WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

WDOT-Skokomish Site near Potlatch

Volume 1.
Rapid Infiltration
Hydrogeologic Study

December 2000

Publication No. 00-03-051
printed on recycled paper

This report is available on the Department of Ecology home page on the World Wide Web at http://www.ecy.wa.gov/biblio/0003051.html

For additional copies of this publication, please contact:

Department of Ecology Publications Distributions Office
Address: PO Box 47600, Olympia WA 98504-7600
E-mail: ecypub@ecy.wa.gov
Phone: (360) 407-7472

Refer to Publication Number 00-03-051

If you have special accommodation needs or require this document in alternative format, please contact Joan LeTourneau, Environmental Assessment Program, at (360)-407-6764 (voice). Ecology's telecommunications device for the deaf (TDD) number at Ecology Headquarters is (360) 407-6006.

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

WDOT-Skokomish Site near Potlatch

Volume 1.
Rapid Infiltration Hydrogeologic Study

by
Barbara M. Carey

Environmental Assessment Program
Olympia, Washington 98504-7710

December 2000

Water Body Number WA-PS-0250

Publication No. 00-03-051
printed on recycled paper

This page is purposely blank for duplex printing

Table of Contents

List of Figures and Tables

Page

Figures

Tables

Abstract

A preliminary hydrogeologic study was conducted at the WDOT-owned site adjacent to Highway 101 on the Skokomish Indian Reservation in Mason County from June 1999 to May 2000, to evaluate the suitability of the site for rapid infiltration of treated municipal effluent. This report represents the first of two volumes that together assess the site suitability. Volume 2 (Pitz, 2000) describes the potential for groundwater mounding at the site based on the hydrogeologic characterization and proposed design conditions.

Four groundwater monitoring wells were installed at the site and sampled for water level (monthly) and water quality constituents (quarterly). Five test pits were logged, and samples from the pits were analyzed for grain size. Five percolation tests were conducted to evaluate soil permeability. Water level elevations at the downgradient wetland also were measured during the winter rainy season.

The unsaturated zone was 15-28 feet thick at the site. The seasonal water table fluctuation was 1.5-3.6 feet. Based on specific capacity tests, hydraulic conductivity was estimated to be 350-400 feet/day in the coarse, outwash material found at the center of the site and 60 feet/day in the westernmost well screened in finer material. Samples, field tests, and visual observations of the native soils indicate rapid permeability and good suitability for rapid infiltration. However, landslide debris soils recently imported onto a large portion of the site surface had very low permeability and are not suited for rapid infiltration. A lower permeability zone was also observed in the boring of the westernmost well and may indicate a contact zone with upslope deposits that are finer than the coarse, native deposits covering most of the site.

Groundwater quality at the site was similar to background concentrations in the area for pH, specific conductance, total dissolved solids, nitrate+nitrite-N, total phosphorus, and chloride. Fecal coliform bacteria were not detected. Petroleum hydrocarbons were also not detected in a single sample from the monitoring well immediately downgradient of the WDOT maintenance shop on the site.

Acknowledgements

I am grateful to the following people for their efforts on this study.

- Teresa Barron of the Skokomish Tribe assisted with field sampling and helped arrange for site access.

- Gordon Munro of KCM, Inc. provided helpful input during the study and comments on the draft report.

- Ryan Larson and Larry Skalicky of WDOT also helped arrange for access to the site.

- The U.S. Forest Service provided partial funding for monitoring well drilling.

- Washington State Department of Ecology staff:
  - ◊ Al Bolinger, Melanie Kimsey, and Jeanette Barreca of the Southwest Regional Office provided input on study design.
  - ◊ Denis Erickson provided input on the study design and data analysis.
  - ◊ Charles Pitz conducted the percolation and specific capacity tests and interpreted the results. He also provided insightful and thoughtful feedback on the report.
  - ◊ Dale Norton provided helpful review comments.
  - ◊ Joan LeTourneau edited and formatted the final report.

Executive Summary

A hydrogeologic study was conducted at the Washington State Department of Transportation's Skokomish site near Potlatch, Washington. The purpose of the study was to evaluate the suitability of the site for a rapid infiltration system. A rapid infiltration system is needed to distribute effluent discharge from a proposed wastewater treatment facility serving the Skokomish Tribe and local residents.

The study results are described in two volumes. Volume 1 (this report) presents a preliminary characterization of the hydrogeology of the site, including descriptions of soil and vadose zone conditions. Volume 2 (Pitz, 2000) describes a modeling analysis conducted to estimate the mounding potential of the unconfined aquifer.

The primary findings of the hydrogeologic characterization (Volume 1) are:

- Test pit observations indicated that native soils are mainly composed of sand and gravel with cobbles and boulders. There was no evidence of fine-grained layers or obstacles to downward flow of water in the native soil test pits.

- Percolation rates were less than one minute/inch in the native soils and roughly eight hours/inch in the landslide debris soils.

- Based on soil types, grain size distributions, inspection of test pits, field tests of percolation, and the rapid water table response to recharge, the native soils appear suitable for rapid infiltration. However, the imported landslide debris soils are not suitable.

- A low permeability layer identified above the water table in the western portion of the site could obstruct downward flow if effluent were applied in this area or similar areas where finer deposits exist above the water table.

- Little, if any, additional treatment can be expected for effluent percolating through the permeable native soil.

- The site has a relatively thick vadose zone (15-28 feet). The range in water table fluctuation was 1.5-3.6 feet over one year.

- Based on specific capacity testing, permeability estimates for the coarse, outwash material found in the central and eastern portions of the site are in the range of 350-400 feet/day. The permeability estimate for the finer sand found in the western portion of the site is roughly 60 feet/day.

- Low-permeability layers may be present at 15 feet below ground surface (bgs) at well Skok-2 and less possibly at 5 and 25 feet bgs at Skok-3. The limited density of samples over the site and the small volume in the samples collected make it impossible to determine the extent of these layers. If extensive, these layers could obstruct downward flow of effluent infiltrated nearby causing effluent to surface before reaching the water table.

- Groundwater flows from northwest to southeast. The horizontal flow gradient between well Skok-1 and the other monitoring wells is 0.2-0.3. The flow gradient between the other three wells is 0.0004-0.003.

- The area near well Skok-4 and test pit TP-1 appears to be the most favorable for infiltration, as long as sufficient distance is maintained from the contact with finer grained material represented in Skok-1. This area is most favorable, because there is no evidence of a fine-grained layer above the water table from test pits or split spoon samples, the unsaturated zone is the thickest observed, and the percolation rate and hydraulic conductivity estimates were high.

- Water quality results for nitrate+nitrite-N, chloride, specific conductance, and total dissolved solids were far below maximum contaminant levels and similar to background concentrations in Mason County.

- No hydrocarbons were found in the one sample collected from the monitoring well downgradient of the abandoned maintenance building. However, this basic screening does not preclude the need for further site investigation of the impacts of past practices at the site.

- Impacts on the wetland downgradient and across the highway from the study site were not analyzed.

The primary findings of the mounding analysis (Volume 2) are:

- A mounding analysis was performed to estimate the potential response of the site unconfined aquifer to the introduction of treated wastewater via a rapid infiltration system.

- The mounding analysis was conducted using simplified assumptions about site hydrogeologic conditions. The analysis assumed that infiltration through the site vadose zone is not a limiting factor for the operation of a rapid infiltration system.

- Both analytical and numerical models were used to estimate the mounding potential of the aquifer. Wet season conditions were assumed for modeling. Modeling scenarios were constructed assuming the discharge system was centered in the south-central portion of the site (Skok-4 area).

- Using a steady-state, average-maximum system discharge rate of 500,000 gallons/day, the modeling results indicate that the water table will not rise to the base of the infiltration system. The analytical modeling results indicate that the water table response to an assumed peak flow rate of 700,000 gal/day would be only slightly greater than predicted under average maximum conditions.

- The numerical modeling results suggest that, under the average maximum discharge rate, the mounding response could reach the downgradient wetland, potentially raising the water table above the ground surface in low-lying areas.

- The analytical modeling results suggest that, under the stated discharge rate, a water table mound may breach the site surface if infiltration is centered over the lower permeability material found in the western portion of the site (Skok-1 area). Likewise breaching could occur if infiltration is centered over native soils where aquifer hydraulic conductivity is significantly lower than that adjacent to well Skok-4 or if hydraulic conductivity is reduced over time by plugging.

On the basis of the above findings, the following activities are recommended:

- Additional subsurface investigation should be considered in the area between wells Skok-1 and Skok-4 to better characterize the depth and eastern extent of the lower permeability sediments encountered in Skok-1. Without further investigation, it is recommended that the infiltration area be centered away from the far-western half of the site.

- On the basis of the permeable soils, deep unsaturated zone, and distance from the landslide debris, the area near well Skok-4 and test pit TP-1 is the most favorable location for the rapid infiltration system. Care is needed even here to avoid the fine-grained material observed in well Skok-1 just west of this area.

- Do not construct the infiltration area in the landslide debris soils.

- A pilot-scale field test is recommended prior to full system construction to minimize the uncertainties of the mounding analysis. Water levels should be closely monitored in the vicinity of the test area to confirm that the aquifer responds as predicted. Monitoring of water levels in areas predicted by the analysis to be at risk for near surface water table rise should also be considered.

- Characterize in detail the soils in the proposed infiltration area to detect any potential obstacles to infiltration, especially areas of low permeability above the water table. If such areas are discovered in the proposed construction area, their vertical and lateral extent should be determined and their impact on downward percolation of water analyzed. (If appropriately designed, a pilot-scale test may preclude the need for detailed soil characterization.)

- Survey monitoring well elevations to 0.01 foot to verify the groundwater flow direction.

- Appropriate operation and maintenance procedures should be implemented to minimize aquifer plugging and ensure that aquifer transmissivity does not diminish over time.

- A professional wetlands scientist should evaluate the consequences of a water-table rise adjacent to or within the wetland.

This page is purposely blank for duplex printing

Introduction

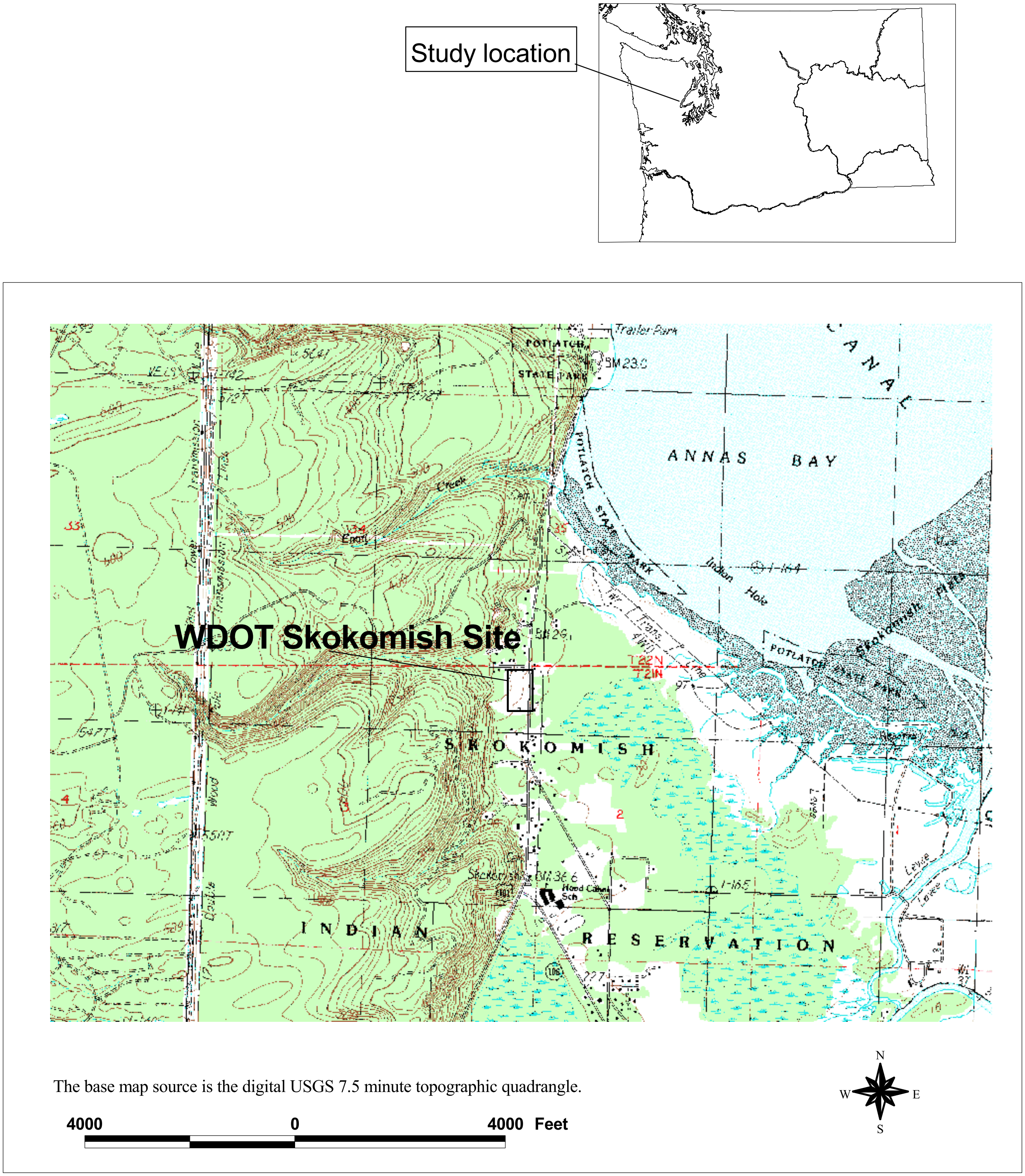
Approximately one-half of the Skokomish Indian Reservation lies in the extensive floodplain of the Skokomish River that drains into Hood Canal just south of Potlatch State Park (Figure 1). Individual on-site sewage systems are currently the only wastewater treatment and disposal option on the reservation. A growing number of on-site systems in low-lying areas flood each year due to poor soils and high precipitation. Serious sanitary, human health, and environmental problems have resulted, because shallow groundwater is the main water source for domestic, livestock, and commercial needs in the area.

In 1994 the Skokomish Tribe contracted with Kramer, Chin and Mayo, Inc. (KCM) to develop a wastewater engineering plan for the reservation. Neither of the potential receiving waters for a surface discharge, the Skokomish River nor Hood Canal, currently meets water quality standards. In addition, nearby Annas Bay is threatened with a shellfish closure (Figure 1). Because of these existing water quality problems, the recommended wastewater treatment discharge option called for rapid infiltration of treated effluent. Rapid infiltration refers to the technique of applying high rates of wastewater either above or below the ground surface for infiltration into the soil. Infiltration is followed by rapid percolation away from the application point (EPA, 1980).

The Skokomish Tribe subsequently became aware of a potential site that could provide a feasible location for below-ground rapid infiltration. The Tribe has begun negotiations with the Washington State Department of Transportation (WDOT), the property owner, to acquire the 15-acre site along Highway 101 (Figure 2).

Before further negotiations or design and construction efforts could proceed, a hydrogeologic study of the site was necessary. Because the Tribe had no other funding source, the Washington State Department of Ecology Southwest Regional Office asked the Ecology Environmental Assessment Program to conduct a study to provide information needed to evaluate the feasibility and design constraints for a rapid infiltration wastewater disposal system at the site.

The site has been used by the WDOT as a storage area and gravel pit for many years, and until a few years ago it was also used as a vehicle maintenance facility. In March 1999 when the hydrogeologic study was about to begin, two large landslides occurred along Highway 101 north of the site. The WDOT transported wet soil and debris from the landslides to the site and distributed it over most of the area previously excavated for gravel. See Figure 2 for spoils location and Figure 3 for a photo of the debris. The debris is 12 or more feet deep in most places. This unexpected event affected the design of the study and greatly affects design considerations of the site for construction of a rapid infiltration system.



The base map source is the digital USGS 7.5 minute topographic quadrangle.

Figure 1. Site location map.

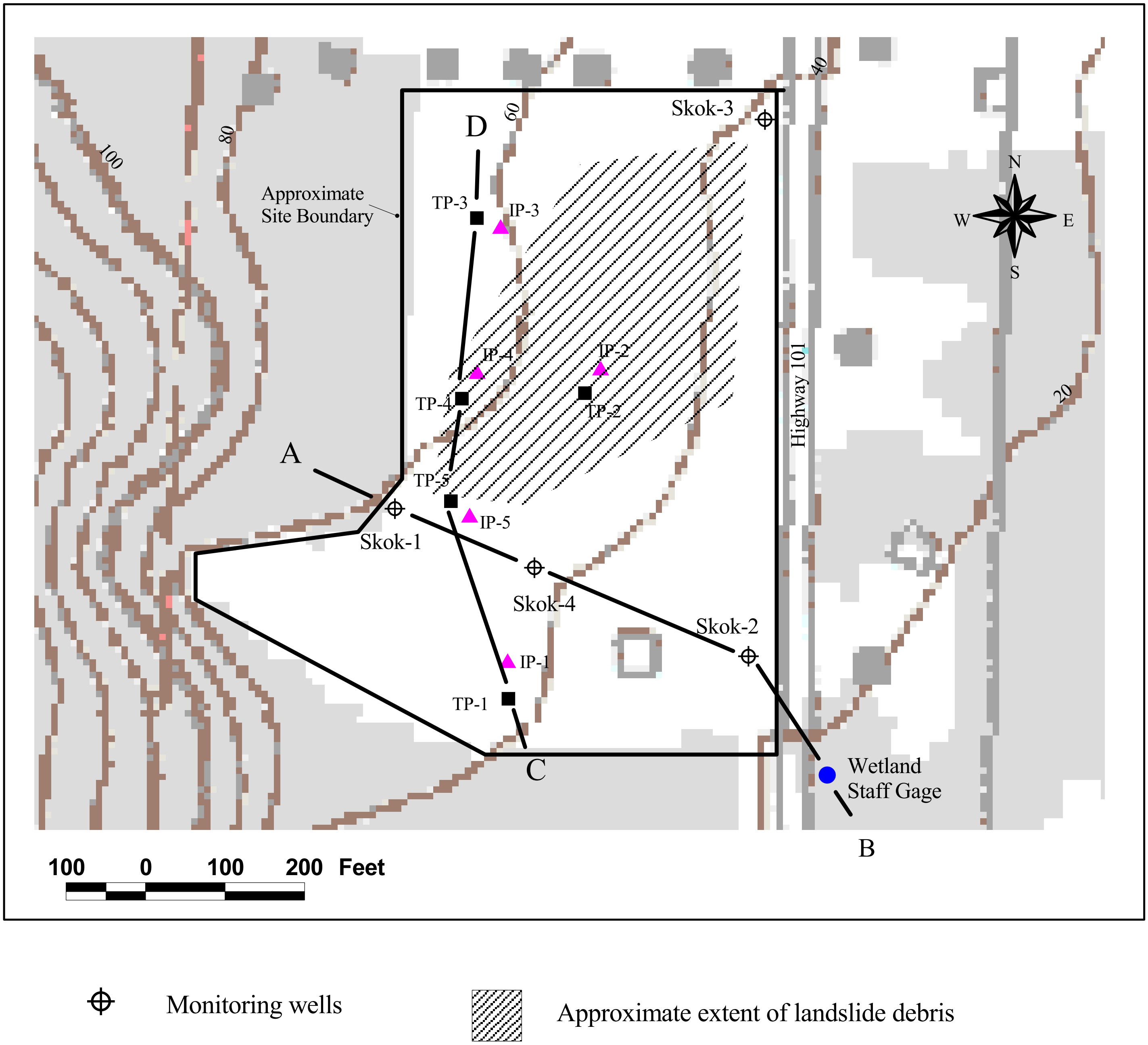


Figure 2. WDOT-Skokomish site map.

This page is purposely blank for duplex printing

Figure 3. Landslide debris placed at the WDOT site on April 16, 1999.

Figure 7. Sidewall of TP-1.

Figure 8. Percolation pit in native soils.

This page is purposely blank for duplex printing

Objectives

This report is the first of a two-volume series that evaluates the feasibility and design constraints of the WDOT site for a rapid infiltration wastewater disposal system for the Skokomish Tribe and local residents.

Volume 1 presents a preliminary characterization of the hydrogeology of the WDOT site on Highway 101 in Mason County, including the soils and vadose zone. Design of a rapid infiltration system is dependent on the type and location of soils on the site. The soils must have the capacity to infiltrate the discharged wastewater in order to avoid overland flow and downstream drainage problems. Hydrogeologic characteristics also influence the design of the rapid infiltration system in terms of maximum flow and discharge pipe location and dimensions. Volume 1 also includes a water quality analysis and establishes a baseline for future reference.

The objective of Volume 2 was to determine if the proposed rapid infiltration system discharge would cause excessive mounding of the water table if the proposed loading rates were to reach the water table (Pitz, 2000).

The overall objectives of the studies were to:

- Characterize local groundwater flow: seasonal variation in depth-to-water and flow direction.
- Characterize hydrologic properties of the aquifer and the overlying vadose zone.
- Evaluate the soils for suitability for infiltrating effluent.
- Determine the probable response of the uppermost aquifer to projected wastewater loading.
- Characterize baseline groundwater quality.

This page is purposely blank for duplex printing

Site Description

Location

The site is located near the north end of the Skokomish Indian Reservation in the northwest quarter of the northwest quarter of Section 2, Township 21 N, Range 4 W. It lies on the west side of Highway 101 just north of the intersection with Reservation Road. The elevation of the site is about 30-60 feet above mean sea level (AMSL) according to the USGS 7.5 minute quadrangle map. The site slopes somewhat steeply downward from northwest to southeast with overall slope of about 10%.

Hydrogeology

The site is located on a localized alluvial fan terrace of recessional outwash deposits from the late Vashon glaciation, according to Molenaar and Noble (1970) (Figure 4). The outwash material (Qvr) is typically loose sand and gravel with varying amounts of silt and clay. The site is located in a transition zone between steep, forested bluffs to the west and forested wetlands to the east. Diagrammatic interpretations of the Skokomish area by Molenaar and Cummans (1973) and Hong West (1994) indicate that a till layer may underlie the recessional outwash in the valley. Below the till layer, Molenaar and Cummans (1973) indicate that sand, gravel, silt and some clay form the bottom of the Vashon materials in the valley.

The steep, forested slope bordering the west side of the property may be represented as three eroded layers, starting at the bottom with Pre-Vashon glacial and interglacial deposits (Pv) as shown in Figure 4. The Pre-Vashon materials are mostly till and outwash deposited before the Vashon glaciation, as well as non-glacial sediments such as the Skokomish Gravels (Hong West, 1994; Molenaar and Noble, 1970).

The next sequence upslope is Vashon advance outwash (Qva) consisting of dense sand and gravel, locally containing fine-grained sediments. The uppermost, extensive sequence of Vashon till (Vt) caps the slope 400-500 feet above the site. The top of the terrace has been clearcut and replanted. The trees on the terrace are about two years old (Barron, 2000). The lack of forested soil conditions may affect recharge through the till.

The eastern border of the site transitions to the forested alluvial floodplain of the Skokomish River. The wetland floodplain drains to Hood Canal about three-fourths mile east of the site.

Soils and topography

Most of the site is mapped as Grove gravelly sandy loam, 0-5% slope by the U.S. Soil Conservation Service (1960). Slopes based on elevations measured during the study were 2-9% at the site. Grove soils are somewhat excessively drained, reddish-brown gravelly soils found in large glacial outwash plains. According to the U.S. Soil Conservation Service (1960),

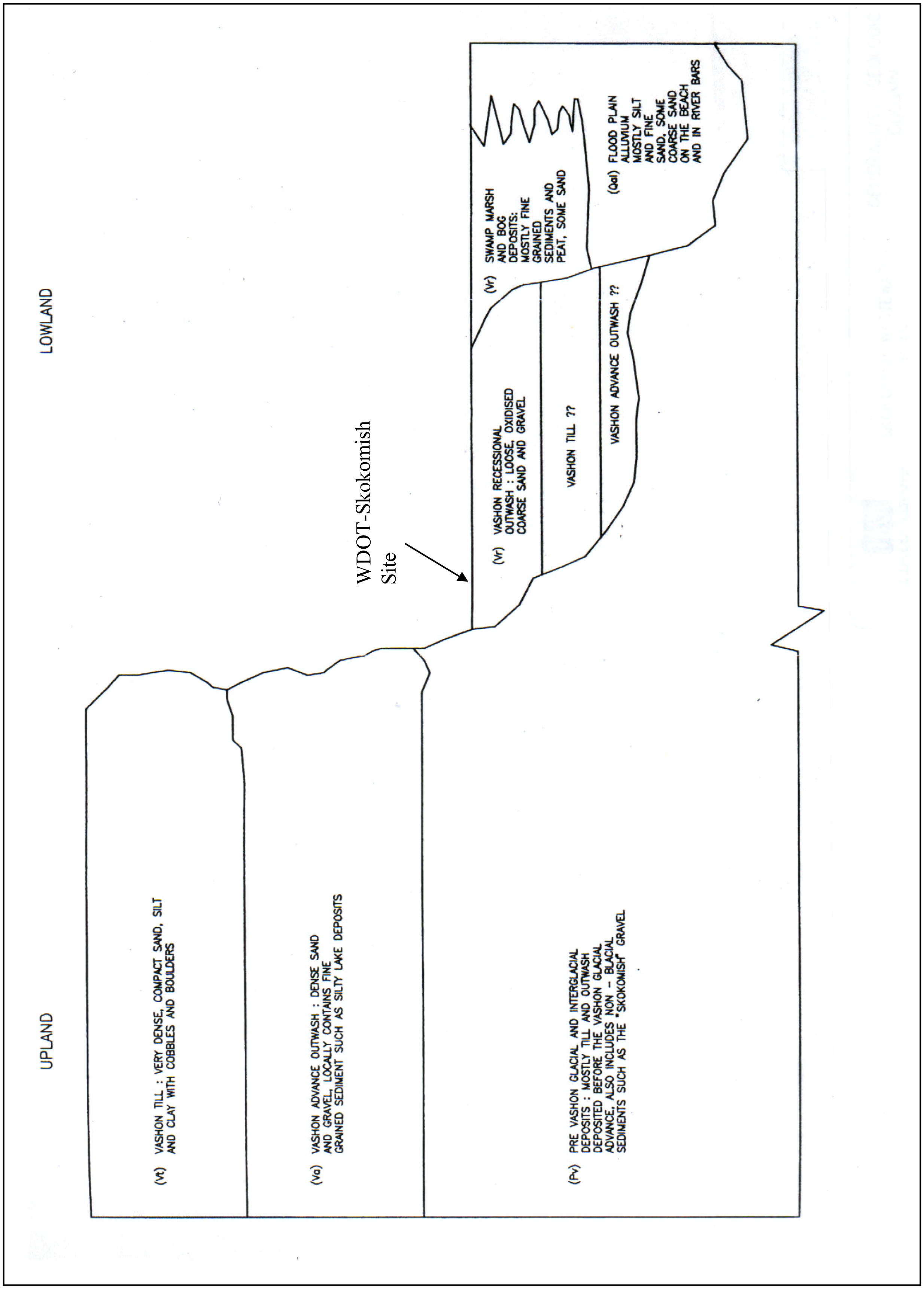


Figure 4. Generalized geologic column from Hong West (1994).

the Grove soils have developed from Vashon glacial drift by inclusions of local basaltic rock and mixed material from the Olympic Mountain glaciers. The soil becomes more gravelly and cobbly with depth to 32 inches.

The western quarter of the site is mapped as Hoodsport gravelly sandy loam, 15-30% slope. This steeper part of the property is mostly forested. These well-drained soils are typically reddish and found in the uplands. According to the U.S. Soil Conservation Service (1960), the Hoodsport soils have developed from granitic till that is highly stained by iron, and contains considerable metamorphosed and basic igneous gravel and stone. This material originated from local glacial till.

Roughly one-third of the site was used for gravel extraction in past years. The extraction depth is not known, but during February 1999 it appeared to be about 10-14 feet. In March 1999 the WDOT covered the gravel extraction area and surrounding area with debris from a large nearby landslide. The approximate extent of the debris coverage is shown in Figure 2.

