493.00 ft
Elevation of Seasonal High Groundwater Table	503.00 ft
Elevation of Starting Water Level	537.65 ft
Elevation of Pond Bottom	537.65 ft
Is there overflow ?	Y
Avg. Effective Storage Coefficient of Soil for Unsaturated Analysis	0.25
Unsaturated Vertical Hydraulic Conductivity	25.80 ft/d
Factor of Safety	2.00
Saturated Horizontal Hydraulic Conductivity	25.80 ft/d
Avg. Effective Storage Coefficient of Soil for Saturated Analysis	0.25
Avg. Effective Storage Coefficient of Pond/Exfiltration Trench	1.00
Time Increment During Storm Event	24.00 hrs
Time Increment After Storm Event	24.00 hrs
Total Number of Increments After Storm Event	6.00

Runoff Hydrograph File Name: Nelson 43_Max Vol.prn

Time of Peak Runoff: 72.00 hrs

Rate of Peak Runoff: 0.40 cfs

Hydraulic Control Features:

	Top	**Bottom**	**Left**	**Right**
Groundwater Control Features - Y/N	N	N	N	N
Distance to Edge of Pond	0.00	0.00	0.00	0.00
Elevation of Water Level	0.00	0.00	0.00	0.00
Impervious Barrier - Y/N	N	N	N	N
Elevation of Barrier Bottom	0.00	0.00	0.00	0.00

Analysis Date: 10/10/2019

MODRET

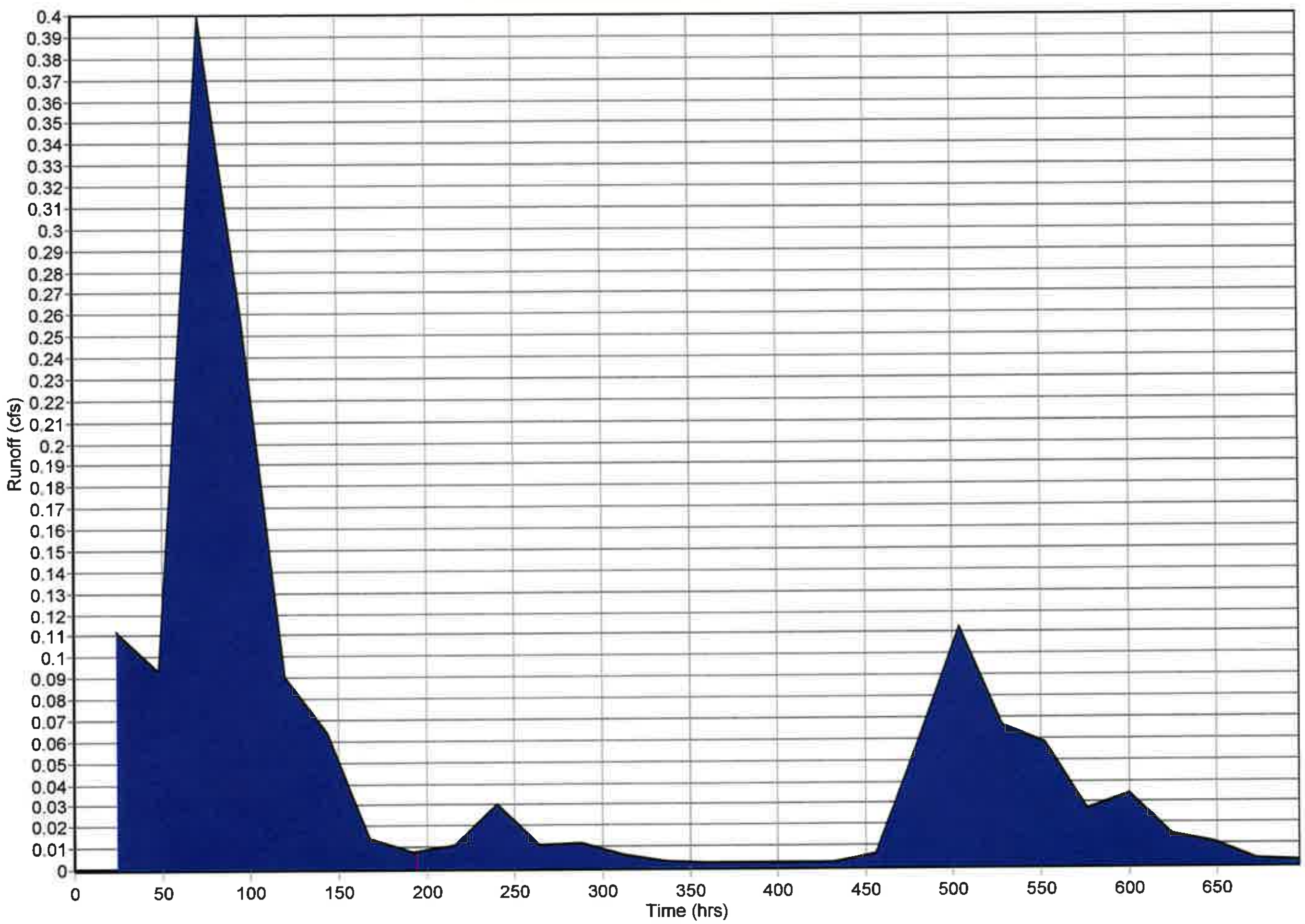
ELEVATION VS OVERFLOW RELATIONSHIP

PROJECT NAME : Nelson 43 Max Volume
ORIFICE STRUCTURE TYPE

Centerline Elevation of Orifice	540.00 ft
Area of Orifice	0.37 in
Coefficient of Discharge	4.98
Orifice Flow Exponent	0.50
Number of Identical Orifices	1.00
Design High Water Level Elevation	553.15 ft