In addition to the sloping topography from west to east, there is an additional 10-foot drop-off in the southeast corner of the site below well Skok-4. The steep cut in the bank was probably excavated to allow development of the WDOT maintenance building and storage areas. Clearing and development of this part of the site has effectively removed some of the unsaturated soils that would have been available for rapid infiltration system treatment and disposal.

Climate

Annual precipitation at the Cushman Dam NOAA Climate Station about two miles north of the site in 1999 (NOAA, 2000) was 149 inches, about 160% of the 1924-1977 average of 93 inches (Shannon & Wilson, 1978). See Hong West (1994) for more information about local climate.

Daily precipitation values used in the study are taken from the Skokomish Tribal Fish Hatchery in Potlatch, about one mile north of the site. Annual precipitation at the hatchery was 147 inches, about the same as at the Cushman Dam NOAA Climate Station. It is assumed that precipitation at the two sites is very similar and that the 1999 total precipitation at the hatchery would be about 160% of the average.

This page is purposely blank for duplex printing

Methods

Monitoring wells

Four monitoring wells were drilled to about ten feet below the top of the water table on June 8, 1999 (Figure 2). One well, Skok-1, was drilled in an area presumed to be hydraulically upgradient of the future rapid infiltration system. Well Skok-4 was built to replace the WDOT well which indicated a silt or clay layer at about three feet below mean sea level (Appendix A). The remaining two wells were placed for maximum areal coverage of the site and for observing downgradient changes. Skok-2 was placed downgradient of the maintenance building in order to observe potential impacts on groundwater.

The monitoring wells were drilled by Holt Drilling, Inc., Puyallup, Washington, using a 4-1/4-inch I.D. diameter hollow stem auger. The wells were two-inch diameter Schedule 40, flush-threaded PVC casing with caps and screens. The screens were ten feet long with a slot size of 20. The sand pack consisted of 10-20 silica sand installed continuously over the screened interval to two feet above the top of the screen. Bentonite chips were placed from the top of the sand pack to within three feet of the ground surface. Neat cement was placed from three feet below ground to the surface. The PVC casing was cut off two feet above the ground level. A five-foot long, six-inch diameter locking, outer protective steel casing was then installed over the well to a depth of about three feet.

During drilling, observations were recorded of subsurface stratigraphy, soil characteristics of split spoon samples collected every five feet, blow counts for split spoon penetration, well construction, and pertinent driller's comments (Appendix A). Samples were placed in labeled, heavy-duty, plastic, zip-lock sampling bags for grain size analysis per American Society for Testing and Materials (ASTM) (1994) Method 2488-90, Standard Practice for Description and Identification of Soils. Samples were then taken to the Ecology/EPA Manchester Environmental Laboratory and transported to Rosa Environmental and Geotechnical Laboratory, Seattle, Washington for grain size analysis.

The drillers developed the wells one day after drilling. They pumped each well at about one gallon/minute using a submersible pump until the discharge was clear, about 30-90 minutes each.

Test pit excavation

Five test pits were excavated with a backhoe operated by the Skokomish Tribal staff on August 17, 1999 to about 12 feet (TP-1, -2,-3,-4,-5) (Figure 2). Soil characteristics were logged in the field. Samples were collected and handled using the same procedures as used for the monitoring well soil samples described above (Appendix B). Like the split spoon samples, test pit soil samples were transported to Manchester Laboratory and transported to Rosa Environmental and Geotechnical Laboratory for grain size analysis. Test pits were covered immediately after sampling.

Percolation tests

Five percolation tests were conducted across the site between August 17 and 19, 1999 to test infiltration rates for the vadose zone soils (IP-1, 2, 3, 4, and 5) (Figure 2). Standard field procedures for falling-head percolation tests were followed, as outlined in EPA (1980).

At each test location, a pit was initially excavated by backhoe to a depth of 3.5 to 4.5 feet below ground surface (bgs). The decision to conduct the percolation tests below the current ground surface was made to avoid disturbed surface conditions and to evaluate the soil character at or immediately below the depth of a typical buried discharge gallery line. The percolation hole used for testing was then excavated by hand at the base of the pit. The soil at the base of several of the test pits contained a significant percentage of gravel and cobbles, causing difficulty in maintaining a percolation test hole of the fixed six-inch diameter required by the test procedures.

With the exception of IP-4, none of the test locations required a pre-test soaking period, due to very high initial infiltration rates. Test hole IP-4, which was located in imported material, was soaked for approximately 23 hours prior to testing. Test hole IP-2 was located in an area that is currently covered or backfilled by imported material. The percolation test conducted at this location was, however, performed in soils lying below a distinct contact interpreted as the transition between imported material and native soils. Percolation tests were repeated for each location until the infiltration rate stabilized.

Specific capacity tests

Specific capacity tests were run on wells Skok-1, Skok-2, and Skok-4 in September and October, 1999. Water was pumped from each well at a rate of approximately six gallons per minute until the water level stabilized. Water level measurements were recorded and entered into a computer program developed by Bradbury and Rothschild (1985). The program corrects for partial penetration effects and well loss. A well loss correction factor of 1 was used for all tests. Saturated aquifer thickness was assumed to be 19 feet, based on depth to the silty-clay layer in the WDOT well log and the lack of such a layer in the 50-foot boring at Skok-4.

This test provides reasonably good estimates of hydraulic conductivity. Results are usually reliable to within an order of magnitude.

Water table elevations

Well head elevations were surveyed to the nearest 0.01 foot, using a Top Con surveyor’s level and rod. Elevations are referenced to a visual estimate of the elevation of Skok-4 from the USGS 7.5 minute topographic quadrangle. The elevation estimate for ground surface at Skok-4 is 45.00 feet above mean sea level (AMSL).

The depth-to-water was measured monthly in the monitoring wells using a commercial electric well probe. A fixed staff was installed at the edge of the wetland southeast of the site entrance along Highway 101 on Nov 16, 1999. Measurements of the wetland water surface elevation were made at least every other week during the wet season and generally more frequently. The elevation of the staff was also surveyed relative to the well head elevations.

Two-meter pressure transducers were installed at Skok-2 and Skok-4 on July 2, 1999. Calibration testing prior to installation indicated that the transducers had a precision of 0.01 foot with 2-6 feet of head above the probe. Transducers were set at 5.5-6.0 feet below the top of the water table. This put the transducers at 21.5 feet bgs at Skok-2, and 35.5 feet bgs at Skok-4. Measurements were recorded every two hours with a Unidata data logger via a locked, weather-proof, steel control box. The data loggers were periodically downloaded and replaced. The frequency of logging was reduced after October 12, 1999 to once every 12 hours. No data were collected at well Skok-2 from September 21 to December 8, 1999, due to a low data logger battery.

Water quality sampling

Samples were collected quarterly for one year at each of the monitoring wells for water quality indicators. Wells were purged and then sampled using a submersible pump pre-rinsed with deionized water. The submersible pump intake was set at one to two feet below the top of the water table, and allowed to run for about ten minutes at about one gallon/minute before samples were collected. The exit tubing for the pump was attached to an enclosed Geotech flow cell where temperature, pH, specific conductance, and dissolved oxygen were measured and recorded during the purging process.

After at least ten minutes of purging and when field parameters had stabilized, the exit tubing was disconnected from the flow cell, and samples requiring laboratory analysis were collected. Samples were collected for the following constituents: ammonia-N, nitrate+nitrite-N, total persulfate N, total phosphorus, total dissolved solids, chloride, fecal coliform bacteria (on two of the four sampling rounds), and hydrocarbon identification (one time at Skok-2). Sample bottles were immediately placed on ice, maintained at 4°C, and delivered the next day to Manchester Laboratory. The methods for analysis and data quality are shown in Table 1.

The hydrocarbon identification sample at Skok-2 on November 8, 1999 was collected to screen for contamination from activities at the adjacent, abandoned maintenance building. The timing of the sample was intended to coincide with a potential first-flush of available, remaining petroleum product with water percolating through the vadose zone.

Table 1. Parameters, test methods, quantitation limits, and required precision and bias.

Parameter	Test Method EPA[1]/Standard Methods[2] ASTM [3]	Quantitation Limit	Matrix[4]	Required Precision (%)	Required Bias (%)
pH (Field)	WTW Probe[5]	0.1 Std Unit	G	15	10
Specific conductance (Field)	WTW Probe[5]	1 umhos/cm	G	15	10
Dissolved oxygen (Field)	WTW Probe[5]	0.1 mg/L	G		
Chloride	EPA 330.0/4110B	0.1 mg/L	G	15	10
Total dissolved solids	EPA 160.1/2540	1 mg/L	G	15	10
Ammonia-N	EPA 350.1/4500 NH3 D	0.01 mg/L	G	15	10
Nitrate+nitrite-N	EPA 353.2/4500 NO3 F	0.01 mg/L	G	15	10
Total persulfate N	EPA 353.2 (Modified)/4500	0.01 mg/L	G	15	10
Total phosphorus	EPA 365.3/4500-P F	0.01 mg/L	G	15	10
Hydrocarbon Identification	MEL SOP No. 730028 [6]	NA[7]	G		
Grain size	ASTM D422-63 (Reapproved 1990)		S		

[1] EPA, 1983. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020. Revised March 1983.

[2] American Public Health Association, 1992. Methods for the Examination of Water and Wastewater, 18th Edition.

[3] ASTM, 1994. ASTM Standards on Ground Water and Vadose Zone Investigations, 2nd Ed. Philadelphia.

[4] Matrix Codes: G=Groundwater, S=Soil.

[5] Wissenshaftlich-Technishce Werkstatten, GmBH.

[6] Manchester Environmental Laboratory Standard Operating Procedure.

[7] This is a screening method. It is not quantitative.

Quality assurance

Blind duplicate samples were submitted from one well on each sampling date to estimate combined analytical and field precision. The results are shown in Table 2 in terms of relative percent difference (RPD). The RPD is the difference between the duplicates divided by their mean.

Data quality was generally good. The RPDs for ammonia-N, nitrate+nitrite-N, and total persulfate N were 0.2-2.0%. However, the first total phosphorus result from Skok-3 was outside the 15% limit for precision on August 2, 1999, with an RPD of 28%. This may have been due to inadequate purging of the well, which may have allowed more sediment to be collected from the first sample than from the second. Chloride, total dissolved solids, and specific conductance had low RPD's of 0-3.4%.

A discrepency occurred in the total persulfate nitrogen results in six of 20 samples. Persulfate N represents the sum of ammonia-N, nitrate+nitrite-N, and organic N; therefore, persulfate N values should be at least as high as the sum of ammonia-N and nitrate+nitrite-N. However, in several samples the total N value was less than that for nitrate+nitrite-N. The maximum difference was 0.04 mg/L. The cause of the discrepency is not known.

Table 2. Relative percent differences between duplicate samples. Concentrations are in mg/L unless specified otherwise.

Well	Date	NH3-N		NO2+NO3-N	TPN	Total P	Chloride	TDS	Specific Conductance-Lab (umhos/cm)
Skok-3	8/2/99	0.036		0.184	0.172	0.280	1.59	67	68.4
	8/2/99	0.032		0.187	0.186	0.080	1.53	61	68.5
	RPD (%)	2.9		0.4	2.0	27.8	1.0	2.3	0.0
	2/11/00	0.110		0.851	0.918	0.106	2.17	71	
	2/11/00	0.010	U	0.870	0.944	0.077	2.19	64	
	RPD (%)	NA		0.6	0.7	7.9	-0.2	2.6	
	5/9/00	0.010	U	0.394	0.410	0.045	1.61	55	73.6
	5/9/00	0.010	U	0.410	0.407	0.033	1.61	63	74.2
	RPD (%)	NA		1.0	0.2	7.7	0.0	3.4	0.2
Skok-4	11/8/99	0.010	U	0.103	0.110	0.034	1.79	68	98.3
	11/8/99	0.010	U	0.102	0.109	0.036	1.67	65	98.3
	RPD (%)	NA		0.2	0.2	1.4	1.7	1.1	0.0

RPD: Relative percent difference, the difference between measurements divided by the mean x 100.

U: Below detection limit.

NC: No detectable petroleum hydrocarbons or products, or any other gas chromatographic compounds.

This page is purposely blank for duplex printing

Results

Monitoring wells

The monitoring well locations are shown in Figure 2. Well logs are shown in Appendix A. All wells were drilled away from the recently imported landslide debris spoils. Split spoon samples from Skok-2, Skok-3, and Skok-4 indicated mostly mixtures of sand and gravel, with more gravel at the surface than at the bottom. A small number of soil samples from Skok-2 and Skok-3 also contained more than 5% silt. Figure 5 shows the ASTM (1994) soils classifications and d_{10} values for the boring samples based on grain size analysis for the cross-section in Figure 2. A summary of the soil classifications and d_{10} values are shown in Table 3.

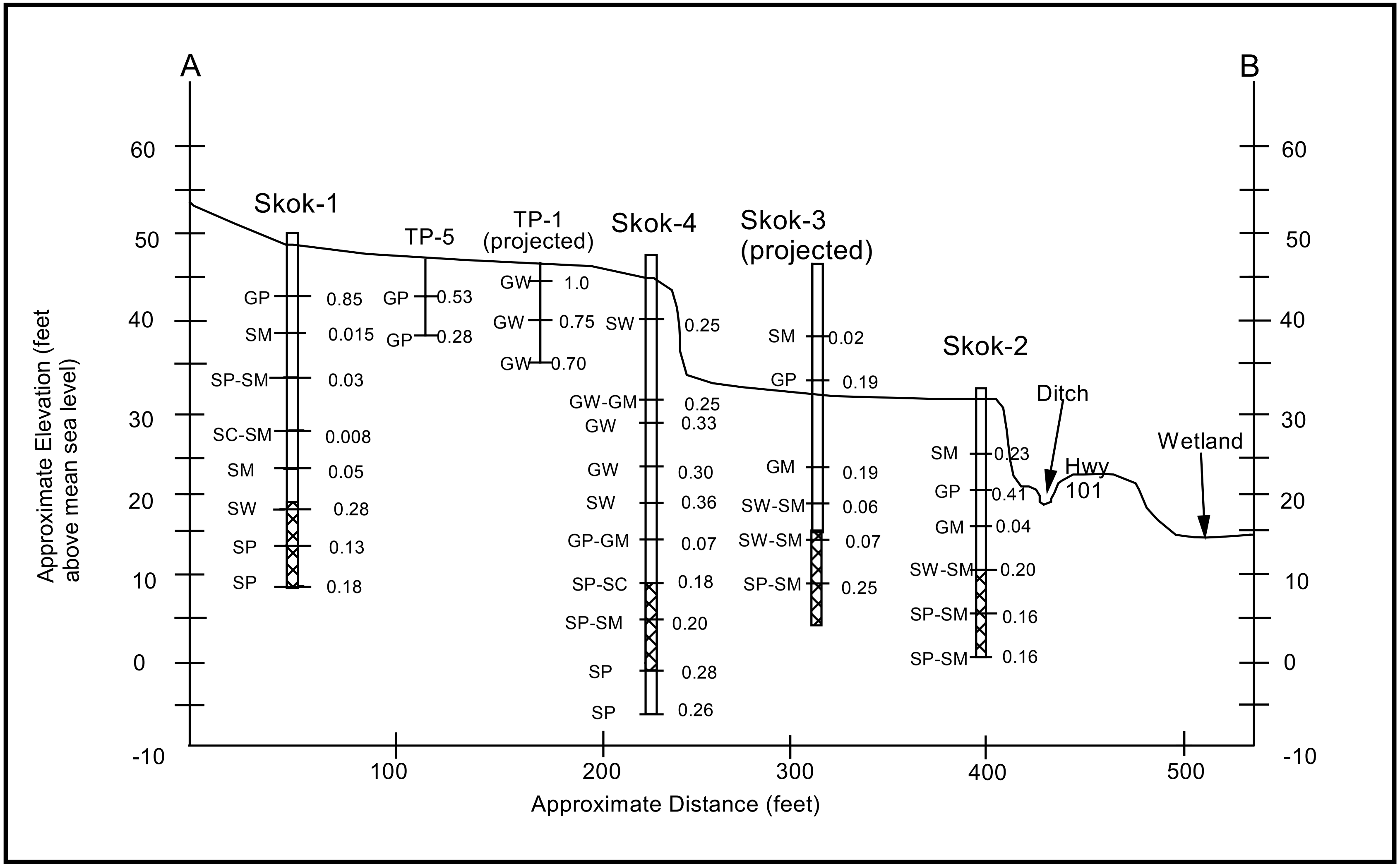
At Skok-2, samples collected at 15, 20, and 30 feet depth contained more than 10% of particles finer than 75 um (No. 200 sieve). At Skok-3, samples from 5, 25, and 30 feet contained more than 10% finer than 75um. The d_{10}, or effective grain size, is the sieve diameter through which 10% of soil particles pass and can be extrapolated from the grain size distribution. Grain size distribution curves for the split spoon samples are shown in Appendix C. Table 4 shows the percent of particles retained for various sieve sizes.

The d_{10} values for Skok-2, Skok-3, and Skok-4 were mainly in the range of 0.2-0.3 mm. The d_{10} values in the few soil samples at Skok-2 and Skok-3 that contained more than 10% silt were about an order of magnitude lower than those without a significant fraction of silt. Split spoon samples tend to underestimate the importance of large cobbles and boulders due to the narrow, 1.5-inch diameter of the sampler. When cobbles and boulders are encountered by the split spoon sampler, they are either broken and small fragments obtained or the sampler simply does not collect a sample. A significant component of the material in the native soil test pits was composed of materials greater than 1.5 inches in diameter to a depth of 12 feet.

Soil samples from Skok-1 indicate a silty-clay layer at 20 feet and silty sand from 10 to 15 feet. The 20-foot sample was a compacted, orange, silty-clayey sand and gravel. The d_{10} value for the 20-foot sample was 0.008 mm, about two orders of magnitude less than those for most samples from the other monitoring wells. The d_{10} values for the 10- and 15-foot samples were about one order of magnitude lower than those from the other wells. The d_{10} values for samples in the fine to medium sand below the till layer, 0.13-0.28 mm, were similar to those in the other wells.

Test pits

The test pit locations are shown in Figure 2. Logs of the test pit excavations are shown in Appendix B. Figure 6 shows the ASTM (1994) soil classifications and d_{10} values for the soil samples based on grain size analysis for the cross-section in Figure 2. Two of the test pit logs, TP-1 and TP-5, are also shown with the monitoring wells in Figure 5.



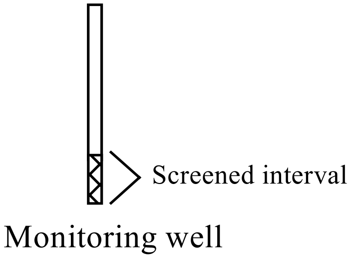


Figure 5. Cross-section A-B showing ASTM (1994) soil classifications and d_{10} values for soil samples. See Table 4 for definition of soil class abbreviations. Elevations are estimated based on the assumption that the ground at Skok-4 is 45.00 feet above mean sea level. The ground surface is approximated.

Table 3. ASTM soil classifications for split spoon samples based on grain size analysis (Method 2487-92 Standard classification of soils for engineering purposes) and effective grain size (d_{10}) estimates.

Lab #	Field I.D.	Depth (ft)	Soil Class	Description	d_{10}[1](mm)
34-8180	SK-1, S1	5	GP	Poorly graded gravel w/ sand	0.85
34-8181	SK-1, S2	10	SM	Silty sand	0.015
34-8182	SK-1, S3	15	SP-SM	Poorly graded sand w/ silt	0.03
34-8183	SK-1, S4	20	SC-SM	Silty, clayey sand and gravel	0.008
34-8184	SK-1, S5	25	SM	Silty sand	0.05
34-8185	SK-1, S6	30	SW	Well graded sand w/ gravel	0.28
34-8186	SK-1, S7	35	SP	Poorly graded sand	0.13
34-8187	SK-1, S8	40	SP	Poorly graded sand	0.18
23-8215	SK-2, S1	5	SM	Silty sand with gravel	0.23
23-8216	SK-2, S2	10	GP	Poorly graded gravel w/ sand	0.41
23-8217	SK-2, S3	15	GW-GM	Well graded gravel with sand and silt	0.04
23-8218	SK-2, S4	20	SW-SM	Well graded sand w/ silt and gravel	0.20
23-8219	SK-2, S5	25	SP-SM	Poorly graded sand w/ gravel and silt	0.16
23-8220	SK-2, S6	30	SP-SM	Poorly graded sand w/ gravel and silt	0.16
23-8221	SK-3, S1	5	SM	Silty sand w/ gravel	0.02
23-8222	SK-3, S2	10	GW	Well graded gravel w/ sand	0.19
23-8223	SK-3, S3	20	GW-GM	Well graded gravel w/ silt and sand	0.19
23-8224	SK-3, S4	25	SW-SM	Well graded sand w/ silt and gravel	0.06
23-8225	SK-3, S5	30	SW-SM	Well graded sand w/ silt and gravel	0.07
34-8188	SK-3, S6	35	SP-SM	Poorly graded sand w/ silt and gravel	0.25
23-8205	SK-4, S1	5	SW	Well graded sand w/ gravel	0.25
23-8206	SK-4, S2	12.5	GW-GM	Well graded gravel w/ silt and sand	0.25
23-8207	SK-4, S3	15	GW	Well graded gravel w/ sand	0.33
23-8208	SK-4, S4	20	GW	Well graded gravel w/ sand	0.30
23-8209	SK-4, S5	25	SW	Well graded sand w/ gravel	0.36
23-8210	SK-4, S6	30	GP-GM	Poorly graded gravel w/ silt and sand	0.07
23-8211	SK-4, S7	35	SP-SC	Poorly graded sand w/ silty clay and gravel	0.18
23-8212	SK-4, S8	40	SP-SM	Poorly graded sand w/ silt and gravel	0.20
23-8213	SK-4, S9	45	SP	Poorly graded sand	0.28
23-8214	SK-4, S10	50	SP	Poorly graded sand	0.26

[1] d_{10} is the particle-size diameter corresponding to 10% passing on the cumulative distribution curve.

Table 4. Grain size results in percent of soil particles retained from split spoon and test pit samples.

										Coarse sand									
Field ID	Depth (feet bgs)	Lab No.	1.5" 37.5 mm	1" 25 mm	**Cobbles**	3/4" 19 mm	1/2" 12.7 mm	3/8" 9.5 mm	**Fine gravel**	**#4 4.75 mm**	#10 2.0 mm	#20 0.85 mm	**Med Sand**	#40 0.425 mm	#60 0.250 mm	#80 0.180 mm	#100 0.125 mm	**Fine Sand**	**Fines #200 0.075 mm**
SK-1, S1	5	34-8180	45.1	0.0	**45.1**	18.0	7.7	7.9	**33.6**	**6.9**	4.7	3.2	**7.9**	2.2	0.7	0.2	0.6	**3.7**	**2.8**
SK-1, S2	10	34-8181	10.4	5.6	**16.0**	4.7	21.9	10.3	**36.9**	**12.1**	8.5	5.3	**13.8**	3.7	1.6	0.5	1.4	**7.2**	**13.9**
SK-1, S3	15	34-8182	0.0	0.0	**0.0**	0.0	31.1	19.1	**50.2**	**21.2**	9.1	4.2	**13.3**	2.2	1.1	0.4	1.1	**4.8**	**10.4**
SK-1, S4	20	34-8183	0.0	0.0	**0.0**	0.0	13.0	19.9	**32.9**	**16.1**	7.6	5.3	**12.9**	3.7	1.9	0.9	4.9	**11.4**	**26.7**
SK-1, S5	25	34-8184	0.0	0.0	**0.0**	2.2	3.4	5.5	**11.1**	**8.3**	9.0	12.9	**21.9**	28.2	12.0	2.8	4.7	**47.7**	**11.0**
SK-1, S6	30	34-8185	0.0	5.6	**5.6**	5.2	16.3	10.2	**31.7**	**11.3**	9.6	23.1	**32.7**	10.6	1.9	0.6	1.5	**14.6**	**4.0**
SK-1, S7	35	34-8186	0.0	0.0	**0.0**	0.6	0.6	0.5	**1.7**	**0.3**	0.7	7.6	**8.3**	47.4	24.4	5.4	7.4	**84.6**	**5.1**
SK-1, S8	40	34-8187	0.0	0.0	**0.0**	0.0	0.0	0.2	**0.2**	**1.2**	3.2	11.2	**14.4**	43.6	29.7	4.6	4.4	**82.3**	**1.9**
SK-2, S1	5	23-8215	0.0	11.3	**11.3**	12.6	4.2	12.5	**29.3**	**13.1**	10.7	8.9	**19.6**	6.5	2.9	1.0	3.0	**13.4**	**13.3**
SK-2, S2	10	23-8216	32.2	13.2	**45.4**	12.5	2.7	9.8	**25.0**	**11.7**	7.7	4.1	**11.8**	2.8	1.2	0.5	1.4	**5.9**	**0.1**
SK-2, S3	15	23-8217	0.0	21.5	**21.5**	8.6	6.1	14.9	**29.6**	**12.1**	7.9	5.5	**13.4**	4.5	2.3	1.0	3.3	**11.1**	**12.3**
SK-2, S4	20	23-8218	0.0	5.6	**5.6**	4.4	8.9	23.9	**37.2**	**22.3**	12.7	5.9	**18.6**	4.8	2.2	0.8	2.1	**9.9**	**6.4**
SK-2, S5	25	23-8219	9.1	0.0	**9.1**	3.1	0.0	5.9	**9.0**	**11.4**	7.8	12.6	**20.4**	27.8	9.9	2.9	5.0	**45.6**	**4.8**
SK-2, S6	30	23-8220	0.0	6.4	**6.4**	9.9	6.0	11.6	**27.5**	**15.8**	14.0	10.7	**24.7**	9.7	4.5	1.3	3.1	**18.6**	**6.8**
SK-3, S1	5	23-8221	0.0	11.4	**11.4**	6.4	8.8	13.9	**29.1**	**13.1**	10.1	7.6	**17.7**	5.4	3.0	1.1	4.0	**13.5**	**15.2**
SK-3, S2	10	23-8222	33.4	16.1	**49.5**	3.3	1.6	8.7	**13.6**	**10.3**	5.7	4.7	**10.4**	4.6	2.2	0.6	3.0	**10.4**	**5.9**
SK-3, S3	20	23-8223	4.3	0.0	**4.3**	20.4	11.1	18.0	**49.5**	**13.0**	9.5	6.5	**16.0**	5.2	2.2	0.9	2.3	**10.6**	**6.7**
SK-3, S4	25	23-8224	0.0	16.5	**16.5**	10.1	4.4	16.4	**30.9**	**14.5**	10.2	6.7	**16.9**	4.7	2.2	0.8	2.5	**10.2**	**10.9**
SK-3, S5	30	23-8225	5.8	11.5	**17.3**	7.5	5.5	16.7	**29.7**	**14.0**	10.9	6.8	**17.7**	4.8	2.1	0.9	2.8	**10.6**	**10.6**
SK-3, S6	35	34-8188	8.7	2.3	**11.0**	6.0	15.1	6.8	**27.9**	**10.1**	19.0	14.8	**33.8**	7.4	1.7	0.4	0.7	**10.2**	**7.1**
SK-4, S1	5	23-8205	6.7	12.5	**19.2**	7.3	6.9	13.8	**28.0**	**15.4**	14.4	8.6	**23.0**	4.5	1.9	0.6	1.9	**8.9**	**5.4**
SK-4,S2	12.5	23-8206	17.9	10.5	**28.4**	11.5	4.4	13.7	**29.6**	**15.4**	9.6	4.6	**14.2**	2.7	1.4	0.6	1.7	**6.4**	**6.0**
SK-4, S3	15	23-8207	14.7	3.2	**17.9**	7.7	8.7	17.2	**33.6**	**18.8**	11.4	6.3	**17.7**	4.0	1.5	0.6	1.6	**7.7**	**4.3**
SK-4, S4	20	**23-8208**	7.6	6.8	**14.4**	13.7	9.7	18.0	**41.4**	**13.2**	12.0	5.3	**17.3**	5.0	1.9	0.7	1.8	**9.4**	**4.5**
SK-4, S5	25	**23-8209**	0.0	9.0	**9.0**	12.1	5.0	17.3	**34.4**	**20.9**	15.9	8.4	**24.3**	4.2	1.4	0.4	1.1	**7.1**	**4.2**
SK-4,S6	30	23-8210	14.2	13.7	**27.9**	8.1	5.4	14.4	**27.9**	**11.2**	7.3	5.0	**12.3**	4.0	2.4	1.0	3.1	**10.5**	**10.3**
SK-4, S7	35	**23-8211**	6.3	6.4	**12.7**	6.1	4.0	10.3	**20.4**	**10.0**	12.9	16.4	**29.3**	12.2	4.6	1.3	2.6	**20.7**	**6.8**
SK-4, S8	40	**23-8212**	0.0	2.3	**2.3**	2.2	2.8	8.6	**13.6**	**16.7**	22.4	16.7	**39.1**	15.9	3.7	1.0	1.4	**22.0**	**6.5**
SK-4, S9	45	23-8213	**45.0**	**45.0**	**90.0**	0.0	0.0	6.2	**6.2**	**23.0**	30.6	23.4	**54.0**	8.7	2.0	0.5	1.2	**12.4**	**4.4**
SK-4, S10	50	23-8214	**50.0**	**50.0**	**100.0**	1.4	0.0	4.9	**6.3**	**11.6**	27.8	29.0	**56.8**	15.9	3.1	0.8	1.4	**21.2**	**4.1**
TP-1, 3 ft		34-8189	43.6	8.9	**52.5**	10.6	5.0	11.4	**27.0**	**7.2**	4.3	3.4	**7.7**	2.6	0.9	0.3	0.6	**4.4**	**1.1**
TP-1, 8 ft		34-8190	11.2	10.3	**21.5**	14.7	10.2	23.7	**48.6**	**12.2**	6.8	4.7	**11.5**	3.3	0.8	0.3	0.6	**5.0**	**0.9**
TP-1, 12 ft		34-8191	18.3	8.9	**27.2**	12.8	5.9	17.7	**36.4**	**14.3**	10.4	5.7	**16.1**	2.8	0.8	0.2	0.5	**4.3**	**1.7**
TP-2, 6 ft		34-8192	3.4	4.1	**7.5**	6.6	15.6	8.5	**30.7**	**7.4**	6.0	5.7	**11.7**	9.1	7.8	4.3	10.7	**31.9**	**10.8**
TP-2, 12 ft		34-8193	46.7	3.0	**49.7**	10.0	2.2	7.1	**19.3**	**6.4**	4.5	3.5	**8.0**	3.7	2.6	1.2	3.1	**10.6**	**6.0**
TP-3, 4 ft		34-8194	20.3	4.1	**24.4**	7.9	5.5	16.4	**29.8**	**14.5**	11.0	7.8	**18.8**	5.4	1.9	0.7	1.4	**9.4**	**3.3**
TP-3, 11 ft		34-8195	8.0	9.1	**17.1**	10.3	5.7	20.5	**36.5**	**12.5**	8.8	7.1	**15.9**	4.9	1.7	1.3	2.2	**10.1**	**8.1**
TP-4, 4 ft		34-8196	22.2	4.1	**26.3**	7.3	3.5	10.3	**21.1**	**8.3**	5.9	5.0	**10.9**	7.2	6.1	2.9	8.1	**24.3**	**9.0**
TP-4, 10 ft		34-8197	0.0	2.5	**2.5**	3.8	8.9	17.2	**29.9**	**30.9**	8.3	7.2	**15.5**	5.3	2.6	1.1	2.4	**11.4**	**9.8**
TP-5, 4 ft		34-8198	20.4	6.3	**26.7**	9.5	13.7	9.4		**16.4**	9.8	**6.5**	**16.3**	3.2	1.2	0.3	0.5	**5.2**	**2.8**
TP-5, 10ft		34-8199	15.8	4.0	**19.8**	11.2	9.8	22.1	**43.1**	12.9	6.5	4.5	**11.0**	4.1	2.0	0.8	1.9	**8.8**	**4.4**

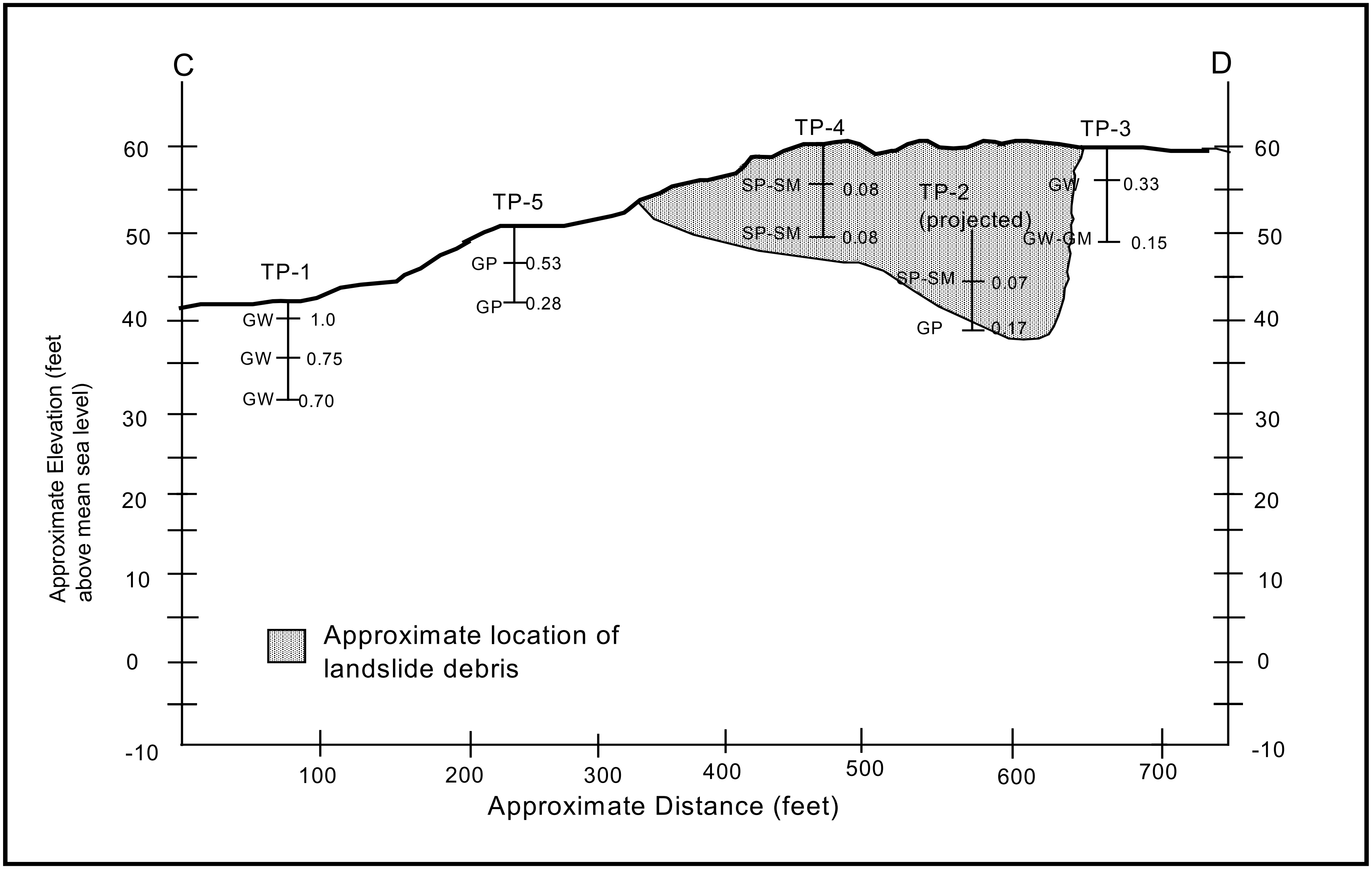


Figure 6. Cross-section C-D showing ASTM (1994) soil classifications and d10 values for test pit samples. See Table 5 for definitions of soil abbreviations. Elevations are estimated based on the assumption that the ground at Skok-4 is 45.00 feet above mean sea level. The ground surface is approximated.

Three of the five test pits were excavated in native soils (TP-1, TP-3, and TP-5) and two at least partially in landslide debris (TP-2 and TP-4). The native soils were coarse sand and gravel with large cobbles. No visual observations of fine-grained bedding or obstructions to downward flow of water were noted. Figure 7 (page 5) shows a side-wall of TP-1.

Soil classifications based on grain size analyses for the native soils (TP-1, TP-3, and TP-5) were all gravel, some well sorted and others poorly sorted (Table 5). The d_{10} values for the native soils ranged from 0.15 mm to 1.0 mm. The median value was 0.53 mm. Soil samples from test pits tend to be biased toward smaller particle sizes, especially when cobbles and boulders are present, as they were in these test pits.

Table 5. ASTM (1994) soil classifications for test pit samples based on grain size analysis (Method 2487-92, Standard classification of soils for engineering purposes) and effective grain size (d_{10}) estimates.

Lab #	Field I.D.	Depth (feet)	Soil Class	Description	d_{10} (mm)
34-8189	TP-1, 3ft	3	GW	Well graded gravel w/ sand and cobbles	1.00
34-8190	TP-1, 8ft	8	GW	Well graded gravel w/ sand and cobbles	0.75
34-8191	TP-1, 12ft	12	GW	Well graded gravel w/ sand and cobbles	0.70
34-8192	TP-2, 6 ft	6	SP-SM	Poorly graded sand w/ silt	0.07
34-8193	TP-2, 12 ft	12	GP	Poorly graded gravel w/sand	0.17
34-8194	TP-3, 4 ft	4	GW	Well graded gravel w/ sand and cobbles	0.33
34-8195	TP-3, 11 ft	12	GW-GM	Well graded gravel w/ sand, silt, and cobbles	0.15
34-8196	TP-4, 4 ft	4	SP-SM	Poorly graded sand w/ silt, gravel, and cobbles	0.08
34-8197	TP-4, 10 ft	10	SP-SM	Poorly graded sand w/ silt, gravel, and cobbles	0.08
34-8198	TP-5, 4 ft	4	GP	Poorly graded gravel w/ sand and cobbles	0.53
34-8199	TP-5, 10 ft	10	GP	Poorly graded gravel w/ sand and cobbles	0.28

Soils in the landslide debris zone (TP-2 and TP-4) consisted of fine to medium sand with 15% or less gravel and scattered woody debris. The landslide soils had an organic odor. The d_{10} values for the landslide soils ranged from 0.07 to 0.17 mm. The bottom two feet of TP-2 between ten and 12 feet and the bottom west corner of TP-4 appeared to be transition zones between the landslide debris and native soils. There was a distinct difference in color and texture of the soil in the transition areas. The d_{10} value at 12 feet in TP-2, 0.17 mm, was also in the range found in native soils.

Percolation tests

The location of the infiltration pits is shown in Figure 2. Four of the five infiltration tests were conducted in native soils (IP-1, IP-2, IP-3, and IP-5). Results of the infiltration tests are shown in Table 6. Infiltration through the native soils was so rapid that it was difficult at times to make accurate water level measurements. Figure 8 (page 5) shows one of the percolation pits in native soil. The infiltration rate in the infiltration pit located in the landslide debris soils, IP-4, was only about 500 minutes/inch.

Table 6. Percolation test results using EPA (1980) Falling Head Percolation Test Procedure.

Location	Field Description	Estimated Infiltration Rate (minutes/inch)
IP-1	gravelly, cobbly sand	<1
IP-2	sand w/ minor gravel	<1
IP-3	very gravelly sand	<1
IP-4	loamy sand w/ gravel, organics	500 (imported material)
IP-5	gravelly, cobbly sand	<1

Specific capacity tests and screened zone materials

The hydraulic conductivity (K_s) estimates for the aquifer materials near the screened zone of the wells were:

- Skok-1: 60 feet/day
- Skok-2: 350 feet/day
- Skok-4: 400 feet/day

Fine sands comprised more than 80% of the particles in the screened zone of Skok-1 with very little gravel compared to 20-45% fine sand in Skok-2 and 12-20% in Skok-4 (Table 3). Skok-2 and Skok-4 had 6-42% gravel and cobbles in the screened zone and more medium to coarse sand than Skok-1.

Water table elevations and flow direction

Monthly water level measurements at all wells are shown in Figure 9. The data are shown in Appendix D. Water level elevations in Skok-1 were consistently four to five feet higher than in the other three wells. Elevations in Skok-2, Skok-3, and Skok-4 were consistently within a few tenths of one foot of one another. Annual water level variation was 3.6 feet in Skok-1 and about 1.5 feet in wells Skok-2, Skok-3, and Skok-4. The water surface elevation in the wetland was within a few tenths of one foot of the elevation of the nearest well, Skok-2, indicating a close connection with the water table aquifer at the site. The unsaturated zone thickness ranged from 15 feet at Skok-2 to 30 feet at Skok-4.

Recharge resulting from precipitation moved rapidly to the water table in wells Skok-2 and Skok-4, where pressure transducers logged daily water table depths during most of the study (Figures 10 and 11). Water table elevations in both wells typically began to rise or fall within

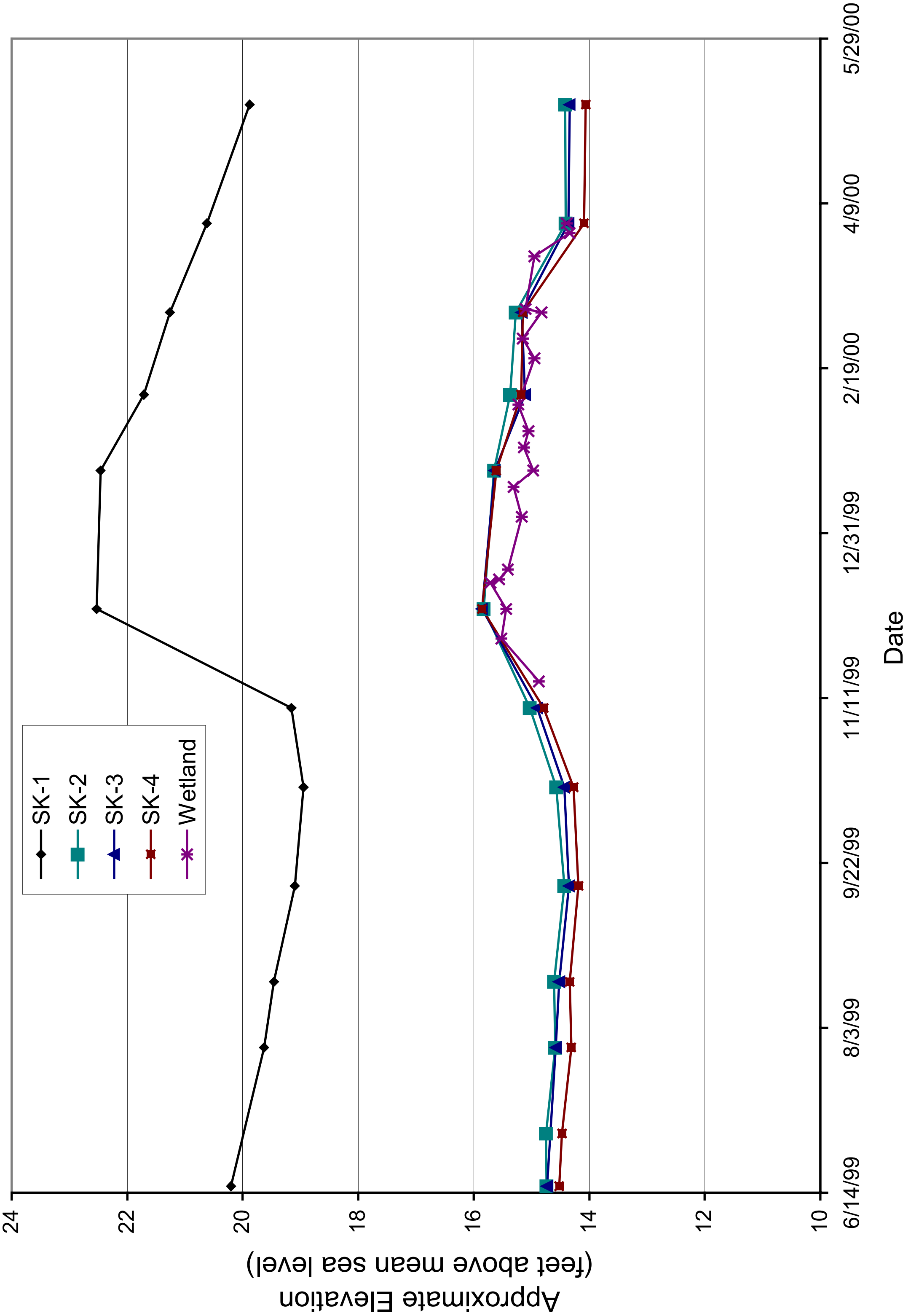


Figure 9. Water table elevations in the monitoring wells and the nearby wetland.

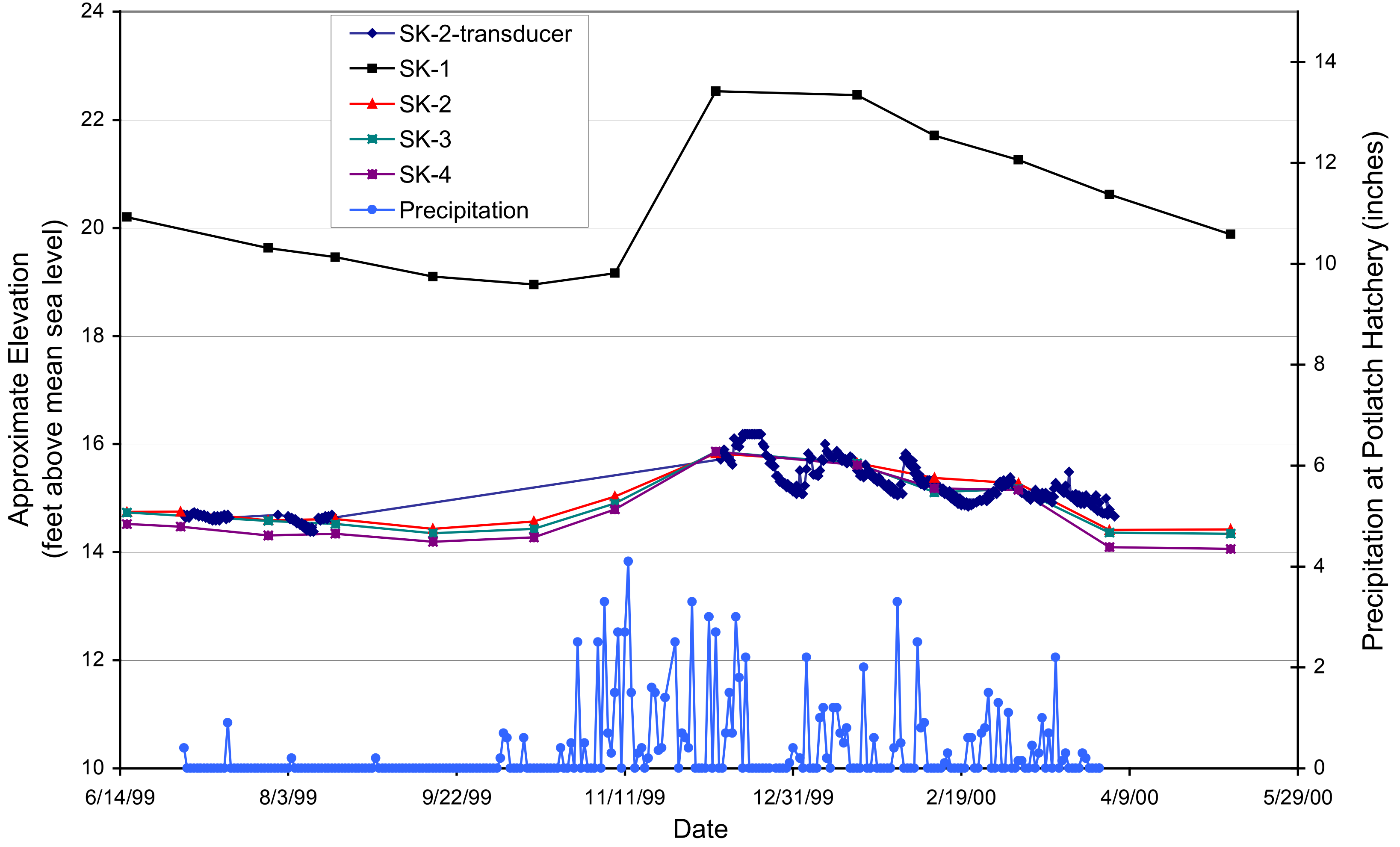


Figure 10. Water table elevations from the transducer at Skok-2, manual measurements at all wells, and daily precipitation at the Potlatch Fish Hatchery.

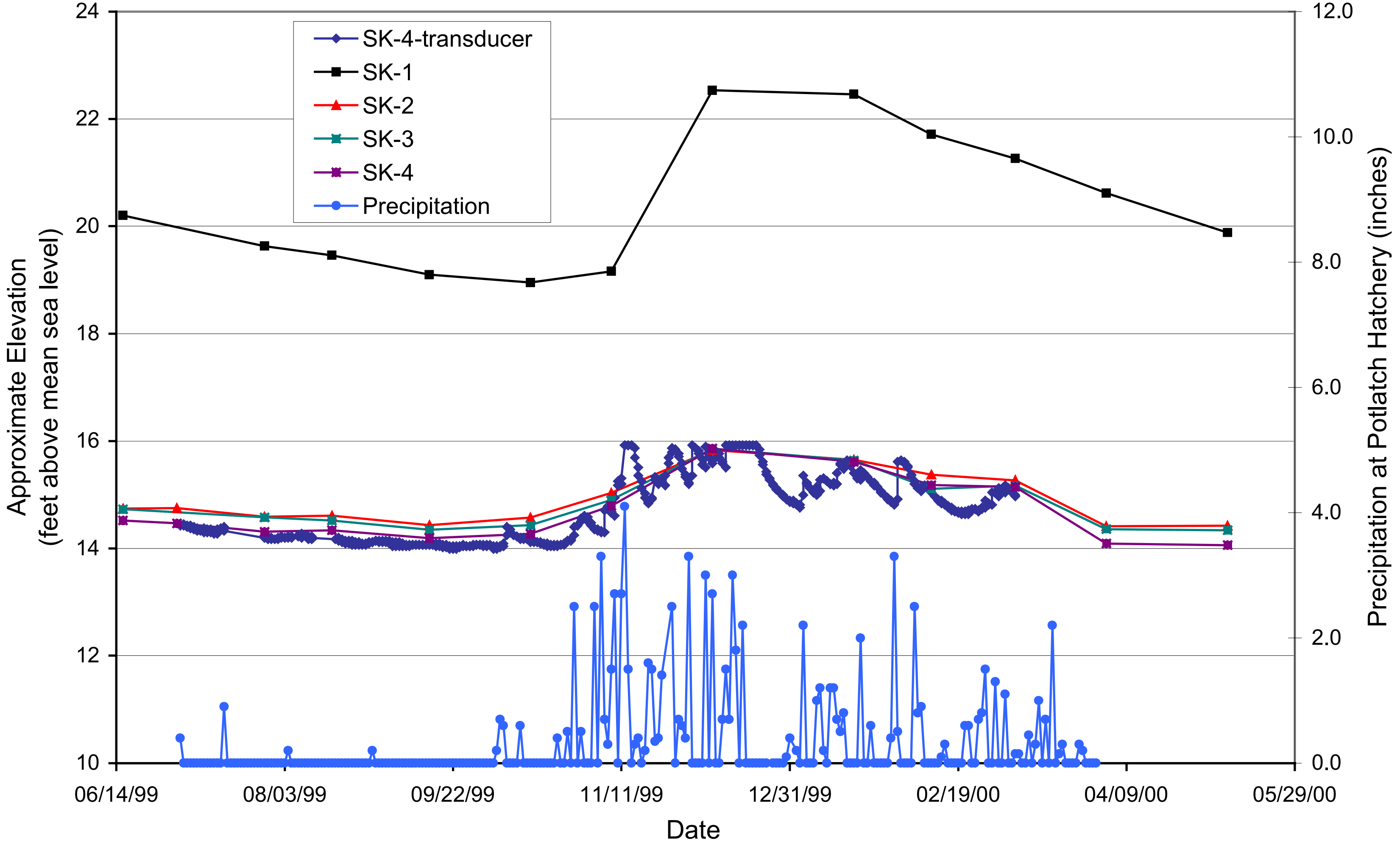


Figure 11. Water table elevations from the transducer at Skok-4, manual measurements at all wells and daily precipitation at the Potlatch Fish Hatchery.

one to three days of a winter rain event. Likewise, dry periods during the winter (i.e., December 18-29, 1999) resulted in rapidly decreasing water table elevations in both wells. The rapid change in water table elevations indicates that flow was rapid not only through the unsaturated zone but also through the underlying saturated zone.

Groundwater in the unconfined aquifer flows from northwest to southeast (Figures 12 and 13). This is the expected groundwater flow direction, from higher to lower elevation and toward Hood Canal in the east. The horizontal gradient between Skok-1 and Skok-4 was 0.2-0.3. The gradient almost completely flattens out between the other wells to gradients of 0.0004-0.003.

Groundwater quality

Results of quarterly water quality sampling from the monitoring wells are shown in Appendix E. All results were well within drinking water standards and, with the exception of nitrate+nitrite-N, similar to background median concentrations found in Puget Sound wells in 1981 by the USGS (Turney, 1986) as shown in Table 7. At that time, more than 75% of wells in the Puget Sound region had nitrate-N concentrations less than 1.0 mg/L.

Table 7. Comparison of median groundwater quality values with USGS (1986) and Washington State drinking water standards (Chapter 246-290 WAC). Concentrations are in mg/L.

	Ecology 1999	USGS (1986)[2]	Drinking Water Standard
NO_3+NO_2-N[1]	0.284	0.04 (0.10)	10.0
Total Dissolved Solids	71.5	--- (102)	500
Chloride	1.8	1.8 (2.1)	250
Specific Conductance (umhos/cm)	97	113 (130)	700

[1] The drinking water standard is for NO_3-N. NO_2-N is usually negligible in groundwater.

[2] Medians are based on five samples.

( ) Data were collected before the USGS (1986) study.

Two of four samples from Skok-1 had nitrate+nitrite-N concentrations between 1 to 2 mg/L. (Nitrite-N is typically negligible in groundwater.) In the other two samples, nitrate+nitrite-N concentrations were below 1 mg/L. The range of nitrate+nitrite-N values in the other three wells was 0.045-0.870 mg/L.

Mean values for the analytes in each well shown in Table 8 indicate slightly higher levels of nitrate+nitrite-N, TPN, total P, TDS, and specific conductance in Skok-1 than in the other wells. Skok-2 had slightly lower values for the same constituents. Values for chloride were similar in all wells, ranging between 1.59 and 2.32 mg/L.