Analysis Date: 10/10/2019

HYDROGRAPH : Nelson 43 Max Volume



Qpeak: 0.4000 cfs   Time of peak: 72.0 hrs   Vtotal: 130,637 ft³

MODRET

SUMMARY OF RESULTS

PROJECT NAME : Nelson 43 Max Volume

CUMULATIVE TIME (hrs)	WATER ELEVATION (feet)	INSTANTANEOUS INFILTRATION RATE (cfs)	AVERAGE INFILTRATION RATE (cfs)	CUMULATIVE OVERFLOW (ft^3)
00.00 - 0.00	503.000	0.000 *		
			0.00000	
0.00	503.000	0.10187		
			0.13500	
72.00	537.650	0.16812		0.00
			0.17917	
96.00	548.438	0.17917		0.00
			0.17917	
120.00	548.066	0.17917		0.00
			0.17917	
144.00	540.710	0.13033		0.00
			0.08150	
168.00	537.650	0.04625		0.00
			0.01100	
192.00	537.650	0.01025		0.00
			0.00950	
216.00	537.650	0.01500		0.00
			0.02050	
240.00	537.650	0.02050		0.00
			0.02050	
264.00	537.650	0.01600		0.00
			0.01150	
288.00	537.650	0.01025		0.00
			0.00900	
312.00	537.650	0.00675		0.00
			0.00450	
336.00	537.650	0.00350		0.00
			0.00250	
360.00	537.650	0.00225		0.00

Analysis Date: 10/10/2019

MODRET

SUMMARY OF RESULTS

PROJECT NAME : Nelson 43 Max Volume

CUMULATIVE TIME (hrs)	WATER ELEVATION (feet)	INSTANTANEOUS INFILTRATION RATE (cfs)	AVERAGE INFILTRATION RATE (cfs)	CUMULATIVE OVERFLOW (ft³)
			0.00200	
384.00	537.650	0.00200		0.00
			0.00200	
408.00	537.650	0.00200		0.00
			0.00200	
432.00	537.650	0.00300		0.00
			0.00400	
456.00	537.650	0.01800		0.00
			0.03200	
480.00	537.650	0.05875		0.00
			0.08550	
504.00	537.650	0.08750		0.00
			0.08950	
528.00	537.650	0.07575		0.00
			0.06200	
552.00	537.650	0.05225		0.00
			0.04250	
576.00	537.650	0.03650		0.00
			0.03050	
600.00	537.650	0.02750		0.00
			0.02450	
624.00	537.650	0.01875		0.00
			0.01300	
648.00	537.650	0.01000		0.00
			0.00700	
672.00	537.650	0.00475		0.00
			0.00250	
696.00	537.650	0.00125		0.00

Analysis Date: 10/10/2019

MODRET

SUMMARY OF RESULTS

PROJECT NAME : Nelson 43 Max Volume

CUMULATIVE TIME (hrs)	WATER ELEVATION (feet)	INSTANTANEOUS INFILTRATION RATE (cfs)	AVERAGE INFILTRATION RATE (cfs)	CUMULATIVE OVERFLOW (ft^3)
			0.00000	
720.00	537.650	0.00000		0.00
			0.00000	
744.00	537.650	0.00000		0.00
			0.00000	
768.00	537.650	0.00000		0.00
			0.00000	
792.00	537.650	0.00000		0.00
			0.00000	
816.00	537.650	0.00000		0.00
			0.00000	
840.00	537.650			0.00

Maximum Water Elevation: 548.438 feet @ 96.00 hours

Recovery @ 768.000 hours

* Time increment when there is no runoff

Maximum Infiltration Rate: 12.900 ft/day

Analysis Date: 10/10/2019

Appendix E

Backfill Specifications

BACKFILL SPECIFICATIONS

Table E-1
Gravel Backfill for Drains Specification

US Sieve Number	Percent Passing
3/4"	100
1/2"	90 - 100
3/8"	70 - 100
#4	0 - 35
#8	0 - 10
#100	0 - 0.5
#200 (wet sieve)	0 - 0.5

Table E-2
4 x 8 Sand Specification

US Sieve Number	Percent Passing
3/8"	100
#4	80 - 100
#10	0 - 20
#20	0 - 5
#100	0 - 1
#200 (wet sieve)	0 - 1

Table E-3
Filter Sand Specification

US Sieve Number	Percent Passing
#4	95 - 100
#8	70 - 100
#16	40 - 90
#30	25 - 75
#50	2 - 25
#100	0 - 2
#200 (wet sieve)	0 - 1