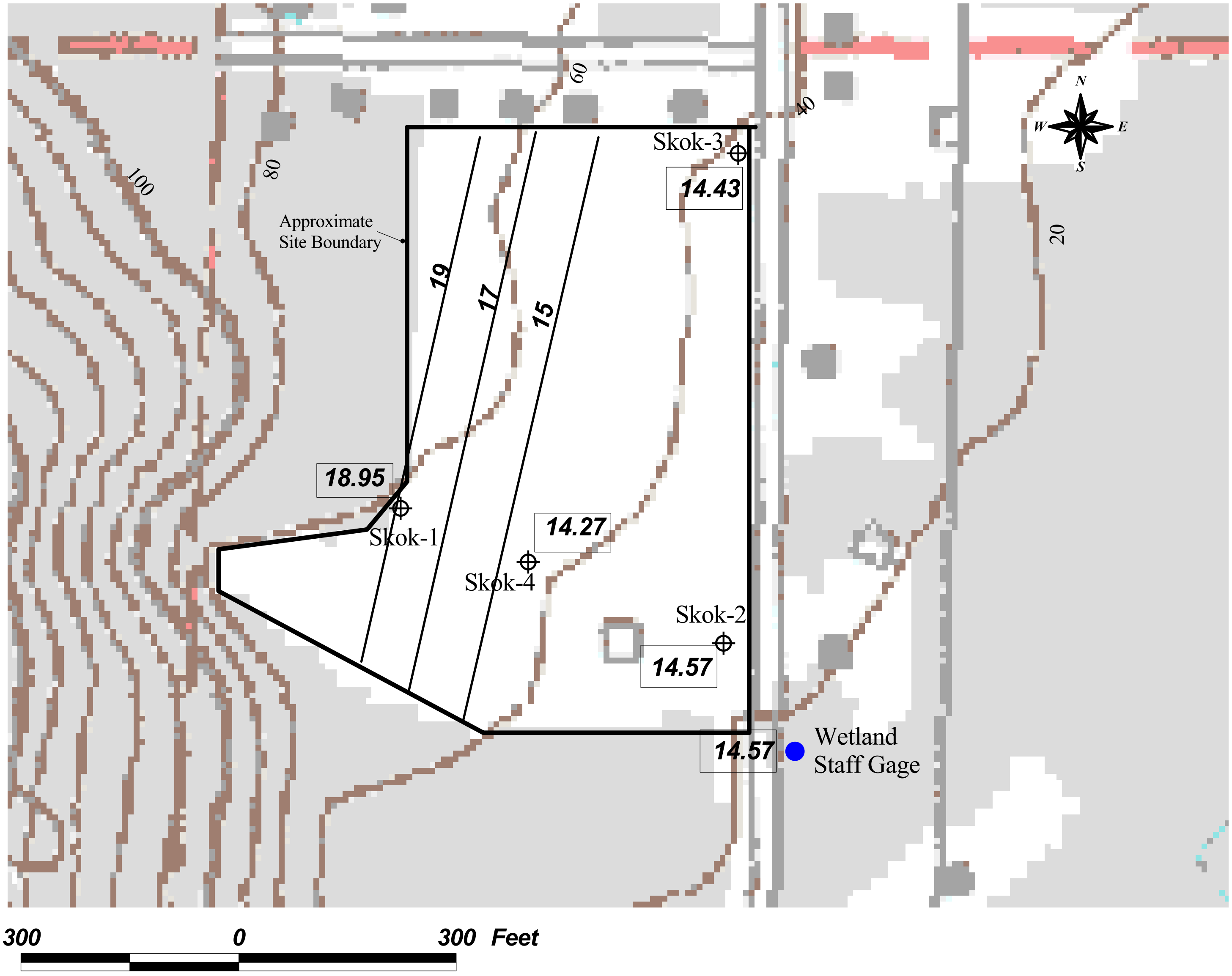


Figure 12. Water table contours for October 15,1999 in feet above mean sea level.

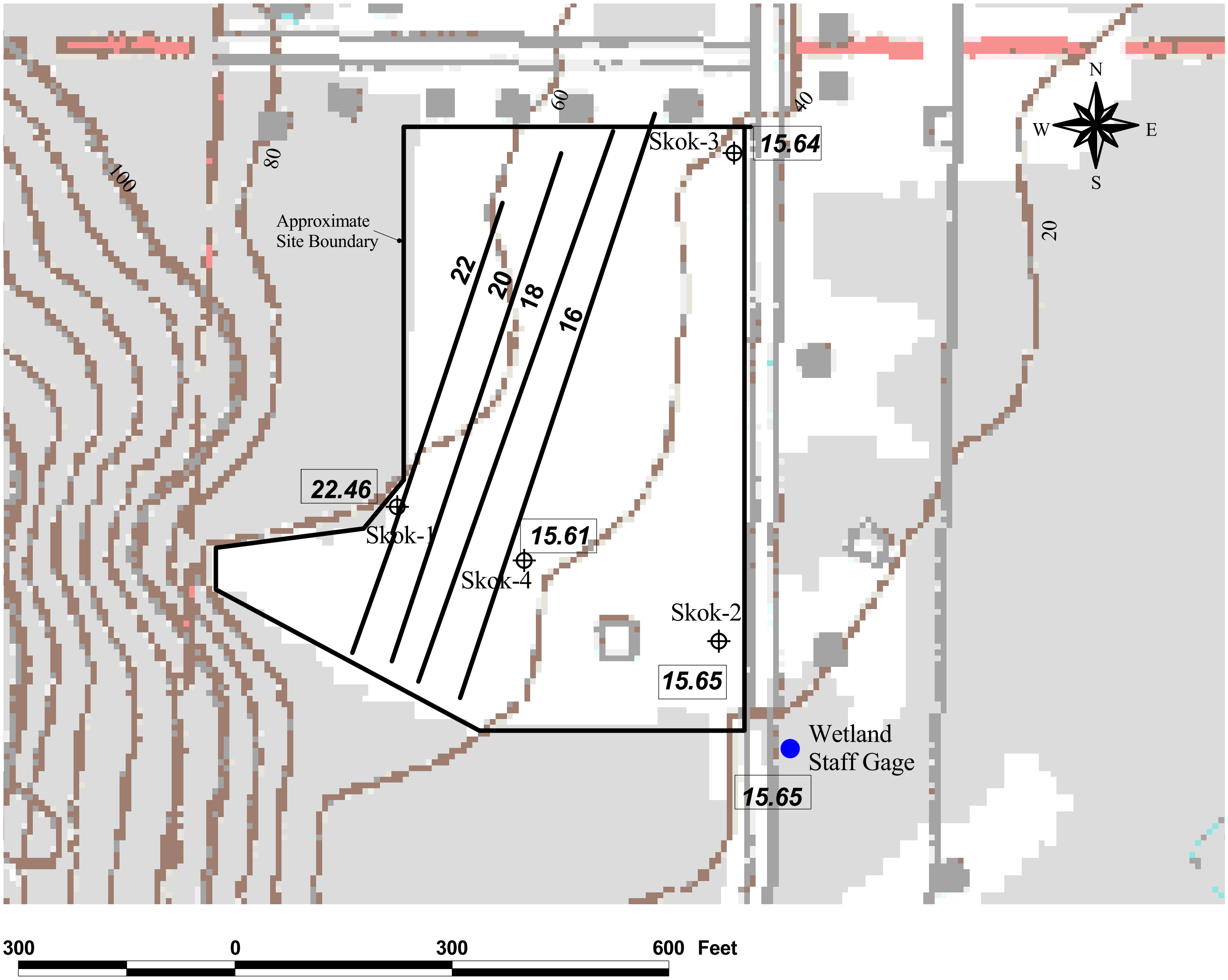


Figure 13. Water table contours for January 19, 2000 in feet above mean sea level.

Table 8. Mean water quality values for quarterly monitoring. Concentrations are in mg/L unless otherwise specified.

Laboratory Analytes							Field Parameters		
Well	NO2+NO3-N	TPN	Total P	Chloride	TDS	Specific Conductance (umhos/cm)	pH (S.U.)	Conductivity (umhos/cm)	Dissolved Oxygen
Skok-1	1.00	1.04	0.181	2.06	91	123	6.8	121	10.0
Skok-2	0.070	0.071	0.039	1.92	55	72	6.4	69	8.6
Skok-3	0.558	0.586	0.126	1.97	66	81	5.8	80	8.3
Skok-4	0.253	0.257	0.103	1.82	76	102	6.3	101	8.0

Fecal coliform bacteria were not detected in any of the wells on August 2, 1999 and May 9, 2000. Neither petroleum hydrocarbons or products, nor other gas chromatographic compounds, were detected in Skok-2. Sampling for hydrocarbons occurred on November 8, 1999, after the onset of winter precipitation and a corresponding rise in the water table. It was not an objective of the study to assess for contamination from past practices at the site.

Discussion

Vadose zone

Information on vadose zone characteristics of the site is available from test pit logs, well logs, grain size analyses, and percolation tests. One of the key findings that impacts the design of a rapid infiltration system facility at the site is that the native soils are permeable sand and gravel with cobbles and boulders. There were no visible signs of fine-grained layers in the native soils, while the landslide deposits are quite impermeable sands with silt. The landslide spoils that cover a large portion of the site to a depth of about 12 feet are unsuitable for a rapid infiltration system.

Discussed below are (1) indications of potential low permeability zones above the water table based on drilling samples, and (2) the thickness and permeability of the vadose zone as a whole.

Screening for low permeability zones

Low permeability zones within the unsaturated zone could prevent infiltrating treated effluent from percolating to the water table and ultimately downgradient. This could lead to effluent surfacing or other problems. The d_{10} value was used as an indicator of soil permeability to screen for potential low permeability zones. Grain size, which is the basis for the d_{10} value, does not take into account other important factors that influence permeability such as soil structure, layering, and water content.

It was assumed that K_s values from specific capacity tests were a reliable estimate of permeability within an order of magnitude. The d_{10} values for the soil samples from the screened zones of the monitoring wells and test pits adjacent to the infiltration pits were compared with d_{10} values for the unscreened zones of the well borings and the test pit samples not adjacent to infiltration pits. Although the hydraulic conductivity of unsaturated materials is typically different from that of saturated soils, saturated hydraulic conductivity estimates were used as a best guess regarding relative soil permeability. It is likely that at least part of the effluent flow will be under saturated conditions.

Field-measured K_s estimates in the monitoring wells, 60 to 400 feet/day, corresponded to d_{10} values in the screened zones of 0.13-0.28 mm (Figure 5). Percolation through the native soils was very rapid. d_{10} values in the test pits beside the infiltration pits in native soils ranged from 0.15 to 1.0 mm, many exceeding those for the saturated zones of the monitoring wells tested (Figure 6). Within the landslide debris, percolation was very slow. Likewise, d_{10} values in the landslide debris test pits were some of the lowest found at the site, 0.07 to 0.08 mm. (A d_{10} value in TP-2 of 0.17 mm was collected in the transition zone between native and landslide spoils, and was therefore not considered representative of landslide debris.)

Based on a comparison of d_{10} values with the specific capacity-based K_s estimates, samples from TP-1, TP-3, and TP-5 indicate K_s values for the vadose zone of about the same order of magnitude as those found in the monitoring wells, or higher. d_{10} values for samples of the unsaturated zone near the monitoring wells were also mostly in the same range as those for the saturated zone near the screened area of the wells tested for specific capacity. Therefore the hydraulic conductivity for most of the soil samples from the vadose zone would be expected to be similar to or greater than those found in the monitoring wells.

Though fewer in number, several grain-size samples for the unsaturated zones of the well borings had d_{10} values in the same range as those for test pits in the landslide spoils. This may indicate zones of slow percolation. Low d_{10} values in Skok-1 at 10- to 25-feet, 0.008-0.05 mm, provide further evidence of a distinct low permeability zone (Figure 5). Less distinct zones of lower permeability may be indicated by soil samples at Skok-2 (15 feet), Skok-3 (5, 25, and 30 feet), and Skok-4 (30 feet). As mentioned previously, samples collected using the small-diameter split spoon sampler may underestimate materials greater than 1.5 inches diameter. In addition, grain size alone is not a conclusive indicator of permeability.

At 15 feet in Skok-2 the d_{10} value, 0.04 mm, was in the same range as the low permeability landslide spoils. Although this depth is relatively close to the water table, if extensive, a low permeability layer at 15 feet could redirect percolating effluent and cause surfacing or drainage problems. The blow counts for this sample indicated loose material. The small sample recovery, 20% of the split spoon length, provides only a small indication of the material present.

Three samples from Skok-3 had d_{10} values in the same range as the landslide spoils, at 5, 25, and 30 feet. The five-foot sample could indicate an obstruction to infiltration if it represents an extensive low permeability layer and if water were infiltrated above it. The split spoon samples at 25 and 30 feet contained at least 30-60% gravel and broken cobbles. Cobbles were a problem during most of the drilling at Skok-3. Therefore the split spoon samples, which were less than half full, may misrepresent the true character of the materials at 25 and 30 feet. Even if the samples truly represent low permeability layers, they should not affect infiltration, because the 25-foot sample is close to the water table and the 30-foot sample is at or below the water table.

In Skok-4 a low d_{10} value at 30 feet, 0.07 mm, also probably does not represent a low permeability layer. The split spoon penetration indicated very hard material. The small sample (less than 17% full) appeared to be mostly broken rock. Therefore the grain size information is probably not representative of the material at that depth.

Although four out of five samples indicating low permeability layers in Skok-2, Skok-3, and Skok-4 are located at 10-20 feet elevation (Figure 5), most of the samples cannot be considered representative of the material at that depth because the samples were so small. The substrate that was being sampled was either too hard or too loose for proper sample collection. It seems unlikely that a low permeability layer extends throughout the site at 10-20 feet elevation, because most of the samples were taken in what appear to be cobbly areas. However, loose soils such as those found in the 15-foot sample in Skok-2 and the 5-foot sample in Skok-3 cannot be ruled out as low permeability zones of unknown extent. Additional sampling would be needed to determine the existence, thickness, and extent of any fine-grained layering and whether they would pose a problem for a rapid infiltration system.

Site-wide vadose characteristics

Samples from the unsaturated zone of the monitoring wells which were drilled through native soils showed somewhat less permeable materials when compared with test pit samples at similar depths. This bias toward smaller particles in split spoon samples is consistent with the small diameter of the sampler, compared to the open excavation available for collecting more representative test pit samples. Cobbles and boulders, which were widespread in the native soil pits, could not be included in monitoring well split spoon samples. Large materials are likewise under-represented in test pit samples.

Assuming no obstacles to percolation, the 15- to 28-foot thick unsaturated zone allows for installation of an effluent discharge line three feet deep and 10-25 feet above the water table. The greatest depth-to-water was found in Skok-4. Excavation and removal of about 10-15 feet of material in the southeast part of the site causes Skok-2 to have the shallowest depth-to-water, about 15 feet during the winter.

The rapid water table response to recharge from 147 inches of precipitation over the year-long study indicates that the soils on the site, as a whole, are highly permeable. This may indicate that low permeability zones described below and observed in soil samples are not extensive enough to obstruct flow on the site as a whole. There is little evidence to indicate that a low permeability zone extends between wells. However, even if not extensive over the site, the area where effluent is infiltrated and the nearby vadose areas should be free of low permeability zones.

Although rapid infiltration is a favorable aspect for construction of a rapid infiltration system, additional treatment of effluent as it percolates is unlikely to be significant.

Water table aquifer

The water table aquifer is composed mainly of Vashon recessional outwash material. Monitoring wells Skok-2, Skok-3, and Skok-4 are screened in medium sand with some gravel and silt. Small cobbles were also observed in grain size analyses, although difficult to represent with the small diameter sampler. A contact between coarse-grained sand and gravels covering most of the site and finer materials was observed in Skok-1 at the base of the bluffs beginning at 10-15 feet bgs. The percent cobbles drops to zero at 15 feet from 45% at 5 feet, and fines increase to 27% at 20 feet from 2.8% at 5 feet. A distinct, fine-grained, oxidized till layer was evident in the 20-foot sample (Table 4). The extent of the layer could not be determined. Below the silty-clay layer, fine sand makes up over 80% of the material.

No distinct, fine-grained layers were visually observed during drilling of the other three monitoring wells, including Skok-4, drilled to 50 feet (elevation -5 feet AMSL). However, grain-size distributions from samples of the Skok-2 and Skok-3 borings indicated zones with lower permeability based on d_{10} values as discussed in the above section, *Screening for low permeability zones.*

In terms of function, the silty-clay layer in Skok-1 does not seem to act as a confining layer. The water levels in Skok-1 are below the elevation of the layer. During drilling there was also no moisture observed above or within the silty-clay layer to indicate perching. However, drilling occurred during the dry summer period when little moisture would be expected to be percolating from above.

A 10-foot thick, gravel and clay layer was noted in the 1956 log for a WDOT well at about elevation -3 feet AMSL, and at a private well just east of the site at elevation -20 feet AMSL (Appendix A). The WDOT well could not be located during the study, but WDOT staff working at the site indicated that it lies between Skok-2 and Skok-4. The log for the WDOT well indicates that the material below the gravel and clay layer was gravel, similar to that above the layer and unlike the fine sand below the silty-clay layer at Skok-1.

The extent of the gravel and clay layer is unknown, but for the purposes of assessing the site for a rapid infiltration system it is assumed that the layer forms the base of the upper aquifer at -3 feet AMSL. The potential thickness of the upper aquifer, therefore, is assumed to be 50 feet over most of the site based on the lack of a confining layer in Skok-4 to at least 50 feet. The saturated thickness of the aquifer during the study was about 20 feet, based on water table elevations (Appendix D). If the overlying unsaturated zone is included, the potential aquifer thickness is 50 feet at Skok-3 and Skok-4 and 35 feet at Skok-2.

The current relatively deep water table, 15-30 feet bgs, allows for a moderate water table rise if a rapid infiltration system is constructed. This is discussed in more detail in Volume 2 (Pitz, 2000).

The moderately high estimate for hydraulic conductivity of the recessional material, 350-400 feet/day, is conducive for flow of infiltrated groundwater off-site. The water table fluctuation of 1.5 feet during the study in the three downgradient wells (Skok-2, Skok-3, and Skok-4) during a year with 1.5 times the normal precipitation, indicates rapid flow of recharge to the aquifer and within the aquifer. However, the lower hydraulic conductivity in the transition zone between the coarse outwash and finer sand material, 60 feet/day (Skok-1), coincided with a 3.5-foot fluctuation during the study. This lower conductivity and larger water table fluctuation resulting from recharge alone could result in a greater water table rise than in the outwash material if water were infiltrated in this zone. The lateral extent of the lower permeability zone could not be determined with the limited number of samples.

Groundwater flow is from northwest to southeast toward the adjacent wetland and Hood Canal. Potential impacts of the projected rapid infiltration system on the downgradient wetland and estuarine water were not addressed in this study.

Groundwater quality

Water quality in the monitoring wells surpassed drinking water standards for specific conductance, total dissolved solids, nitrate, and chloride (Chapter 246-290 WAC). Results from the monitoring wells at the site were similar to background concentrations found in Mason

County by the U.S. Geological Survey in 1981 (Turney, 1986) as shown in Table 7. Skok-1 had slightly higher concentrations of nitrate+nitrite-N, TPN, total P, TDS, and specific conductance than the other wells. The slightly higher concentrations in Skok-1 may be related to differences in aquifer materials.

Hydrocarbons and products were not found when analyzed in the well closest to the WDOT maintenance facility, Skok-2. However, this result does not preclude the need for further site investigation of potential impacts from past practices at the maintenance facility. The sample was taken merely as a basic screening tool and was not a stated objective of the study.

This page is purposely blank for duplex printing

Conclusions

- Test pit observations indicated that native soils are mainly composed of sand and gravel with cobbles and boulders. There was no evidence of fine-grained layers or obstacles to downward flow of water in the native soil test pits.

- Percolation rates were less than one minute/inch in the native soils and roughly eight hours/inch in the landslide debris soils.

- The site has a relatively thick vadose zone (15-28 feet). The thinner zone at well Skok-2 is due to excavation.

- Hydraulic conductivity estimates for the coarse, outwash material found in wells Skok-2, Skok-3, and Skok-4 based on specific capacity testing are in the range of 350-400 feet/day. The permeability estimate for the finer sand found in Skok-1 at the base of the bluff is roughly 60 feet/day.

- Based on soil types, grain size distributions, inspection of test pits, and the rapid water table response to recharge, the native soils appear suitable for rapid infiltration. However, the imported landslide debris soils are not suitable.

- Percolation rates in the native soils were so high that little additional treatment can be expected for effluent percolating through the soil.

- The low permeability layer at about 15-25 feet in well Skok-1 could obstruct downward flow if effluent were applied in this area or similar areas in the western part of the site where finer deposits exist above the water table.

- Low-permeability layers may be present at 15 feet bgs at well Skok-2 and less possibly at 5 and 25 feet bgs at Skok-3, based grain size analysis of split spoon samples. The limited density of samples over the site and low sample recovery makes it impossible to determine the extent of these layers if they exist. If extensive, these layers could obstruct downward flow of effluent infiltrated nearby, causing effluent to surface before reaching the water table.

- Groundwater flows from higher elevation to lower elevation or from northwest to southeast. The horizontal flow gradient is steep between well Skok-1 and the other wells due to its location at the base of the steep bluffs and because it is completed in finer material than the other wells. The flow gradient is flat between the other three wells.

- The area near well Skok-4 and test pit TP-1 appears to be the most favorable for infiltration as long as sufficient distance is maintained from the contact with finer grained material represented in Skok-1. This area is most favorable, because there is no evidence of a fine-grained layer above the water table, and the unsaturated zone is the thickest observed.

- Water quality results for nitrate+nitrite-N, chloride, specific conductance, and total dissolved solids were far below maximum contaminant levels and similar to background concentrations in Mason County.

- No hydrocarbons were found in one sample from the monitoring well downgradient of the abandoned maintenance building. However, it was not an objective of the study to assess the potential for contamination at the site.

- Impacts on the wetland downgradient and across the highway from the study site were not analyzed.

Recommendations

- Construct one or more additional investigative borings between wells Skok-1 and Skok-4 to gain more information about the elevation and geometry of the fine-grained unit identified in Skok-1.
- Survey monitoring well elevations to 0.01 foot to verify correct groundwater flow direction.
- Due to the permeable soils, deep unsaturated zone, distance from the landslide spoils and lack of more detailed information, the area near well Skok-4 and test pit TP-1 appears to be a favorable location for the rapid infiltration system. Care is needed to avoid the fine-grained material just west of this area observed in Skok-1.
- Do not construct the infiltration area in the landslide debris soils.
- Characterize the soils in the proposed infiltration area in detail to detect any potential obstacles to infiltration.
- A pilot-scale infiltration field test is recommended prior to system construction to minimize the uncertainties discussed in this report.
- Appropriate operation and maintenance procedures should be implemented to minimize aquifer plugging over time and ensure that aquifer transmissivity does not diminish over time.

This page is purposely blank for duplex printing

References

ASTM Standards on Ground Water and Vadose Zone Investigations, 2nd Edition, 1994. American Society for Testing and Materials (ASTM) Publication Code No. (PCN): 03-418094-38. Philadelphia, PA., 432 p.

Barron, T., 2000. Personal communication. Skokomish Tribe, Shelton, WA. Nov. 9, 2000.

Bradbury, K. R. and E. R. Rothschild, 1985. A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data, Ground Water, 23(2):240-246.

Chapter 246-290 WAC, 1999. Group A Public Water Systems. Washington State Department of Health, Olympia, WA. April 9,1999.

EPA, 1980. Design manual for onsite wastewater treatment and disposal. EPA/625/1-80/012, Office of Water Program Operations, Washington, DC, 391 p.

Hong West, 1994. Technical Memorandum from Larry West to Gordon Munro, KCM (Kramer, Chin and Mayo, Inc.), Portland OR. Skokomish Wastewater Facility Report No. 94032. Preliminary Hydrogeologic Evaluation. September 19, 1994.

Molenaar, D. and J. E. Cummans, 1973. Water Resources of the Skokomish Indian Reservation, Washington. U.S. Geological Survey Open-File Report, 58 p.

Molenaar, D. and J. B. Noble, 1970. Geology and related ground-water occurrence, Southeastern Mason County, Washington. Washington State Department of Water Resources, Water-Supply Bulletin No. 29, 145 p., 2 Plates.

NOAA, 2000. Climatological data for Washington. National Oceanic and Atmospheric Administration, Asheville, NC.

Pitz, C., 2000. WDOT-Skokomish Site near Potlatch, Volume 2: Groundwater Mounding Analysis. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-052.

Shannon & Wilson, 1978. Skokomish Indian Reservation Water Resources Project, Mason County, Washington. Report No. W-3302-01, September 1978.

Turney, G.L., 1986. Quality of ground water in the Puget Sound Region, Washington, 1981. U.S. Geological Survey Water-Resources Investigations Report 84-4258.

U.S. Soil Conservation Service, 1960. Soil Survey, Mason County, Washington.

This page is purposely blank for duplex printing

Appendices

This page is purposely blank for duplex printing

Appendix A

Drilling logs

This page is purposely blank for duplex printing

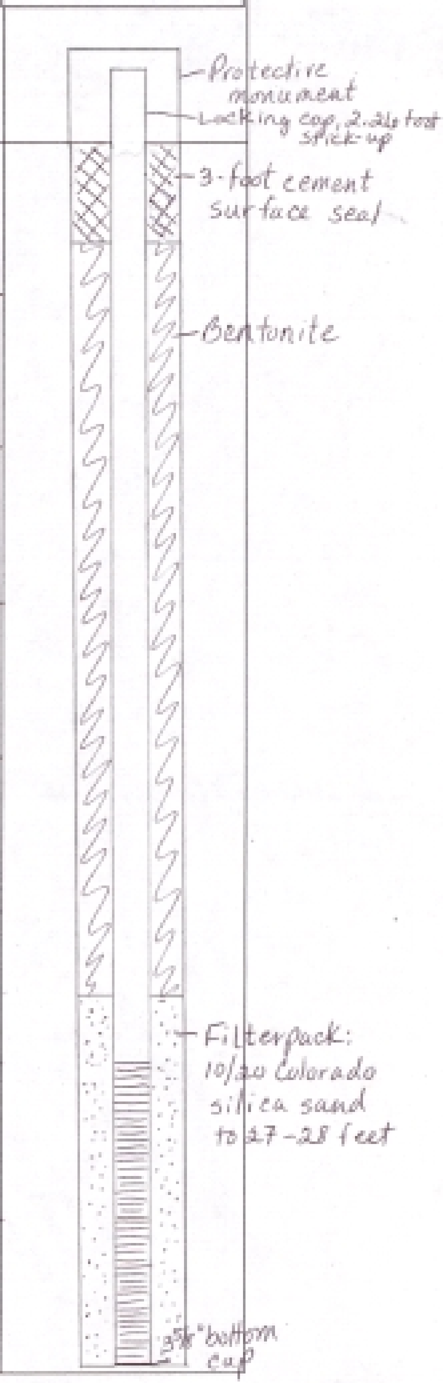
SKok-1

GEOLOGIC LOG

Drilling Contractor: Holt Drilling
Date Completed: 6/8/99
Altitude Ground Surface: 48.03 feet AMSL assuming SKok-4 is at 45.00 feet

	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)
GROUND SURFACE				0
Poorly graded GRAVEL with sand	S-1	11/15/16	GP	5
Silty SAND with gravel, cobbles, and silt (Gravel 30-40%)	S-2	4/10/31	SM	10
	S-3	13/20/28		15
At 20 feet: silty, clayey SAND and GRAVEL (Till layer), orange, compacted	S-4	9/15/16		20
Poorly graded SAND At 25 feet: no gravel, fine sand, and silt (Sand: brown and grey)	S-5	6/14/25		25
At 30 feet: with gravel; medium sand; moist	S-6	7/24/48	SP	30
At 35-40 feet: no gravel; fine to medium sand; wet	S-7	14/37/35		35
	S-8	12/35/50 for 5"		40

AS-BUILT DATA



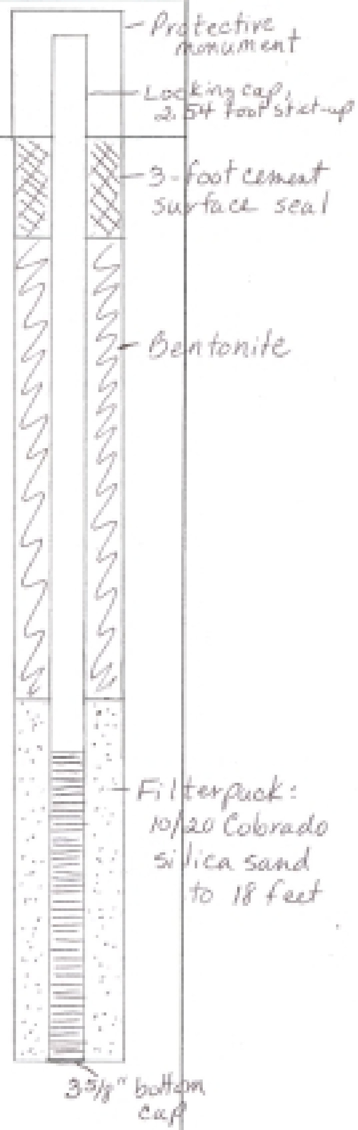
SKok-2

GEOLOGIC LOG

Drilling Contractor: Holt Drilling
Date Completed: 6/8/99
Altitude Ground Surface: 30.97 feet AMSL assuming SKok-4 is at 45.00 feet

GROUND SURFACE	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)
				0
Silty GRAVEL with sand and cobbles to silty SAND with gravel and cobbles (Gravel: 30-60%) Wet at 15 feet (Sand: fine to medium, brown)	S-1	3/4/4	GM to SM	5
	S-2	13/25/28		10
	S-3	2/3/5		15
SAND with gravel and silt (Gravel: 35-40%) (Sand: coarse, grey and brown)	S-4	6/10/30	SW-SM to SP-SM	20
	S-5	45/55		25
	S-6	30/35/33		30
				35
				40

AS-BUILT DATA



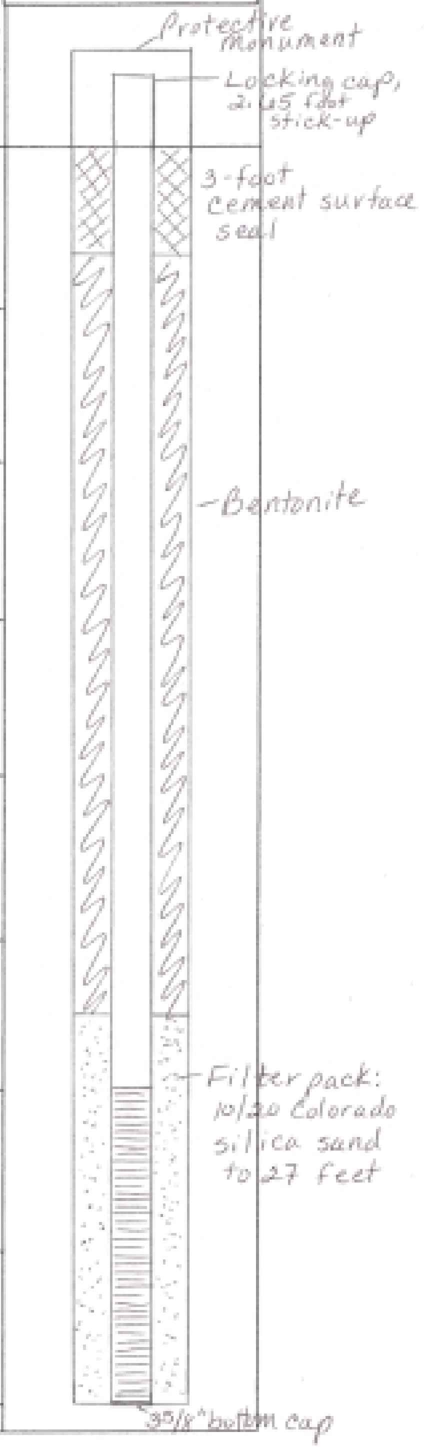
SKoK-3

GEOLOGIC LOG

Drilling Contractor: Holt Drilling
Date Completed: 6/8/99
Altitude Ground Surface: 44.57 feet AMSL assuming SKoK-4 is at 45.00 feet

	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)
GROUND SURFACE				0
(wood debris at surface) Silty SAND with gravel and cobbles (Sand: dark brown, fine to medium)	S-1	11/10/9	SM	5
wood debris at 10 feet	S-2	15/25/22		10
Well graded GRAVEL with silt, sand and cobbles. (Sand: brown, fine to medium) No samples at 15' and 17.5'. Cobbles to 3-4 inches in cuttings.		5/9/25	GW-GM	15
		10/14/16		
Moist at 20'	S-3	14/25/29		20
Well graded SAND with silt and gravel (Gravel 30%) Poorly graded SAND at 35' Wet at 30'	S-4	10/11/19	SW-SM	25
	S-5	11/17/23		30
	S-6	22/50 to 5"		35
	S-7	13/32/50 for 4"		40

AS-BUILT DATA



SKoK-4

GEOLOGIC LOG

Drilling Contractor: Holt Drilling
Date Completed: 6/8/99
Altitude Ground Surface: 45.00 feet Amsl taken from USGS 7.5 min. topo map

GROUND SURFACE

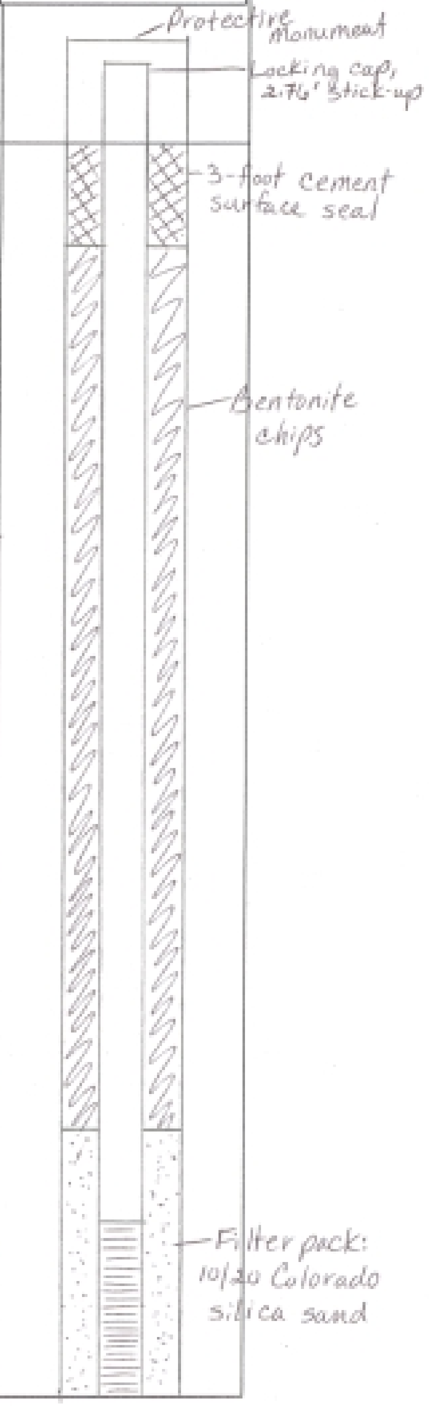
Well graded GRAVEL with sand and cobbles. (Sand: medium to coarse, brown and grey. Gravel 30%)

Poorly graded SAND with silt, clay, and gravel (Sand: medium to coarse, grey and brown. Gravel 25-30%)

wet at 30.'

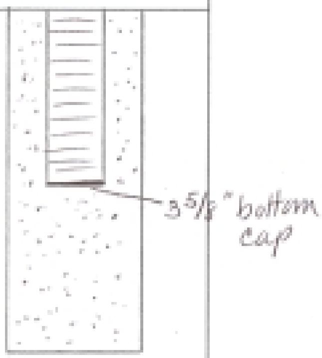
Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)
			0
S-1	11/25/33		5
	9/5/4	GW	10
S-2	10/11/23		
S-3	14-23/35		15
S-4	13/15/17		20
S-5	6/27/41		25
S-6	23/50 for 5½"	SP-SM	30
S-7	29/40/48		35
S-8	5/10/29		40

AS-BUILT DATA



SKoK-4 (continued)

GEOLOGIC LOG Drilling Contractor: Date Completed: Altitude Ground Surface:	Soil Sample	Blow Counts	Hydrologic Unit	Depth (feet)	AS-BUILT DATA
GROUND SURFACE					
Poorly graded SAND (grey and brown) (Gravel 15% at 40' No gravel at 45-50')			SP		
	5-9	6/14/ 49		45	
	5-10	35/ 50 for 3"		50	



Original and First Copy with
Division of Water Management
ond Copy — Owner's Copy
rd Copy — Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

WRC
8739

Application No. ....
Permit No. ....

) **OWNER:** Name Washington State Highway Dept. Address P.O. Box 327, Olympia 98501

) **LOCATION OF WELL:** County Mason — NW ¼ NW ¼ Sec. 2 T. 21 N., R. 4 W., W.M.
ring and distance from section or subdivision corner 700' south and 525' east from Northwest corner of Section 2

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

) **TYPE OF WORK:** Owner's number of well (if more than one) ....
New well ☐ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☒ Driven ☐
Reconditioned ☐ Rotary ☐ Jetted ☐

) **DIMENSIONS:** Diameter of well 6' inches.
Drilled 66 ft. Depth of completed well 66 ft.

) **CONSTRUCTION DETAILS:**

Casing installed: ......" Diam. from ...... ft. to ...... ft.
Threaded ☐ ......" Diam. from ...... ft. to ...... ft.
Welded ☐ ......" Diam. from ...... ft. to ...... ft.

Perforations: Yes ☒ No ☐
Type of perforator used..........
SIZE of perforations .... in. by .... in.
.... perforations from 42 ft. to 63 ft.
.... perforations from .... ft. to .... ft.
.... perforations from .... ft. to .... ft.

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

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

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

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

8) **WATER LEVELS:** Land-surface elevation above mean sea level.... .... ft.
tatic level 22 1/2 ft. below top of well Date March 1956
rtesian pressure .... lbs. per square inch Date..........
Artesian water is controlled by.......... (Cap, valve, etc.)

9) **WELL TESTS:** Drawdown is amount water level is lowered below static level
'as a pump test made? Yes ☒ No ☐ If yes, by whom? well driller

ield:	gal./min. with	ft. drawdown after	hrs.
" 75	"	13" "	"
" 60	"	11" "	"

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

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 1956
ailer test.......... gal./min. with.......... ft. drawdown after.......... hrs.
rtesian flow.......... g.p.m. Date..........
emperature of water.......... Was a chemical analysis made? Yes ☒ No ☐

(10) **WELL LOG:**

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

MATERIAL	FROM	TO
Loose Gravel	0'	32'
Gravel w/clay, little water	32	42
Loose gravel, lots of water	42	66

Work started.......... 19...... Completed.......... 19......

WELL DRILLER'S STATEMENT:

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

NAME Webber Well Drilling Co.
(Person, firm, or corporation) (Type or print)

Address Shelton, Washington

[Signed] ....
(Well Driller)

License No. .... Date.........., 19......

(USE ADDITIONAL SHEETS IF NECESSARY)

. F. No. 1256—OS—(Rev. 5-69)—5-69.

30pc

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. W111719
Unique Well I.D. # AFB151
Water Right Permit No.

(1) OWNER: Name BAUER, ED Address 1633 OLD BAYSHORE HWY SAN JOSE, CA 95112-

(2) LOCATION OF WELL: County MASON - SW 1/4 NW 1/4 Sec 2 T 21N N., R 4W WM
(2a) STREET ADDRESS OF WELL (or nearest address) 19879 HWY 101 N, SHELTON

(3) PROPOSED USE: DOMESTIC

(4) TYPE OF WORK: Owner's Number of well (If more than one)
NEW WELL Method: CABLE

(5) DIMENSIONS: Diameter of well 6 inches
Drilled 44 ft. Depth of completed well 44 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 6 " Dia. from +1 ft. to 44 ft.
WELDED CASING " Dia. from ft. to ft.
" Dia. from ft. to ft.

Perforations: NO
Type of perforator used
SIZE of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

Screens: YES
Manufacturer's Name HOUSTON
Type SLOTTED Model No.
Diam. 5 slot size 080 from 35 ft. to 39 ft.
Diam. 5 slot size .050 from 39 ft. to 44 ft.

Gravel packed: NO Size of gravel
Gravel placed from ft. to ft.

Surface seal: YES To what depth? 18 ft.
Material used in seal BENTONITE
Did any strata contain unusable water? NO
Type of water? Depth of strata ft.
Method of sealing strata off

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

(8) WATER LEVELS: Land-surface elevation above mean sea level ... ft.
Static level 5 ft. below top of well Date 06/23/99
Artesian Pressure lbs. per square inch Date
Artesian water controlled by

(10) WELL LOG

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

MATERIAL	FROM	TO
FILL DIRT	0	6
BROWN CONGLOMERATE MOIST	6	22
GRAVEL & WATER	22	31
BROWN CONGLOMERATE GRAVEL	31	38
BROWN CLAY GRAVEL	38	40
GRAVEL & WATER	40	44

Work started 06/21/99 Completed 06/23/99

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

Recovery data
Time Water Level Time Water Level Time Water Level

Date of test / /
Bailer test 20 gal/min. 0 ft. drawdown after 1 hrs.
Air test gal/min. w/ stem set at ft. for hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? NO

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

NAME ARCADIA DRILLING INC.
(Person, firm, or corporation) (type or print)

ADDRESS SE 176 WALKER PARK RD

[SIGNED] Mark H Nelson License No. 1952

Contractor's
Registration No. ARCADDI095K1 Date 06/24/99

Appendix B

Test pit logs

This page is purposely blank for duplex printing

TP-1

GEOLOGIC LOG

DRILLING CONTRACTOR: Skokomish Tribe
DATE COMPLETED: 8/17/99
ALTITUDE GROUND SURFACE:

GEOLOGIC LOG		HYDROLOGIC UNIT	Depth (feet)	AS-BUILT DATA
GROUND SURFACE			0	
SW-SM	Light brown well graded sand with silt, gravel, and cobbles (Gravel and cobbles > 20%)		2 4	
SW	Well graded sand with gravel, fewer cobbles than 1-5 feet; sloughs easily.		6	
SW-SM	Light brown sand with gravel and silt.		8 10	
			12	

TP-2

GEOLOGIC LOG

DRILLING CONTRACTOR: Skokomish Tribe
DATE COMPLETED: 8/17/99
ALTITUDE GROUND SURFACE:

HYDROLOGIC UNIT
Depth (feet)
AS-BUILT DATA

GROUND SURFACE — 0

SM or OL/OH

Dark brown to black organic soil, <10% gravel, some to lots of woody debris, fine to coarse sand, silt. Organic odor.

Grey to black, fine to coarse sand, <10% gravel, wood debris, organic odor.

SW

Well graded grey sand with gravel and cobbles up to 24 in. Transition zone between land slide debris deposited in March 1999 and the former gravel pit. Bottom of the pit is light brown silty sand, very sticky.

0
2
4
6
8
10
12

TP-3

GEOLOGIC LOG

DRILLING CONTRACTOR: Skokomish Tribe
DATE COMPLETED: 8/17/00
ALTITUDE GROUND SURFACE:

		HYDROLOGIC UNIT	Depth (feet)	AS-BUILT DATA
GROUND SURFACE			0	
SW	Fine to medium sand with 10-20% gravel. Gravel to 5in.			
			2	
			4	
	Medium to coarse brown sand and gravel. Gravel 15-25%, up to 3-4 in.		6	
	Asphalt chunks at 8 ft.		8	
			10	
			12	

TP-4

GEOLOGIC LOG

DRILLING CONTRACTOR: Skokomish Tribe
DATE COMPLETED: 8/17/99
ALTITUDE GROUND SURFACE:

HYDROLOGIC UNIT

Depth (feet)

AS-BUILT DATA

GROUND SURFACE

0

SM or OL/OH

Grey to black fine to medium sand, organic, and gravel. Gravel about 15% up to 3in. A few cobbles and boulders, some woddy debris, organic odor. (Landslide debris soil)

2

4

6

8

West side of pit appears to be a transition zone with native soil, brown gravelly to cobbly sand.

10

12

TP-5

GEOLOGIC LOG

DRILLING CONTRACTOR: Skokomish Tribe
DATE COMPLETED: 8/17/99
ALTITUDE GROUND SURFACE:

HYDROLOGIC UNIT

Depth (feet)

AS-BUILT DATA

GROUND SURFACE

		Depth (feet)
SW-SM	Light brown medium to coarse sand with some fines. Gravel 20-30%, cobbles.	0
		2
		4
		6
		8
		10

Appendix C

Grain size results for test pit and monitoring well split spoon samples

This page is purposely blank for duplex printing

State of Washington Department of Ecology
Manchester Environmental Laboratory
7411 Beach Dr. East Port Orchard WA. 98366

July 19, 1999

Project: Skokomish River Study

Samples: 23-8205-25

Laboratory: Rosa Environmental

By: Pam Covey

Case Summary

Twenty-one (21) sediment samples required Grain Size analyses using ASTM-D422 method sieve only and four samples required further hydrometer analysis. The samples were received at the Manchester Environmental Laboratory on June 11, 1999 and transported to the contract lab on June 15, 1999 for Grain Size analyses.

The analyses were reviewed for qualitative and quantitative accuracy, validity and usefulness. The results are acceptable for use as reported.

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

815 Harrison Street, #100
Seattle, WA 98109-5187
(206) 287-9122

Client: WDOE, Manchester Laboratory	REGL Project No.: 1004-023
Client Project No.: Skokomish River Study	Sample Batch Nos.: 1004-023

Case Narrative

1. Samples were received on June 15, 1999, and were in good condition.
2. The original scope was modified by adding 4 hydrometer analyses to the total.
3. Each sieve sample was placed in a tare, oven dried, washed, dried again, and sieved. The data is reported on the attached tables. One table shows the accumulative percent passing, and the other shows the amount retained in each sieve size. Also, plots of the cumulative percent passing are provided.
4. The hydrometer samples were set up on June 21, 1999, and were run on June 22-23, 1999. Following the hydrometer test, the samples were washed over a #200 sieve, oven dried and sieved. The data is reported on the attached tables and plots. The samples contained mostly gravel and sand with few fines. There was some curve fitting to get the sieve portion and the hydrometer portions to match up, there was about a 2-3 percent step on samples 23-8511 and 23-8512. This was done by small adjustments to the assumed specific gravity of 2.65 to match up the two curves.
5. Copies of the computer entry sheets are provided as requested.
6. There were no other anomalies to the samples or the testing.

Approved by: ______________________ Date: 6/24/99
Title: Laboratory Manager

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

1001 SW Klickitat Way, Suite 107
Seattle, WA 98134
(206) 287-9122

June 2, 2000

Ms. Barbara Carey
WA Dept. of Ecology
PO Box 47710
Olympia, WA 98504

Regarding: Skokomish River Study, REGL Project No. 1004-023

Dear Ms. Carey;

Enclosed are the corrected results of the Skokomish River study grain size analysis. We are sorry for any inconvenience this may have caused you. Please call me if you have any questions or comments on the data or its presentation.

Best Regards,
Rosa Environmental & Geotechnical Laboratory, LLC

Harold Benny

Harold Benny
Quality Assurance Manager

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project

Percent Finer Than Indicated Size

Sample No.	Gravel					Coarse Sand		Medium Sand				Fine Sand	
ieve Size (micron	1.5"	1"	3/4"	1/2"	3/8"	#4	#10 (2000)	#20 (850)	#40 (425)	#60 (250)	#80 (180)	#100 (125)	#200 (75)
23-8205	100.0	93.3	80.8	73.5	66.6	52.8	37.4	23.0	14.4	9.8	7.9	7.3	5.4
23-8506	100.0	82.1	71.6	60.1	55.7	42.0	26.6	17.0	12.4	9.6	8.3	7.7	6.0
23-8507	100.0	85.3	82.1	74.4	65.7	48.5	29.7	18.3	12.0	8.0	6.4	5.8	4.3
23-8510	100.0	85.8	72.1	64.0	58.6	44.2	33.0	25.7	20.7	16.7	14.3	13.4	10.3
23-8513	100.0	100.0	100.0	100.0	100.0	93.8	70.9	40.2	16.9	8.2	6.2	5.6	4.4
23-8514	100.0	100.0	100.0	98.6	98.6	93.7	82.0	54.2	25.2	9.4	6.3	5.4	4.1
23-8515	100.0	100.0	88.7	76.1	71.9	59.4	46.2	35.5	26.6	20.2	17.3	16.3	13.3
23-8516	100.0	69.2	56.6	44.5	42.1	32.6	21.5	14.1	10.2	7.5	6.3	5.8	4.4
23-8517	100.0	100.0	78.5	69.9	63.8	48.9	36.8	28.9	23.3	18.8	16.5	15.5	12.3
23-8518	100.0	100.0	94.4	90.0	81.1	57.2	34.9	22.2	16.3	11.4	9.3	8.5	6.4
23-8519	100.0	90.9	90.9	87.8	87.8	81.9	70.6	62.8	50.2	22.4	12.6	9.7	4.8
23-8520	100.0	100.0	93.6	83.5	77.5	65.9	50.2	36.2	25.5	15.8	11.2	9.9	6.8
23-8521	100.0	100.0	88.6	82.2	73.4	59.5	46.4	36.3	28.7	23.3	20.3	19.3	15.2
23-8522	100.0	66.6	50.5	47.2	45.6	38.9	26.6	20.9	16.2	11.7	9.5	8.9	5.9
23-8523	100.0	95.7	95.7	75.3	64.2	46.2	33.3	23.8	17.3	12.1	9.9	9.0	6.7
23-8524	100.0	100.0	83.5	73.4	69.0	52.6	38.1	27.9	21.1	16.5	14.2	13.4	10.9
23-8525	100.0	94.2	82.7	75.2	69.7	53.0	39.0	28.0	21.3	16.4	14.3	13.4	10.6

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project
Grain Size Distribution, Percent Retained in Each Size Fraction

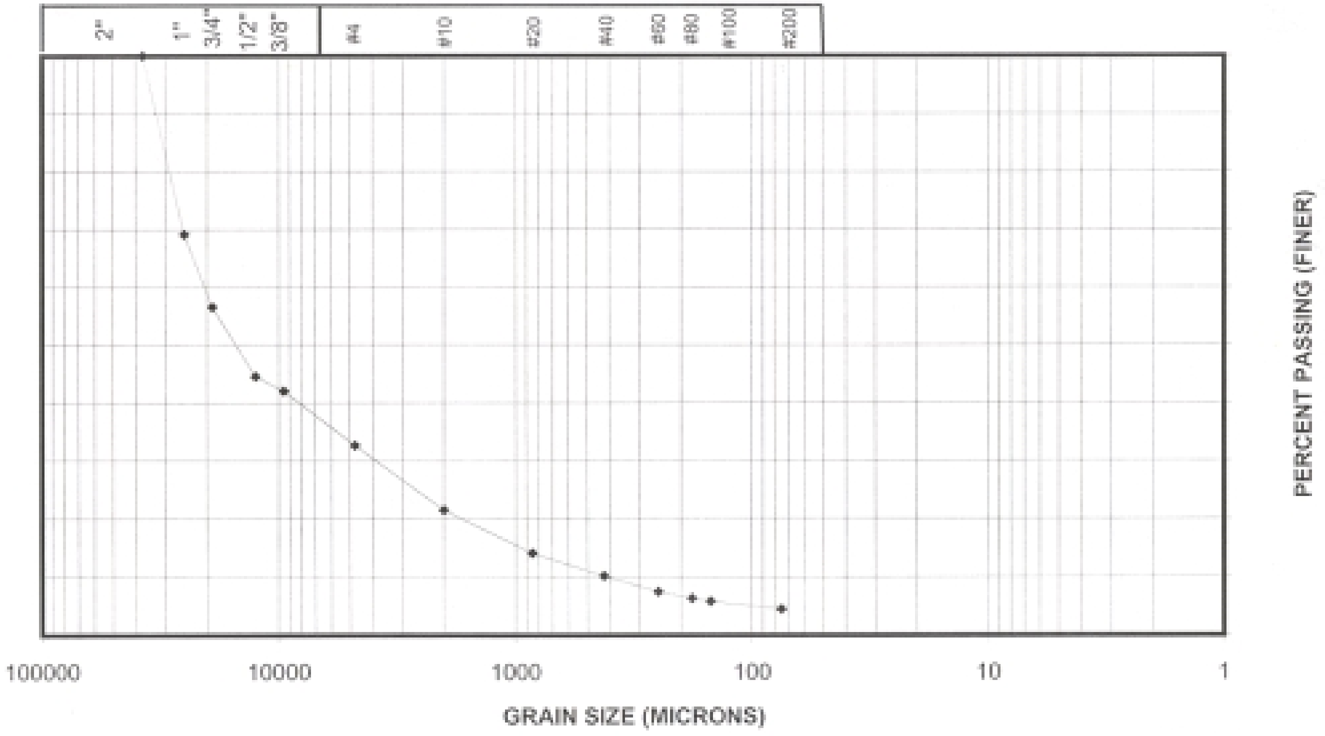
Size (microns)	> 4750	4750-2000	2000-850	850-425	425-250	250-180	180-125	125-75	<75
23-8205	47.2	15.4	14.4	8.6	4.5	1.9	0.7	1.9	5.4
23-8506	58.0	15.4	9.6	4.6	2.7	1.4	0.6	1.7	6.0
23-8507	51.5	18.8	11.4	6.3	4.0	1.5	0.6	1.6	4.3
23-8510	55.8	11.2	7.3	5.0	4.0	2.4	1.0	3.1	10.3
23-8513	6.2	23.0	30.6	23.4	8.7	2.0	0.5	1.2	4.4
23-8514	6.3	11.6	27.8	29.0	15.9	3.1	0.8	1.4	4.1
23-8515	40.6	13.1	10.7	8.9	6.5	2.9	1.0	3.0	13.3
23-8516	67.4	11.2	7.4	3.9	2.7	1.2	0.5	1.4	4.4
23-8517	51.1	12.1	7.9	5.5	4.5	2.3	1.0	3.3	12.3
23-8518	42.8	22.3	12.7	5.9	4.8	2.2	0.8	2.1	6.4
23-8519	18.1	11.4	7.8	12.6	27.8	9.9	2.9	5.0	4.8
23-8520	34.1	15.8	14.0	10.7	9.7	4.5	1.3	3.1	6.8
23-8521	40.5	13.1	10.1	7.6	5.4	3.0	1.1	4.0	15.2
23-8522	63.1	10.3	5.7	4.7	4.6	2.2	0.6	3.0	5.9
23-8523	53.8	13.0	9.5	6.5	5.2	2.2	0.9	2.3	6.7
23-8524	47.4	14.5	10.2	6.7	4.7	2.2	0.8	2.5	10.9
23-8525	47.0	14.0	10.9	6.8	4.8	2.1	0.9	2.8	10.6

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8216

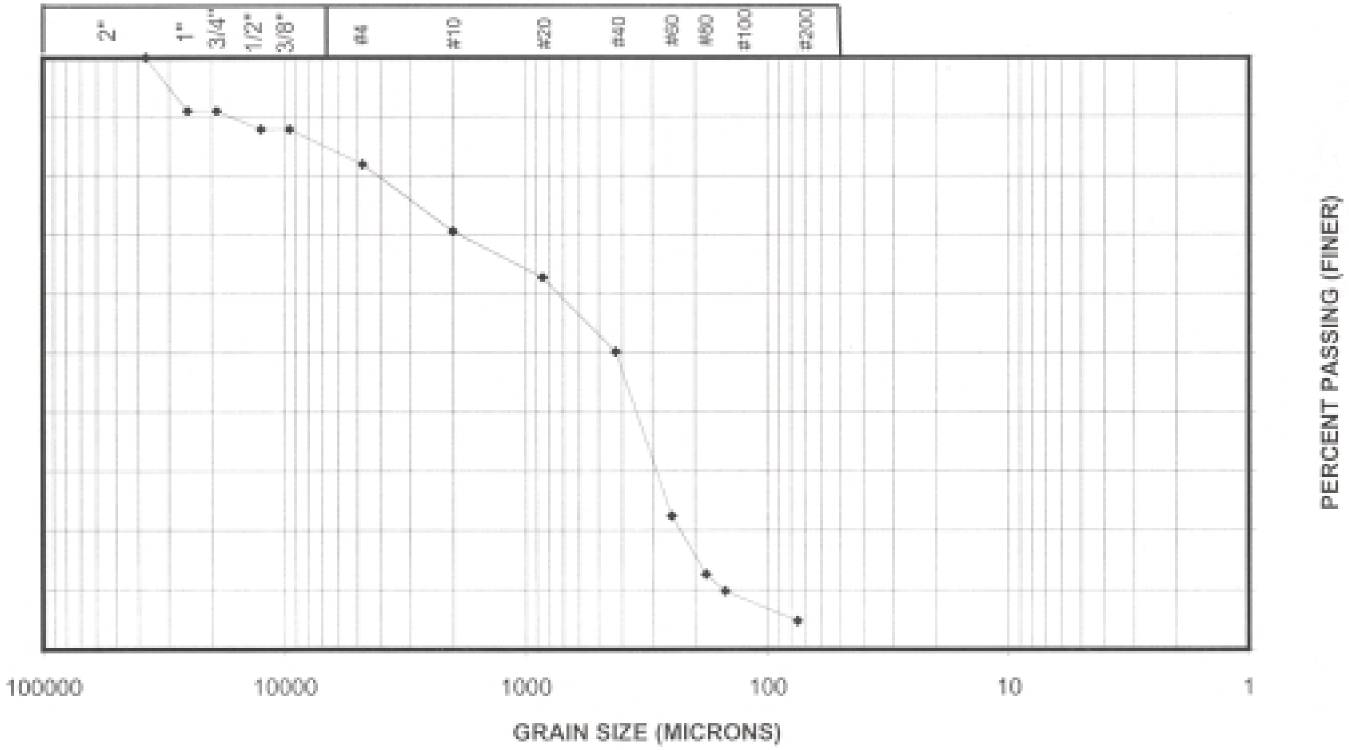


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8219

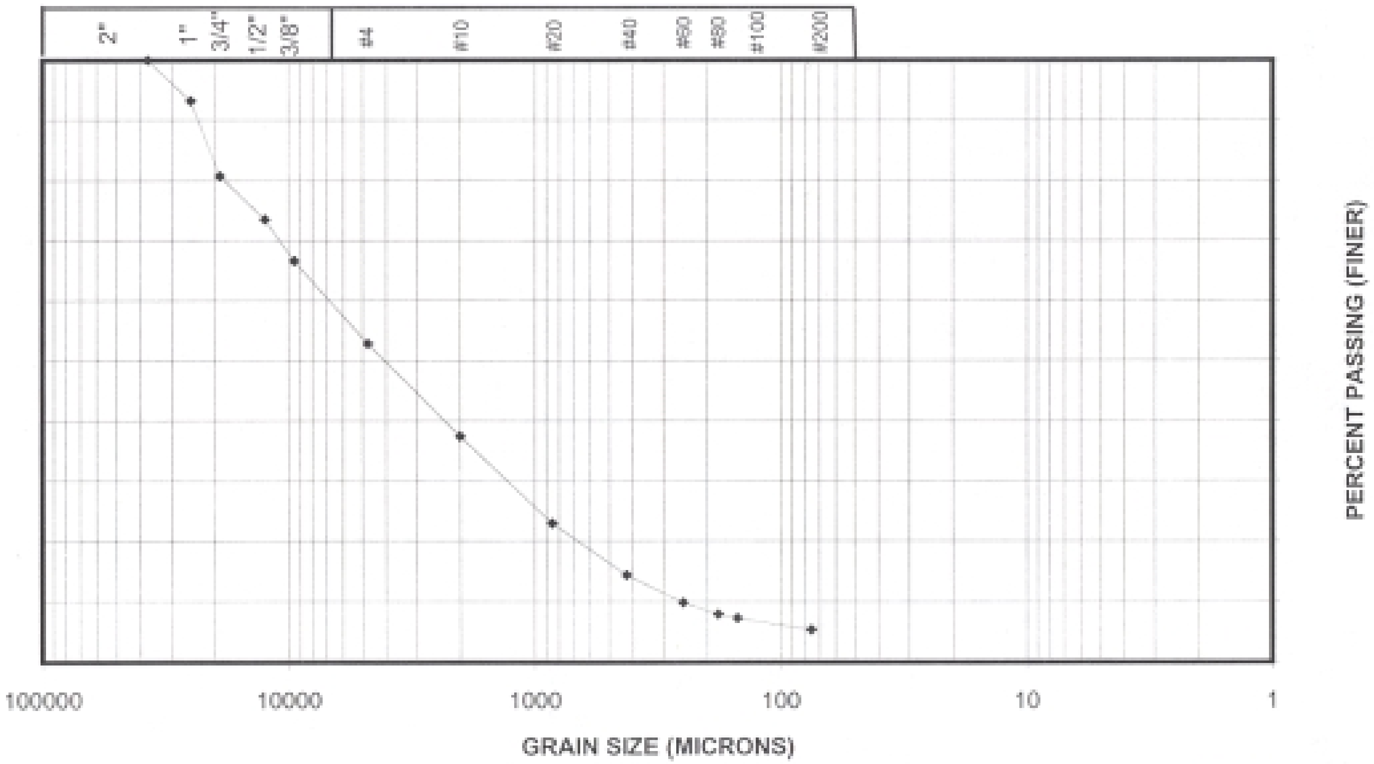


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8205

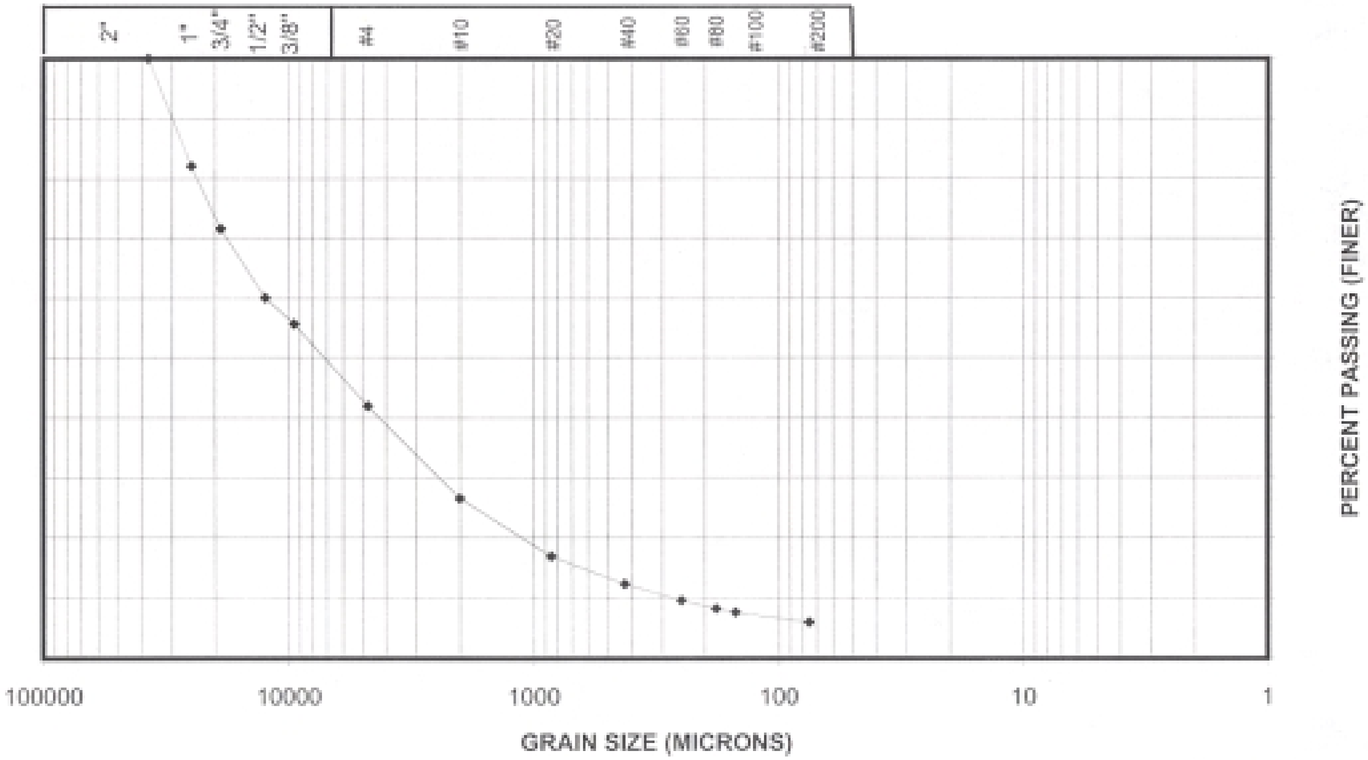


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8206

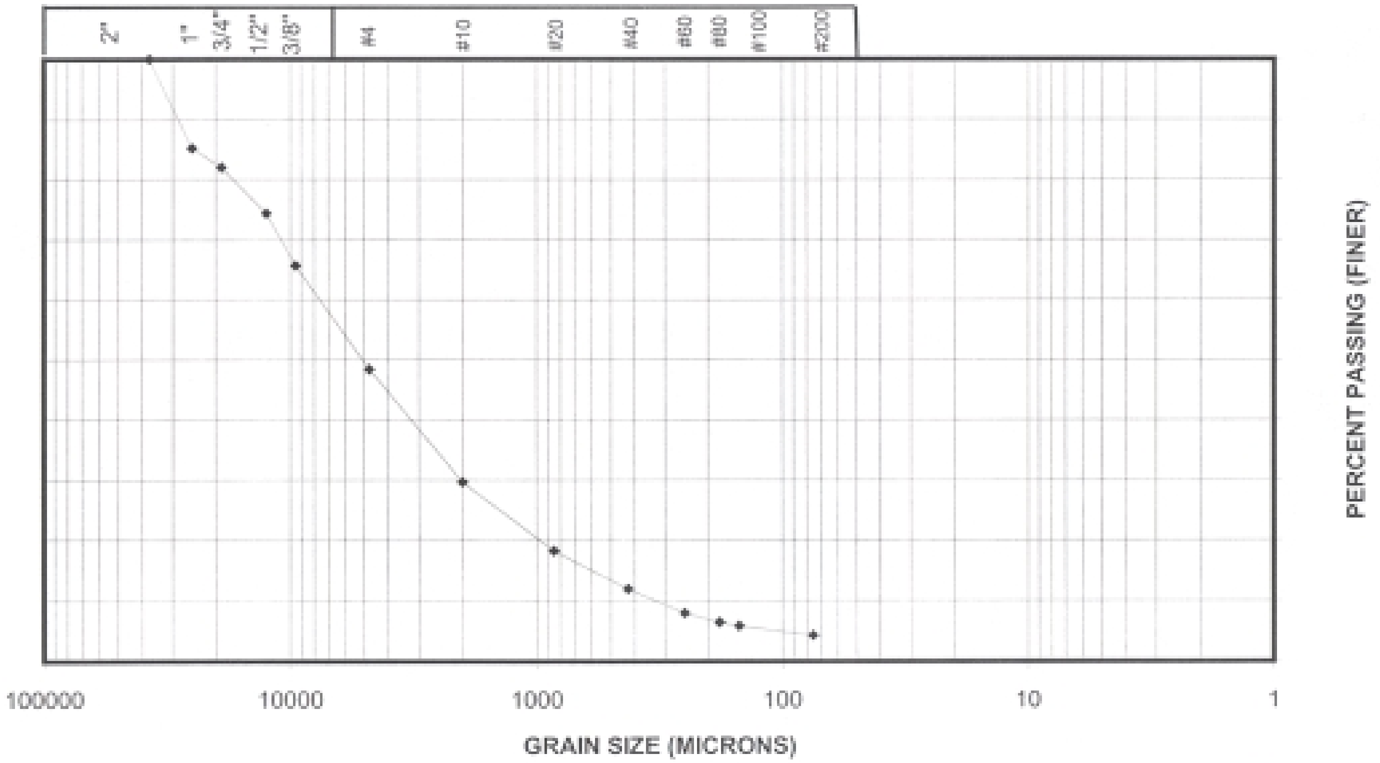


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8207

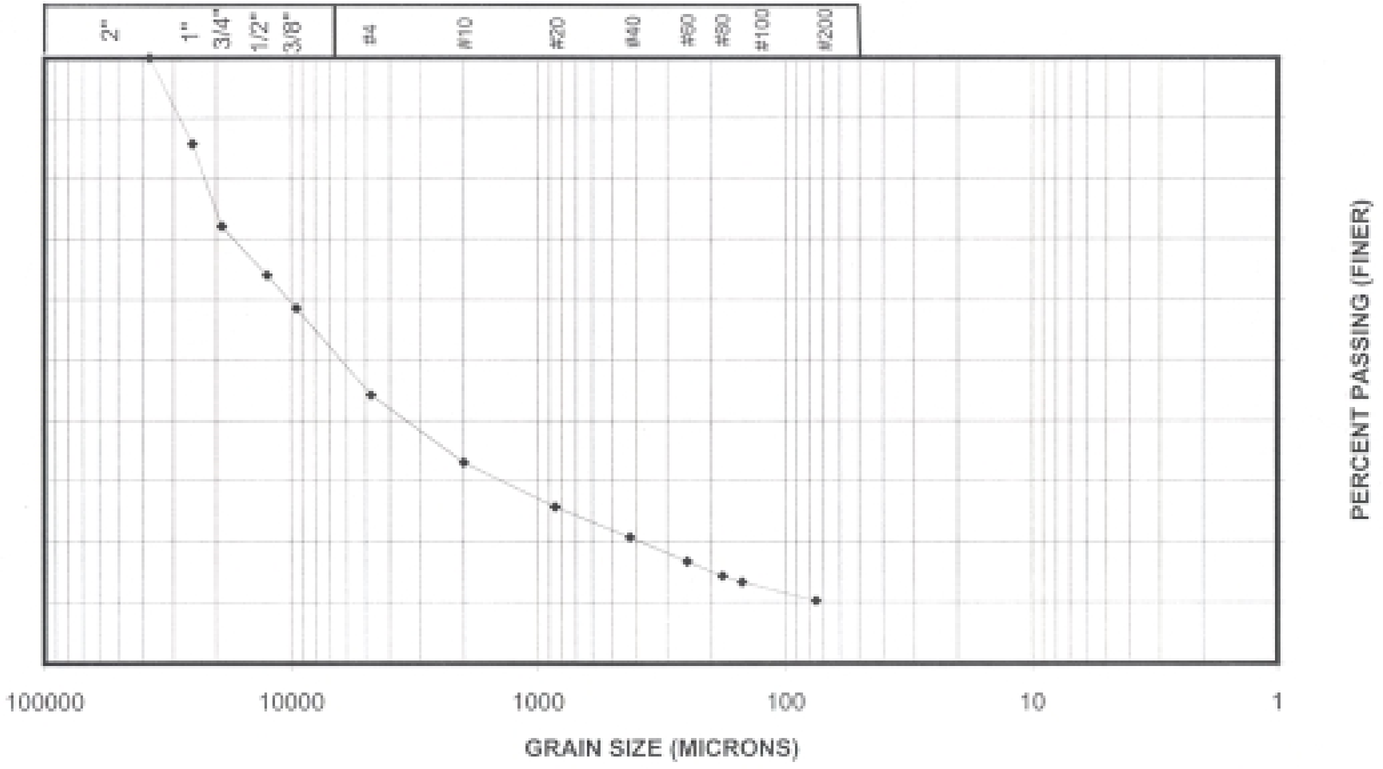


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8210

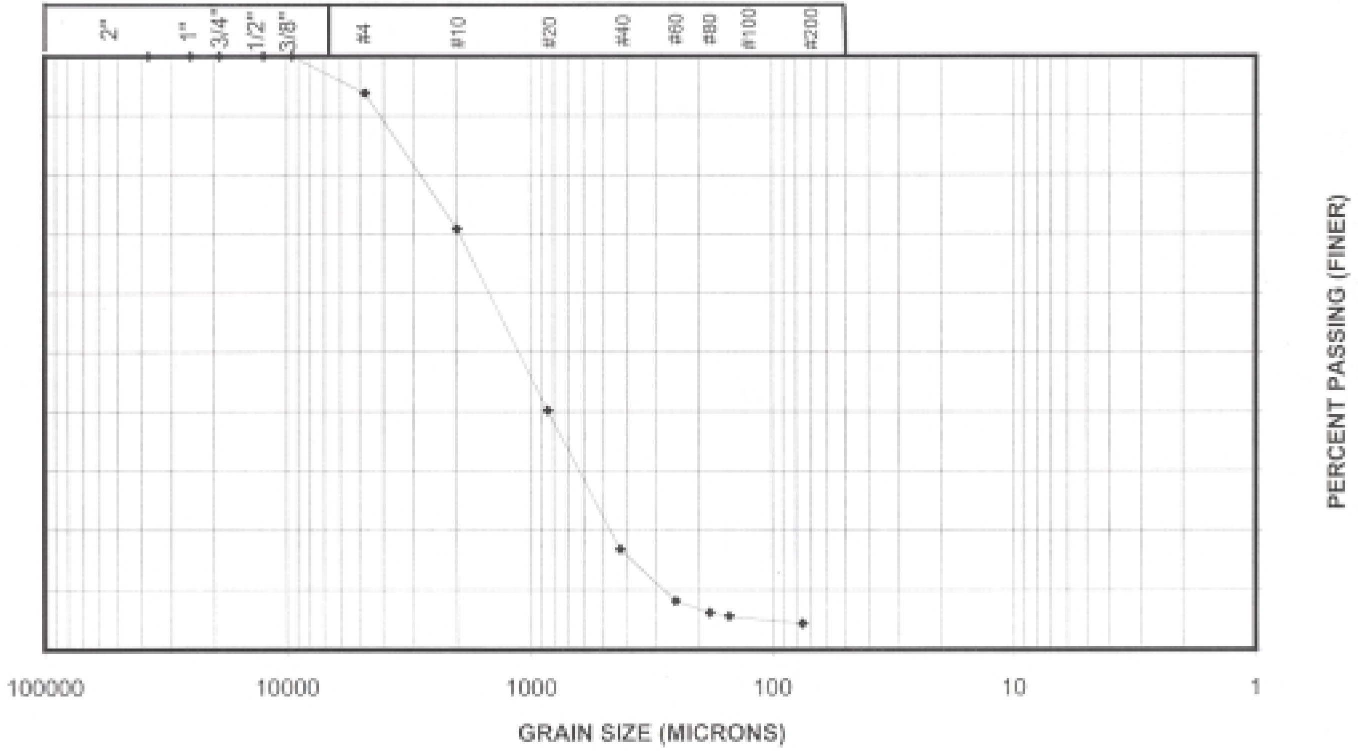


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8213

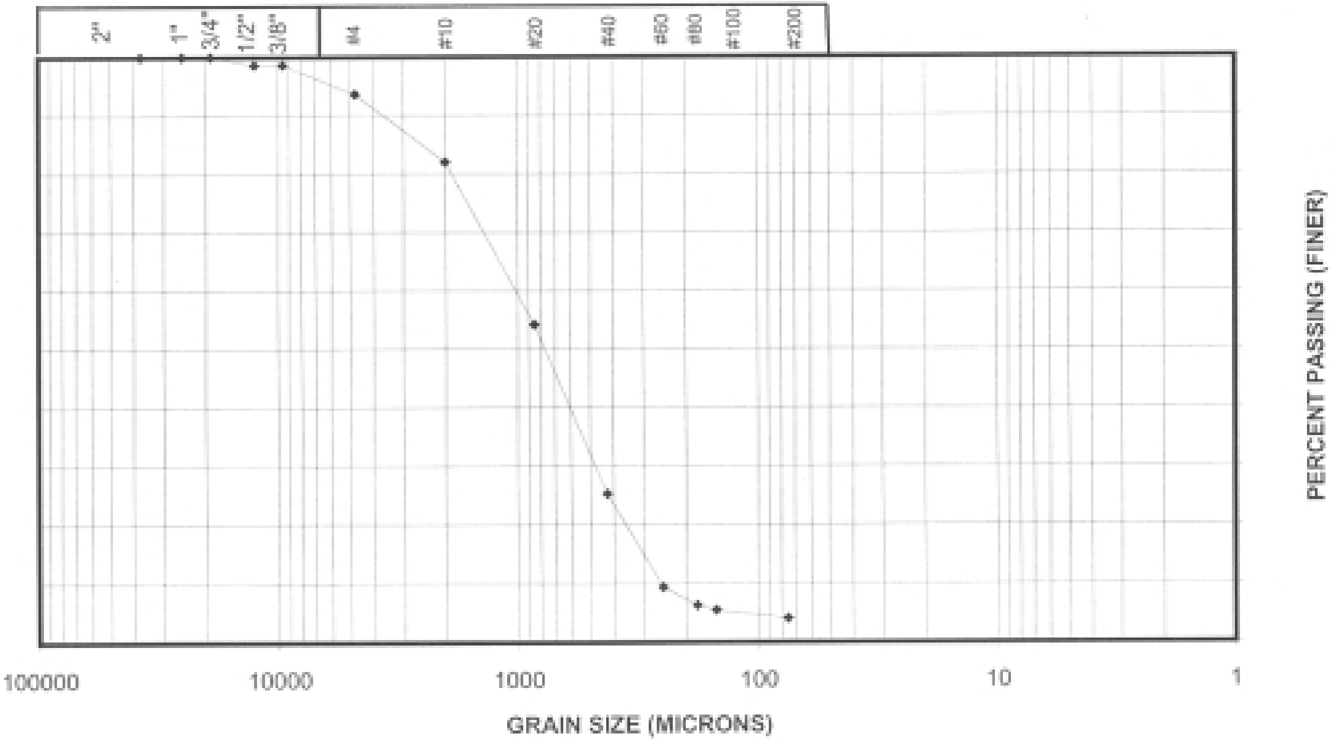


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8214

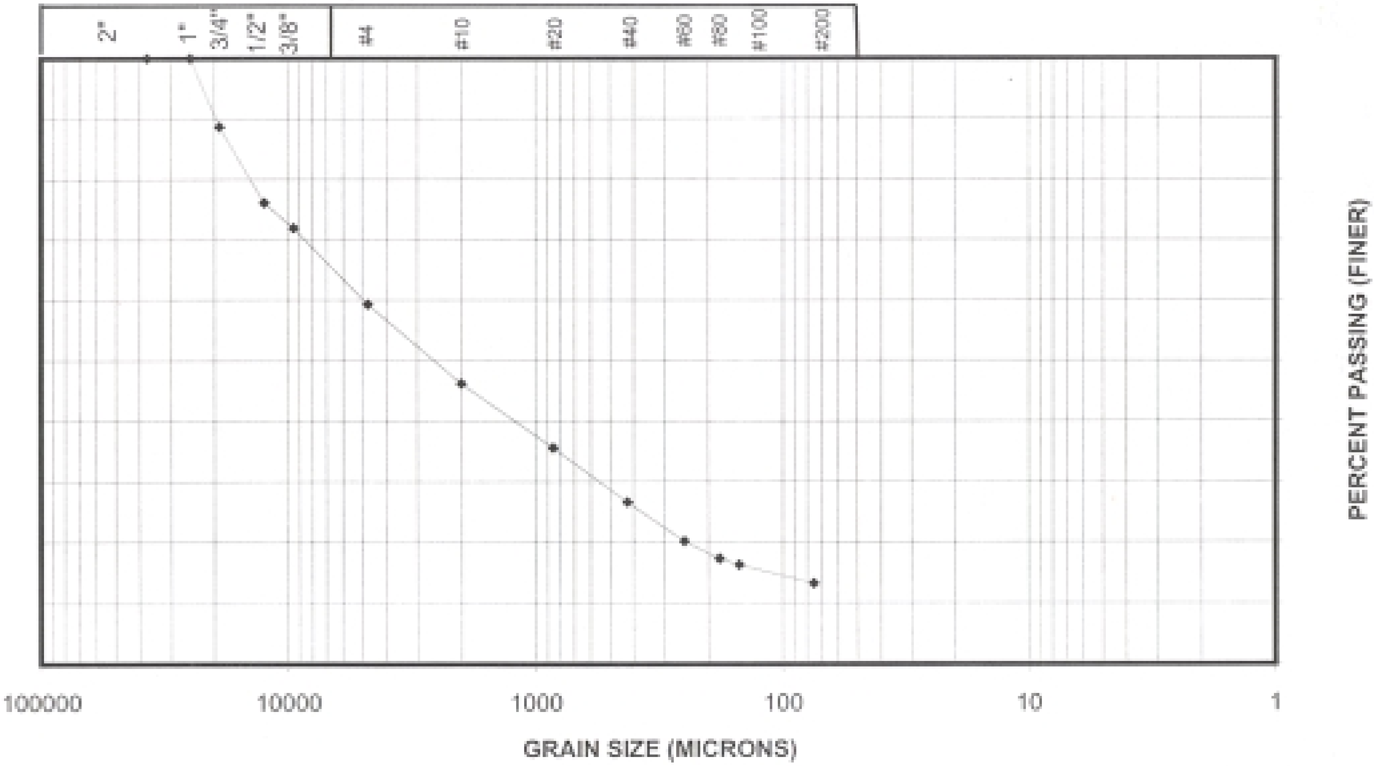


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8215

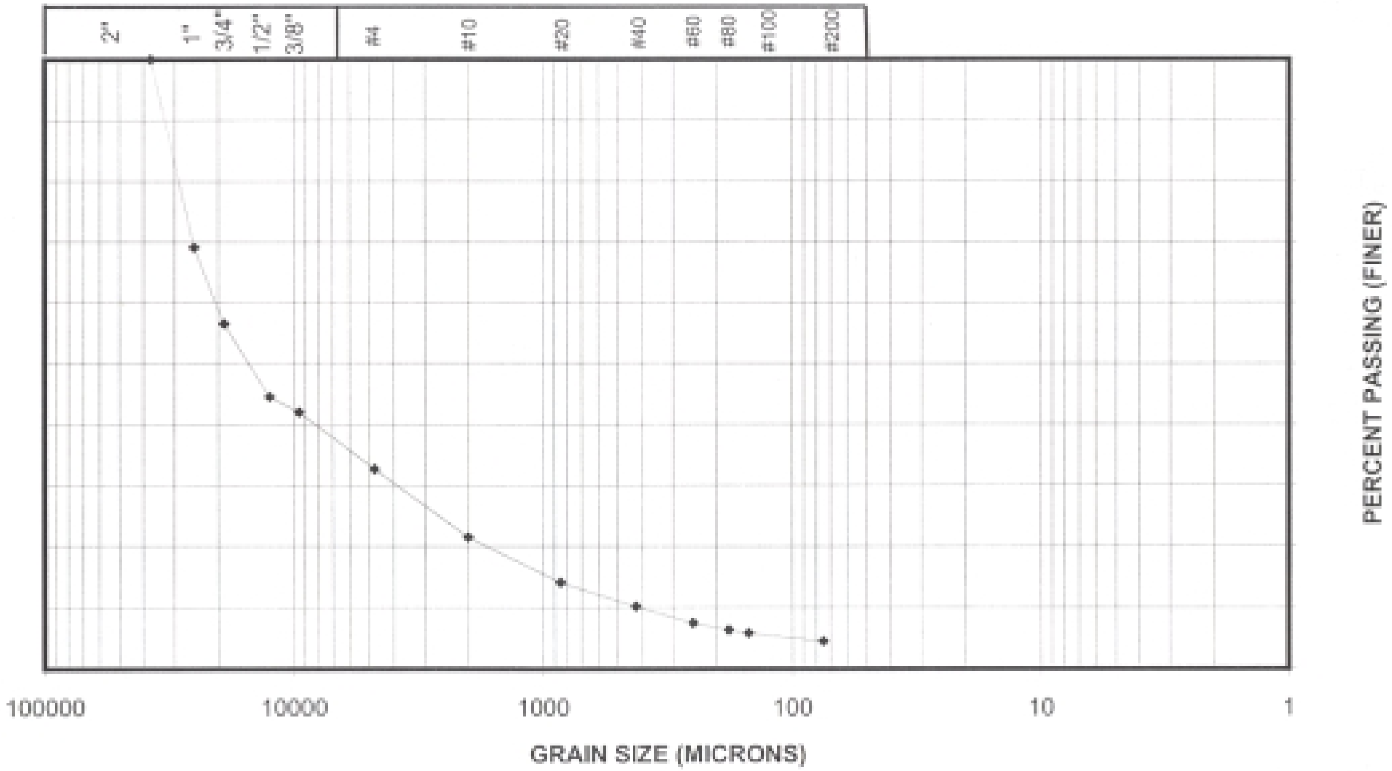


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8216

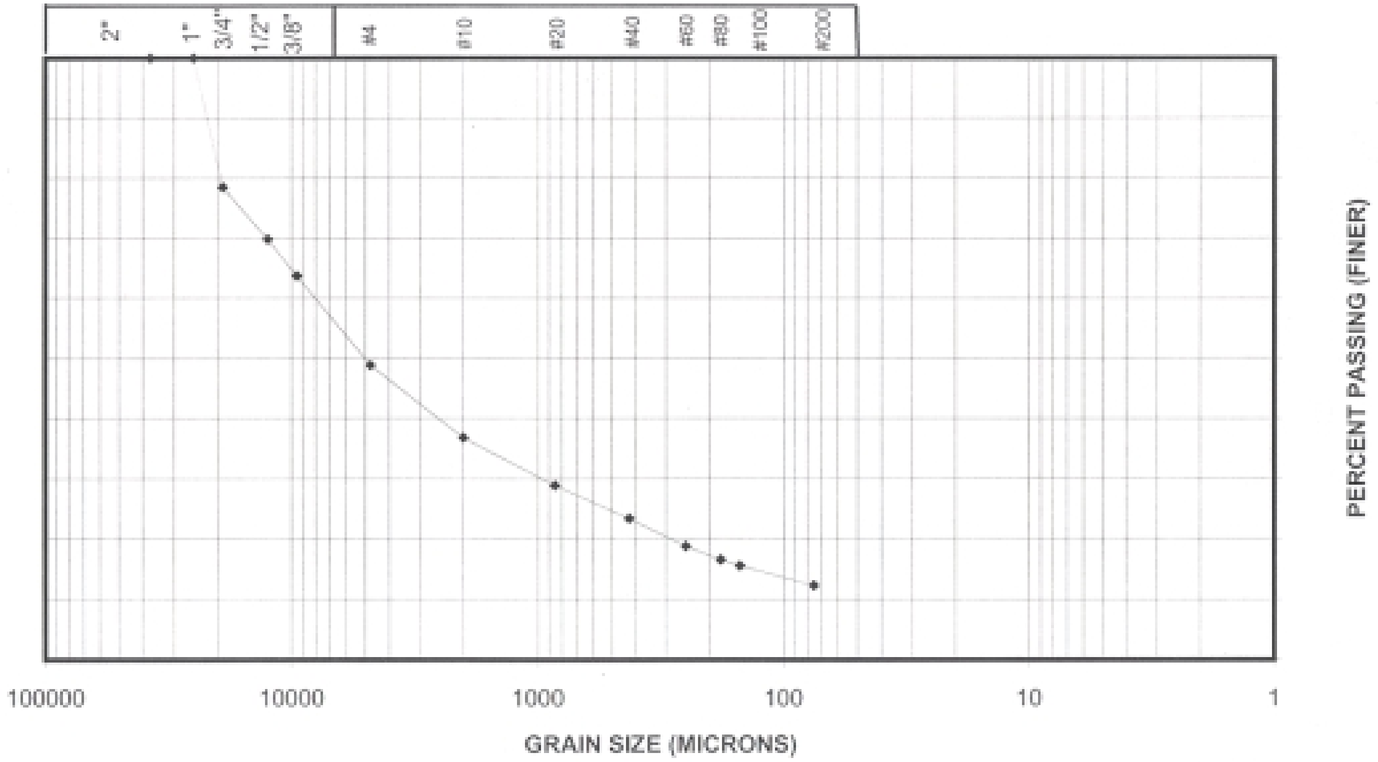


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8217

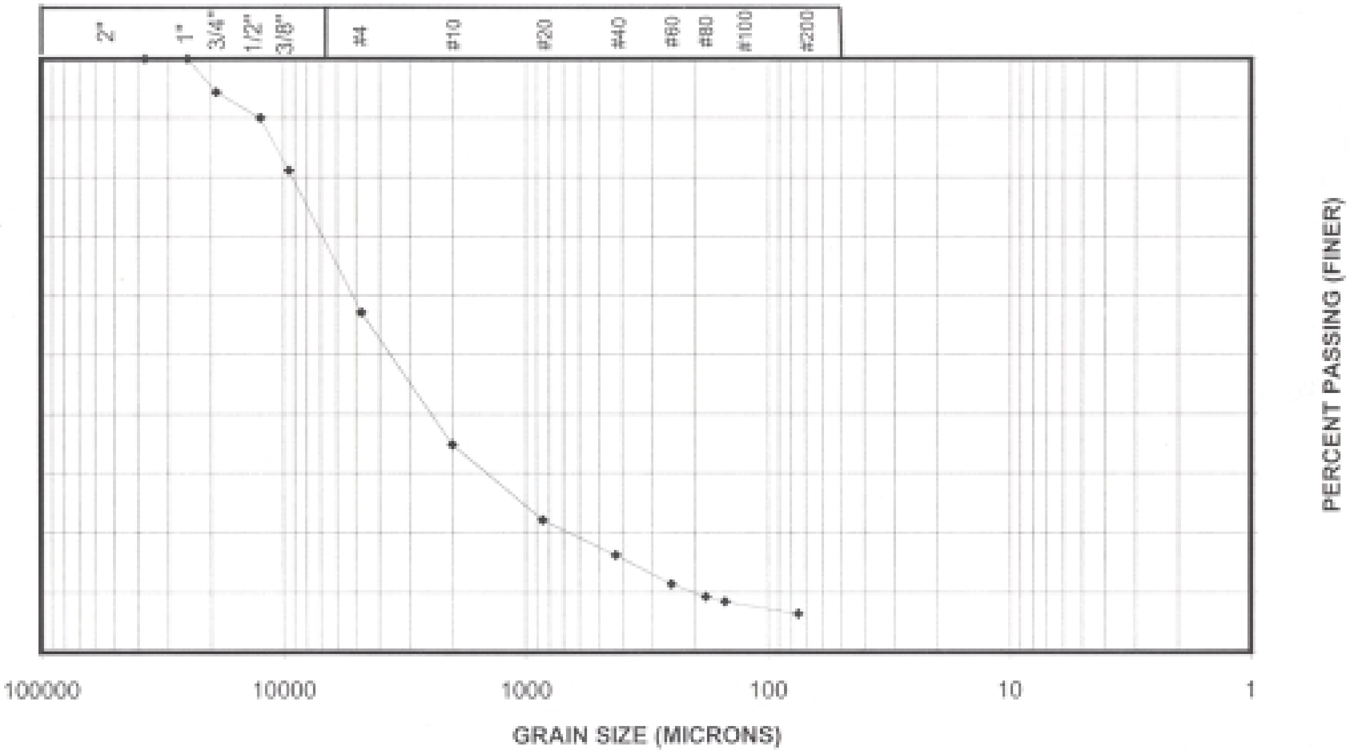


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8218

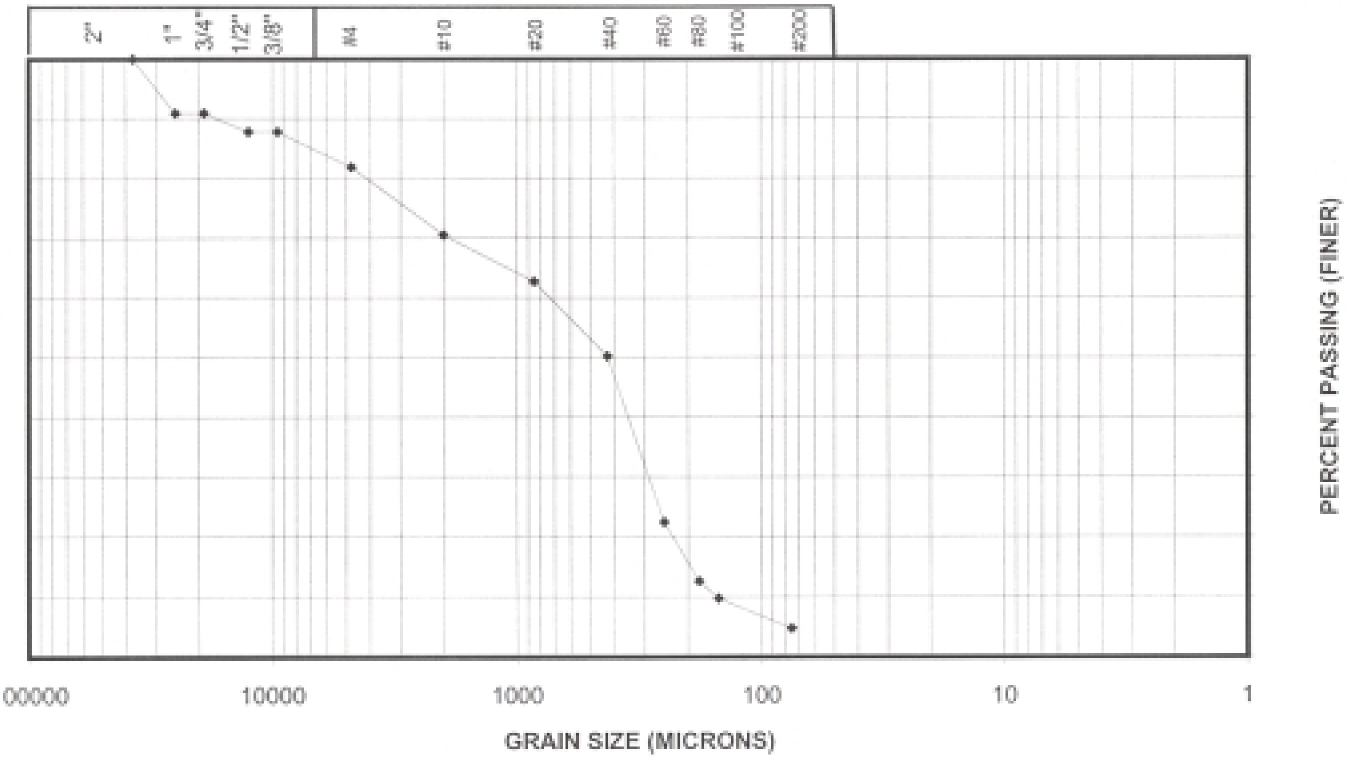


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8219

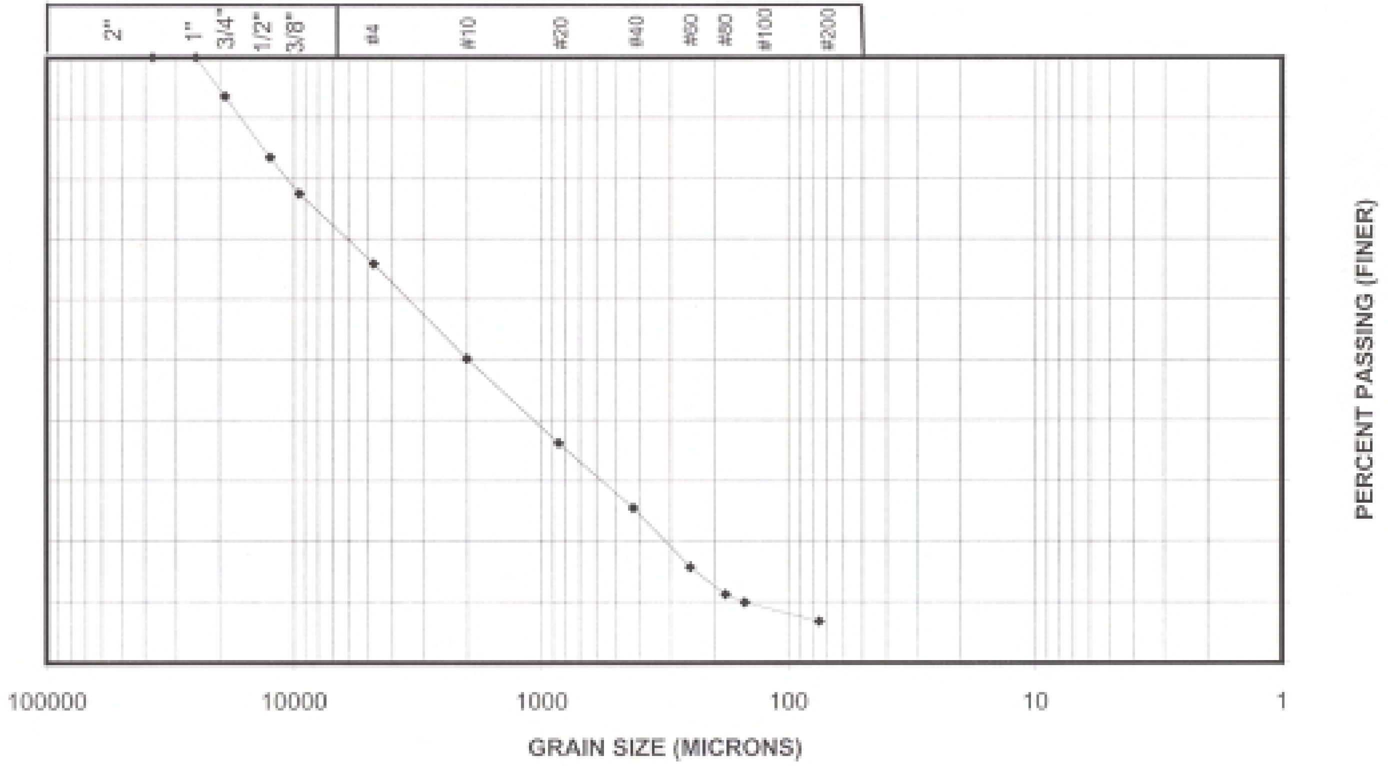


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8220

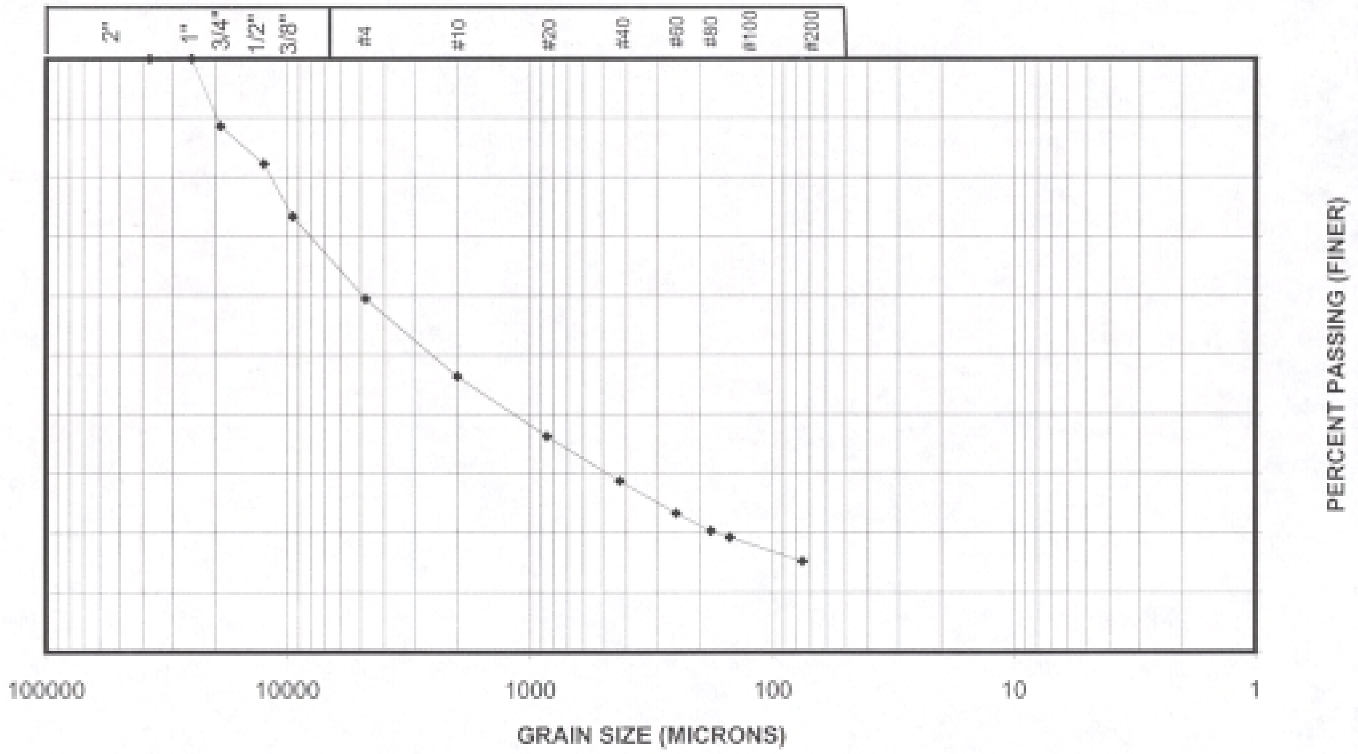


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8221

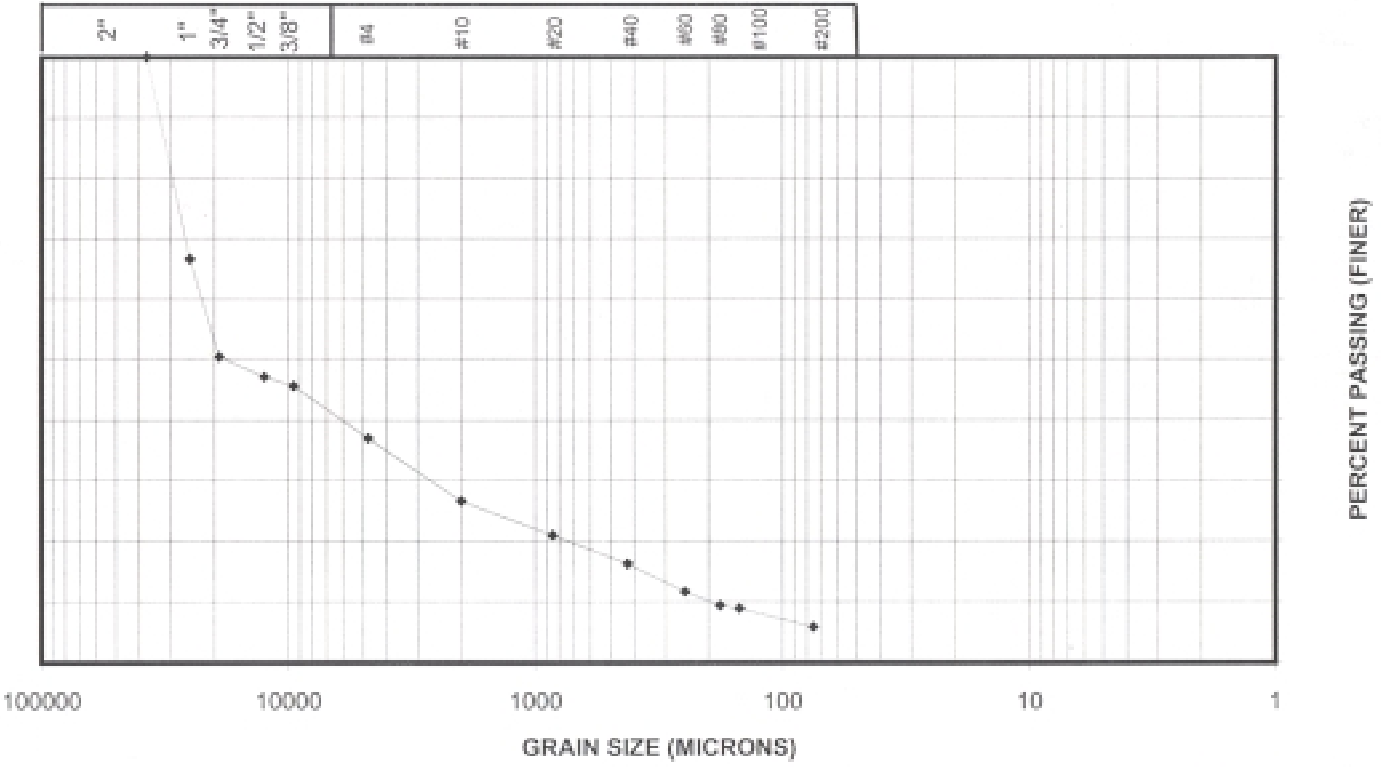


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8222

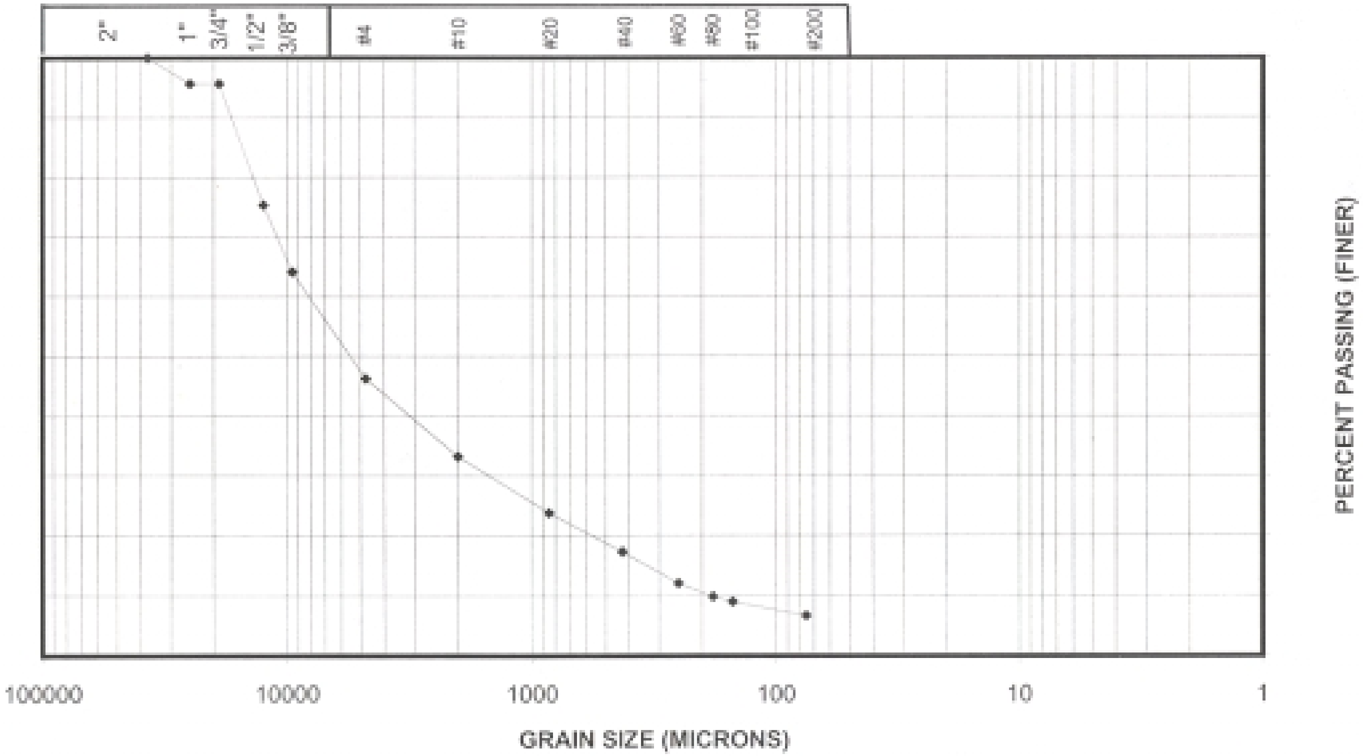


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8223

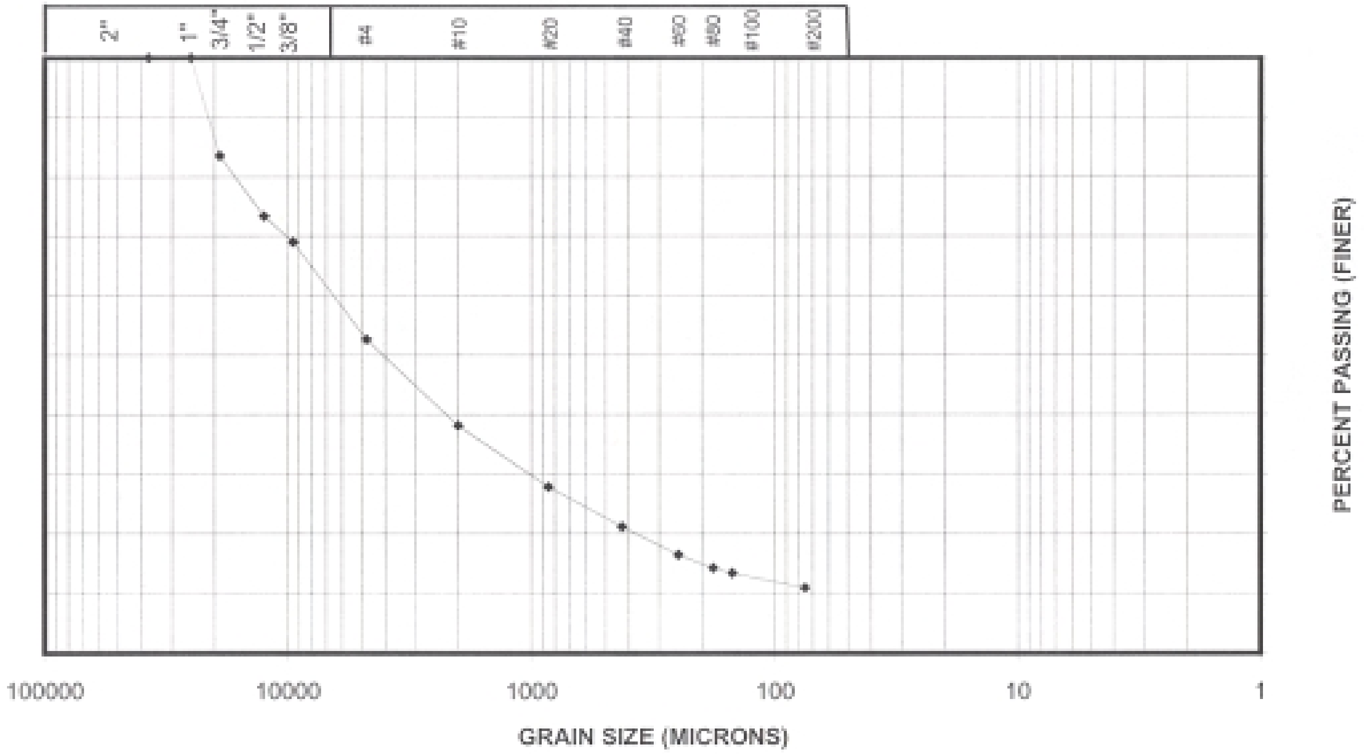


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8224

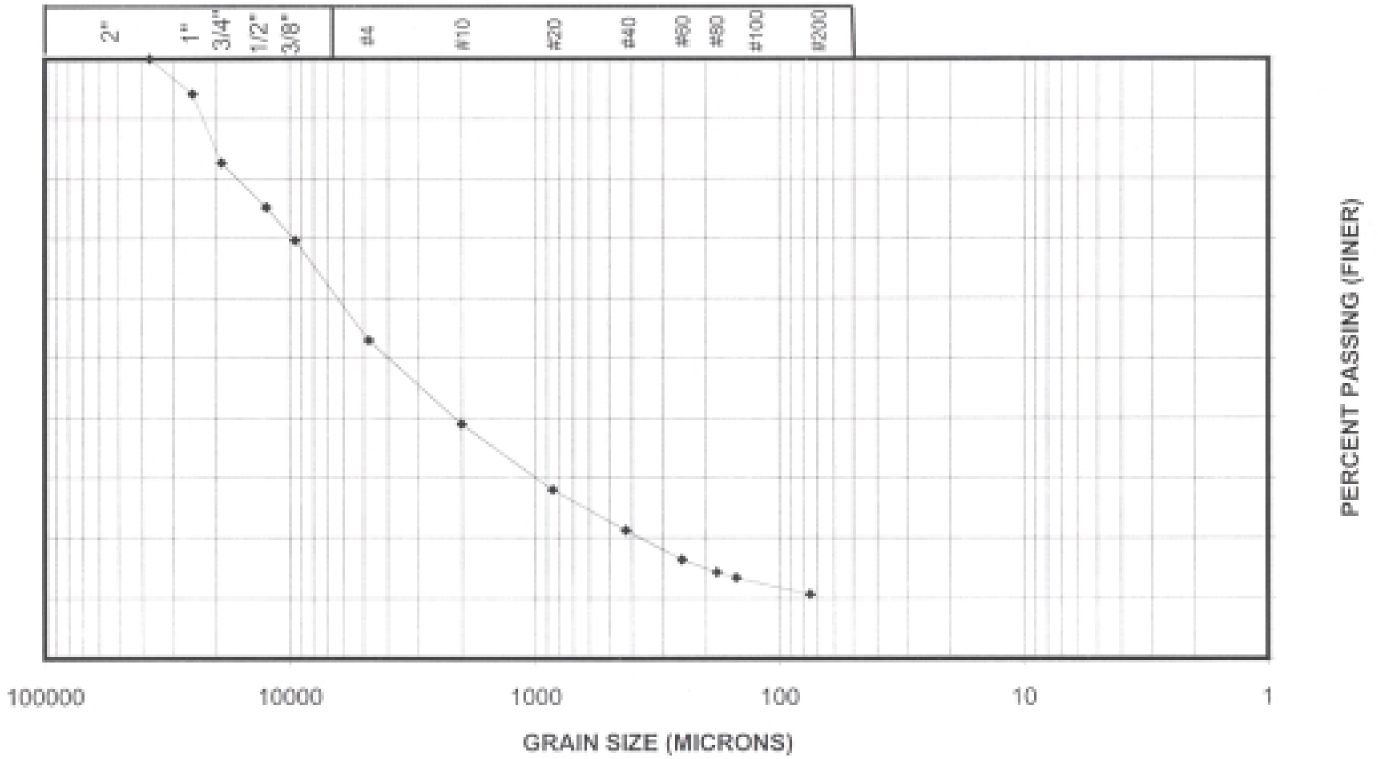


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 23-8225

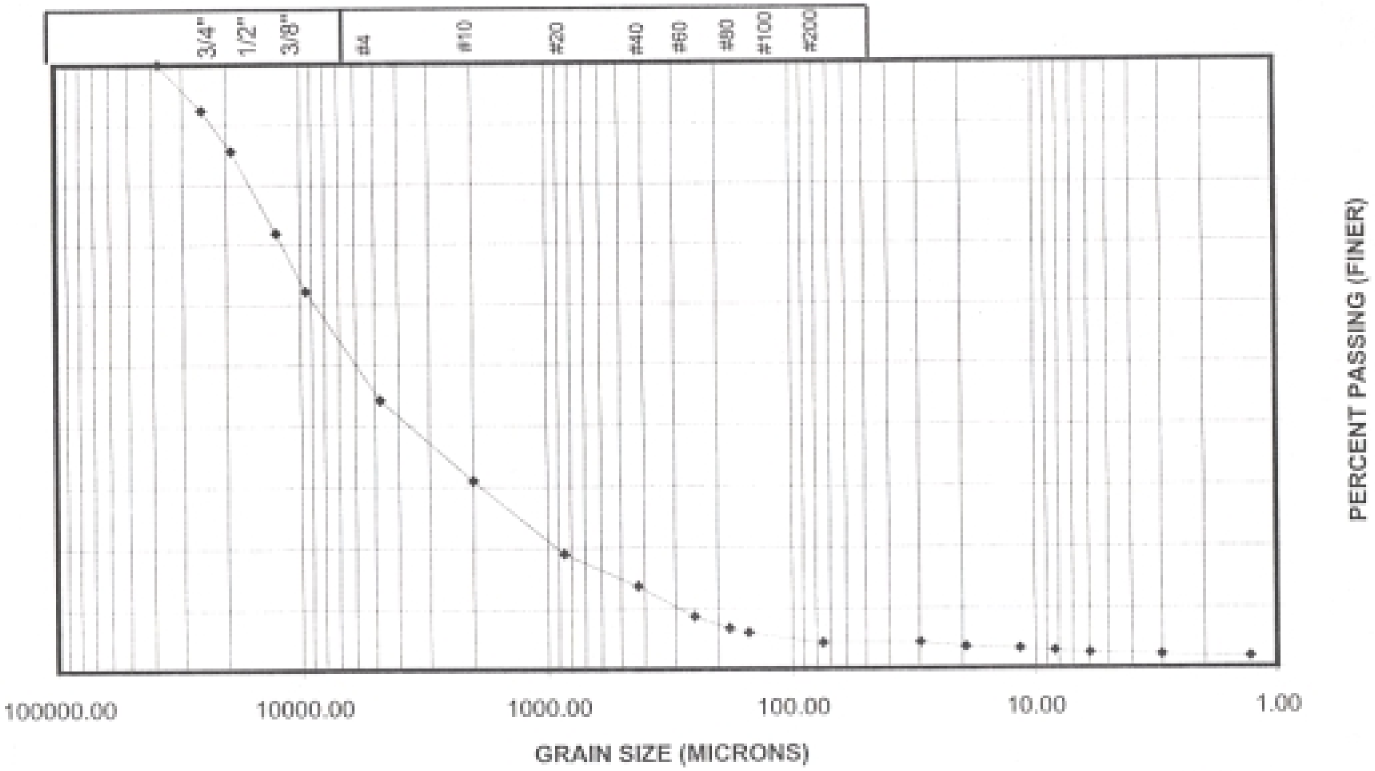


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY

ASTM D-422 GRAIN SIZE DISTRIBUTION

WDOE Skokomish Study
Sample No.: 23-8508

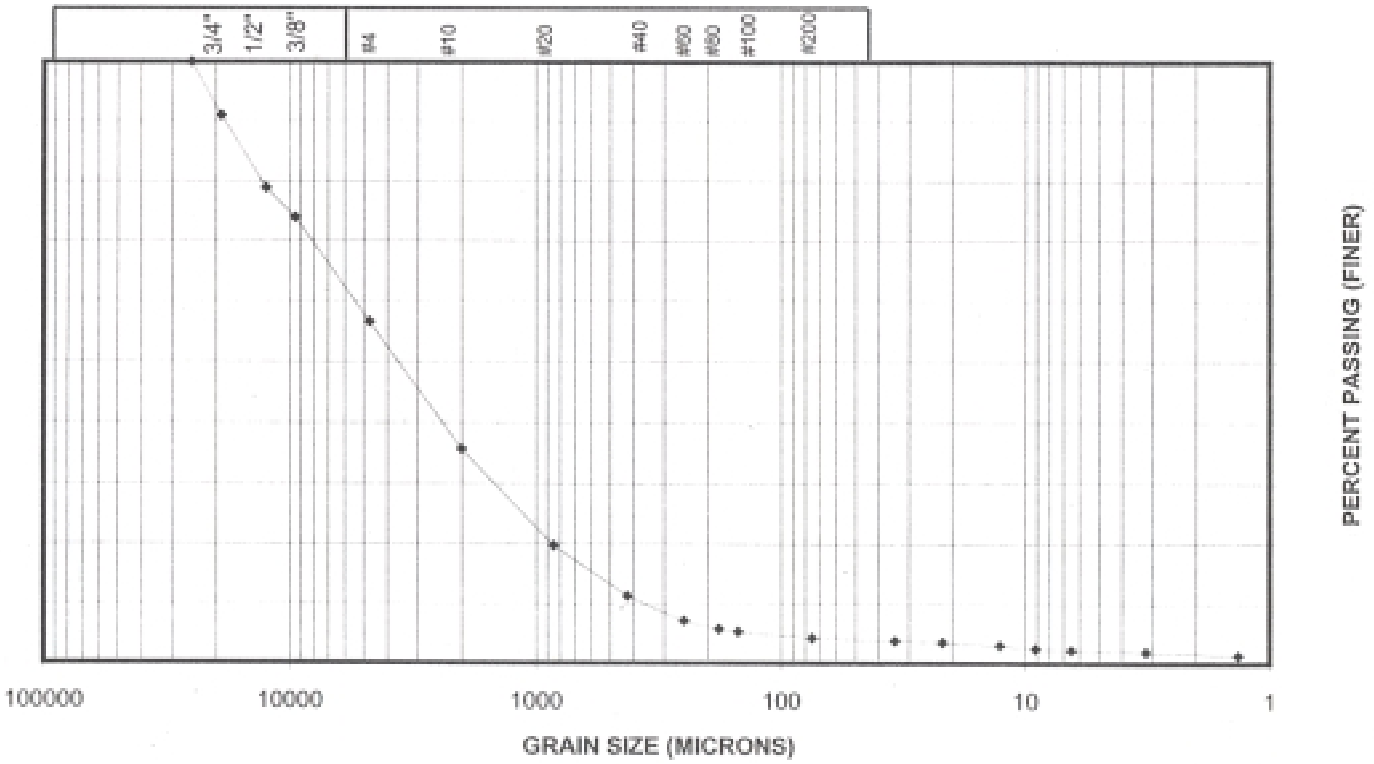


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY

ASTM D-422 GRAIN SIZE DISTRIBUTION

WDOE Skokomish Study
Sample No.: 23-8509

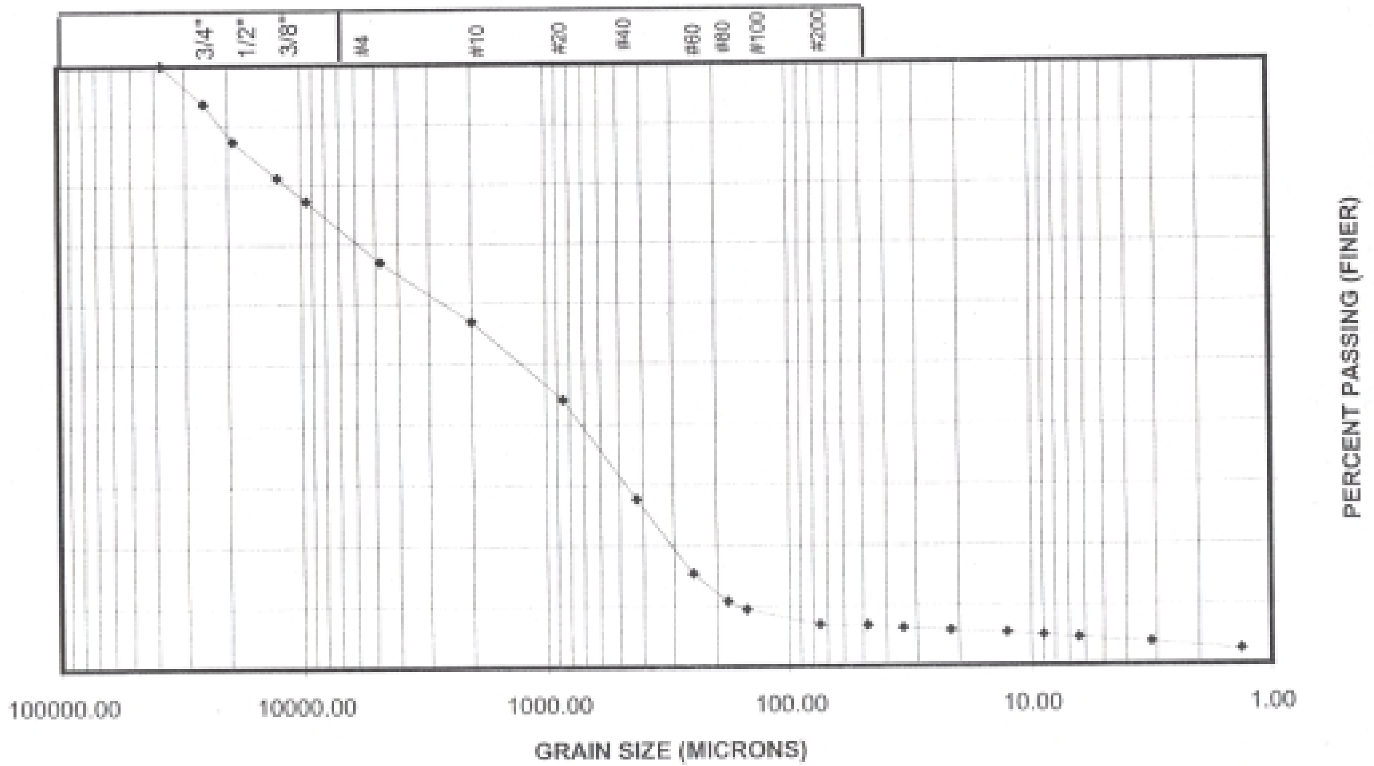


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY

ASTM D-422 GRAIN SIZE DISTRIBUTION

WDOE Skokomish Study
Sample No.: 23-8511

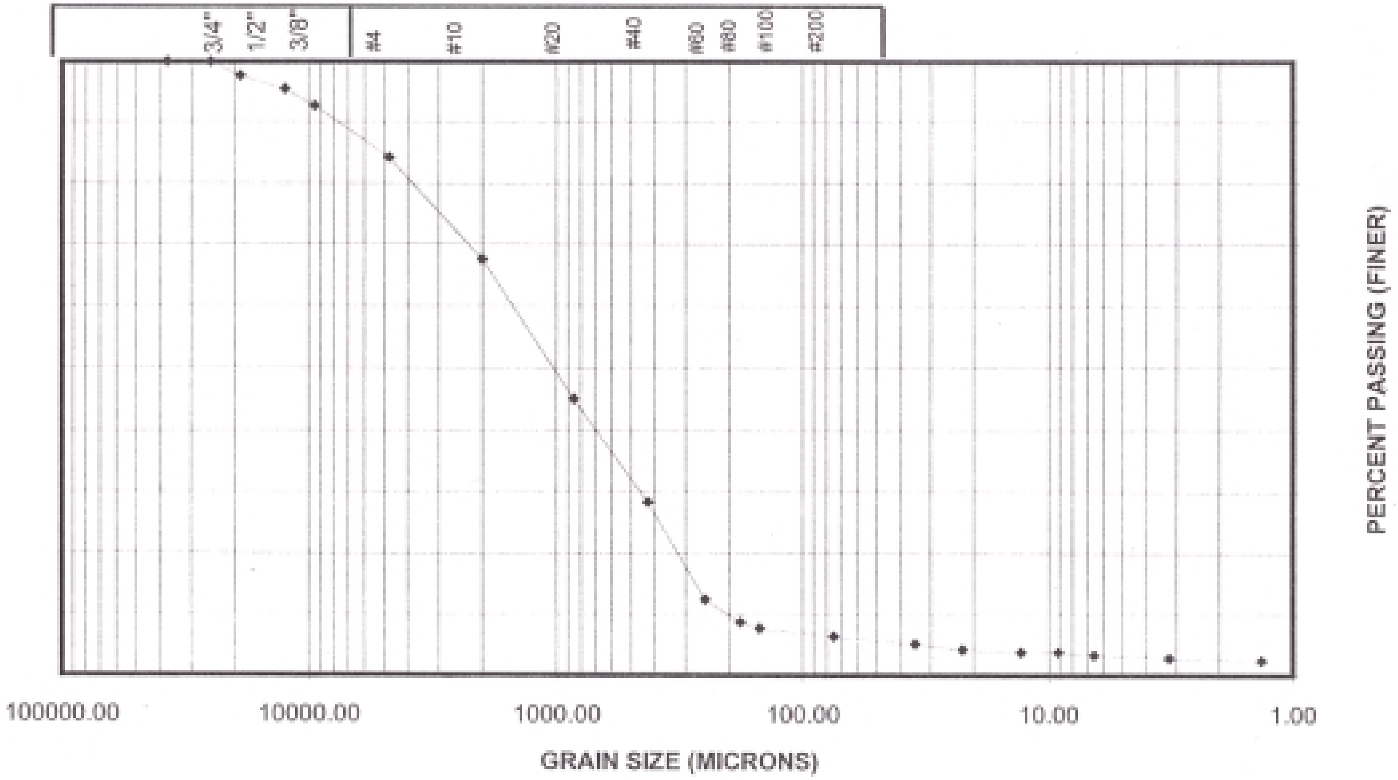


1004-023

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY

ASTM D-422 GRAIN SIZE DISTRIBUTION

WDOE Skokomish Study
Sample No.: 23-8512



1004-023

State of Washington Department of Ecology
Manchester Environmental Laboratory
7411 Beach Dr. East Port Orchard WA. 98366

September 23, 1999

Project: Skokomish Hydrogeology Study

Samples: 34-8180-99

Laboratory: Rosa Environmental

By: Pam Covey

Case Summary

Sixteen (16) sediment samples required Grain Size analyses using ASTM-D422 method sieve only and four samples required further hydrometer analysis. The samples were received at the Manchester Environmental Laboratory on August 25, 1999 and transported to the contract lab on August 27, 1999 for Grain Size analyses.

The analyses were reviewed for qualitative and quantitative accuracy, validity and usefulness. The results are acceptable for use as reported.

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

815 Harrison Street, #100
Seattle, WA 98109-5187
(206) 287-9122

Client: WDOE, Manchester Laboratory	REGL Project No.: 1004-026
Client Project No.: Skokomish River Study	Sample Batch Nos.: 1004-026

Case Narrative

1. Samples were received on August 27, 1999, and were in good condition.
2. Each sieve sample was placed in a pan, oven dried, washed over the #200 sieve, dried again, and shaken in a sieve shaker. The data is reported on the attached tables. One table shows the accumulative percent passing, and the other shows the amount retained in each sieve size. Also, plots of the cumulative percent passing are provided.
3. Many of the samples were quite gravely. This was sieved separately, and the results were combined with the analysis of the fine portion, as shown on the data sheets.
4. The hydrometer samples were set up on August 30, 1999, and were run on September 2-3 , 1999. Following the hydrometer test, the samples were washed over a #200 sieve, oven dried and sieved. The data is reported on the attached tables and plots.
5. With samples 34-8197 and 34-8198, we had a slight mismatch between the sieve portion of the analysis and the hydrometer portion. A separate 200 wash was run on these samples to verify the percentage passing the #200 sieve. The #200 wash confirmed the hydrometer data, and the total sample weight was adjusted to lower the sieve data to match the hydrometer portion into a smooth curve. This mismatch may be due to the large amounts of gravel in the sample making the split for the hydrometer analysis (on material passing a #10 sieve) difficult, a difference in the specific gravity between the coarse and fine material, or to an error in recording the initial wet weight of the total hydrometer sample.
6. Copies of the computer entry sheets are provided as requested.
7. There were no other anomalies to the samples or the testing.

Approved by: ______________ Date: 9/9/99
Title: Laboratory Manager

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project

Percent Finer Than Indicated Size

Sample No.	Gravel					Coarse Sand		Medium Sand				Fine Sand	
Sieve Size (microns)	1.5"	1"	3/4"	1/2"	3/8"	#4	#10 (2000)	#20 (850)	#40 (425)	#60 (250)	#80 (180)	#100 (125)	#200 (75)
34-8180	100.0	54.9	54.9	36.9	29.2	21.3	14.4	9.7	6.5	4.3	3.6	3.4	2.8
34-8181	100.0	89.6	84.0	79.3	57.4	47.1	35.0	26.5	21.2	17.5	15.9	15.4	13.9
34-8184	100.0	100.0	100.0	97.8	94.4	88.9	80.6	71.6	58.7	30.5	18.5	15.7	11.0
34-8185	100.0	100.0	94.4	89.2	72.9	62.7	51.4	41.8	18.7	8.1	6.2	5.6	4.0
34-8186	100.0	100.0	100.0	99.4	98.8	98.3	98.0	97.3	89.7	42.3	17.9	12.5	5.1
34-8187	100.0	100.0	100.0	100.0	100.0	99.8	98.6	95.4	84.2	40.6	10.9	6.3	1.9
34-8188	100.0	91.3	89.0	83.0	67.9	61.1	51.0	32.0	17.2	9.8	8.1	7.7	7.1
34-8189	100.0	56.4	47.5	36.9	31.9	20.5	13.3	9.0	5.6	3.0	2.1	1.8	1.1
34-8190	100.0	88.8	78.5	63.8	53.6	29.9	17.7	10.9	6.2	2.9	1.8	1.5	0.9
34-8191	100.0	81.7	72.8	60.0	54.1	36.4	22.1	11.7	6.0	3.2	2.4	2.2	1.7
34-8192	100.0	96.6	92.5	85.9	70.3	61.8	54.4	48.4	42.7	33.6	25.8	21.5	10.8
34-8193	100.0	53.3	50.3	40.3	38.1	31.0	24.6	20.1	16.6	12.9	10.3	9.1	6.0
34-8194	100.0	79.7	75.8	67.9	62.4	46.0	31.5	20.5	12.7	7.3	5.4	4.7	3.3
34-8195	100.0	92.0	82.9	72.6	66.9	46.0	33.5	24.7	17.6	12.7	11.0	10.3	8.1
34-8196	100.0	77.8	73.7	66.4	62.9	52.6	44.3	38.4	33.4	26.2	20.1	17.2	9.0
34-8199	100.0	84.2	80.2	69.0	59.2	37.1	24.2	17.7	13.2	9.1	7.1	6.3	4.4

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project
Grain Size Distribution, Percent Retained in Each Size Fraction

Size (microns)	> 4750	4750-2000	2000-850	850-425	425-250	250-180	180-125	125-75	<75
34-8180	78.7	6.9	4.7	3.2	2.2	0.7	0.2	0.6	2.8
34-8181	52.9	12.1	8.5	5.3	3.7	1.5	0.6	1.4	13.9
34-8184	11.1	8.3	9.0	12.9	28.2	11.9	2.8	4.7	11.0
34-8185	37.3	11.3	9.6	23.2	10.5	1.9	0.6	1.5	4.0
34-8186	1.7	0.3	0.7	7.6	47.5	24.3	5.4	7.4	5.1
34-8187	0.2	1.2	3.2	11.2	43.5	29.7	4.6	4.4	1.9
34-8188	38.9	10.1	19.0	14.8	7.4	1.6	0.4	0.7	7.1
34-8189	79.5	7.2	4.3	3.4	2.6	0.9	0.3	0.6	1.1
34-8190	70.1	12.2	6.9	4.7	3.3	1.1	0.3	0.6	0.9
34-8191	63.6	14.2	10.4	5.7	2.7	0.8	0.3	0.5	1.7
34-8192	38.2	7.5	6.0	5.6	9.2	7.7	4.4	10.7	10.8
34-8193	69.0	6.4	4.5	3.5	3.7	2.6	1.2	3.1	6.0
34-8194	54.0	14.5	11.0	7.8	5.4	1.9	0.7	1.4	3.3
34-8195	54.0	12.5	8.8	7.1	4.9	1.8	0.7	2.2	8.1
34-8196	47.4	8.3	5.9	5.0	7.2	6.1	2.9	8.1	9.0
34-8199	62.9	12.9	6.6	4.5	4.1	2.0	0.8	1.9	4.4

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project

Percent Finer Than Indicated Size

Sample No.	Gravel					Coarse Sand		Medium Sand				Fine Sand		Silt					Clay	
Sieve Size (microns)	1.5"	1"	3/4"	1/2"	3/8"	#4	#10 (2000)	#20 (850)	#40 (425)	#60 (250)	#80 (180)	#100 (125)	#200 (75)	36	24	14	10	7	3.3	1.4
34-8182	100.0	100.0	100.0	100.0	68.9	49.8	28.5	19.4	15.2	13.0	11.9	11.5	10.5	10.2	9.7	8.3	7.6	6.8	5.4	3.8
34-8183	100.0	100.0	100.0	100.0	87.0	67.1	51.0	43.4	38.1	34.4	32.5	31.7	26.8	19.9	15.9	11.9	10.6	9.3	7.9	4.6
34-8197	100.0	100.0	97.5	93.7	84.8	67.6	36.7	28.4	21.2	15.8	13.2	12.1	9.8	5.3	4.4	3.5	3.5	3.1	2.7	1.8
34-8198	100.0	79.6	73.3	63.8	50.1	40.7	24.3	14.5	7.9	4.7	3.6	3.3	2.6	2.2	2.2	2.2	1.5	1.5	0.9	0.6

Tests conducted according to ASTM D421/D422

Grain Size Distribution, Percent Retained in Each Size Fraction

Size (micrc	> 4750	4750-2000	2000-850	850-425	425-250	250-180	180-125	125-75	75-36	36-24	24-14	14-10	10-7	7-3.3	3.3-1.4	<1.4
34-8182	50.20632	21.24389	9.104525	4.205765	2.246261	1.051441	0.406239	1.051441	0.292019	0.477755	1.433264	0.637006	0.796258	1.433264	1.592515	3.822037
34-8183	32.93586	16.06757	7.580052	5.284684	3.736645	1.868323	0.85409	4.91102	6.911608	3.970029	3.970029	1.323343	1.323343	1.323343	3.308357	4.6317
34-8197	32.39356	30.88696	8.329897	7.224158	5.344403	2.616914	1.068881	2.358909	4.466073	0.88504	0.88504	0	0.44252	0.44252	0.88504	1.77008
34-8198	59.33178	16.35485	9.846866	6.536282	3.197402	1.160119	0.282956	0.452729	0.669459	0	0	0.6193	0	0.6193	0.30965	0.6193

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

WDOE, Manchester Laboratory

Skokomish River Project

Grain Size Distribution, Percent Retained in Each Size Fraction

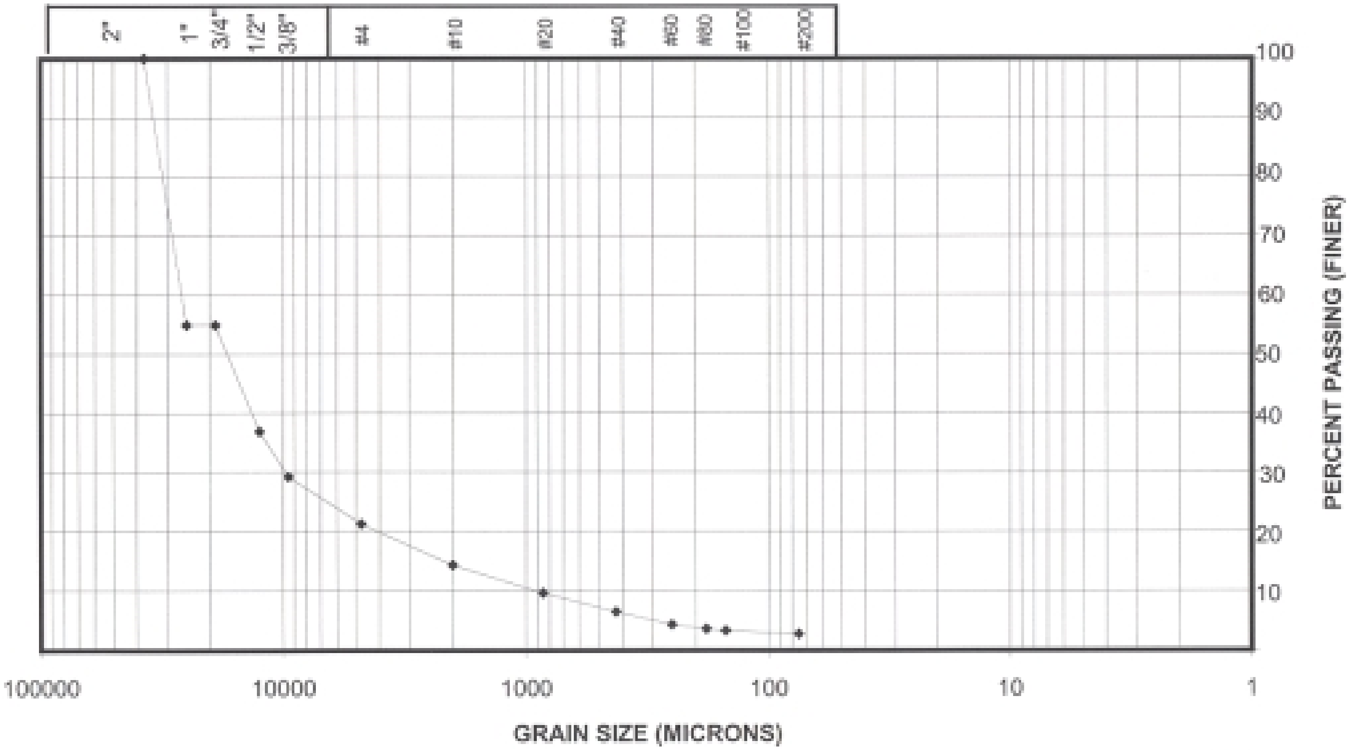
Size (microns)	> 4750	4750-2000	2000-850	850-425	425-250	250-180	180-125	125-75	75-36	36-24	24-14	14-10	10-7	7-3.3	3.3-1.4	<1.4
34-8182	50.2	21.2	9.1	4.2	2.2	1.1	0.4	1.1	0.3	0.5	1.4	0.6	0.8	1.4	1.6	3.8
34-8183	32.9	16.1	7.6	5.3	3.7	1.9	0.9	4.9	26.8	4.0	4.0	1.3	1.3	1.3	3.3	4.6
34-8197	32.4	30.9	8.3	7.2	5.3	2.6	1.1	2.4	9.8	0.9	0.9	0.0	0.4	0.4	0.9	1.8
34-8198	59.3	16.4	9.8	6.5	3.2	1.2	0.3	0.5	2.8	0.0	0.0	0.6	0.0	0.6	0.3	0.6

Tests conducted according to ASTM D421/D422

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8180

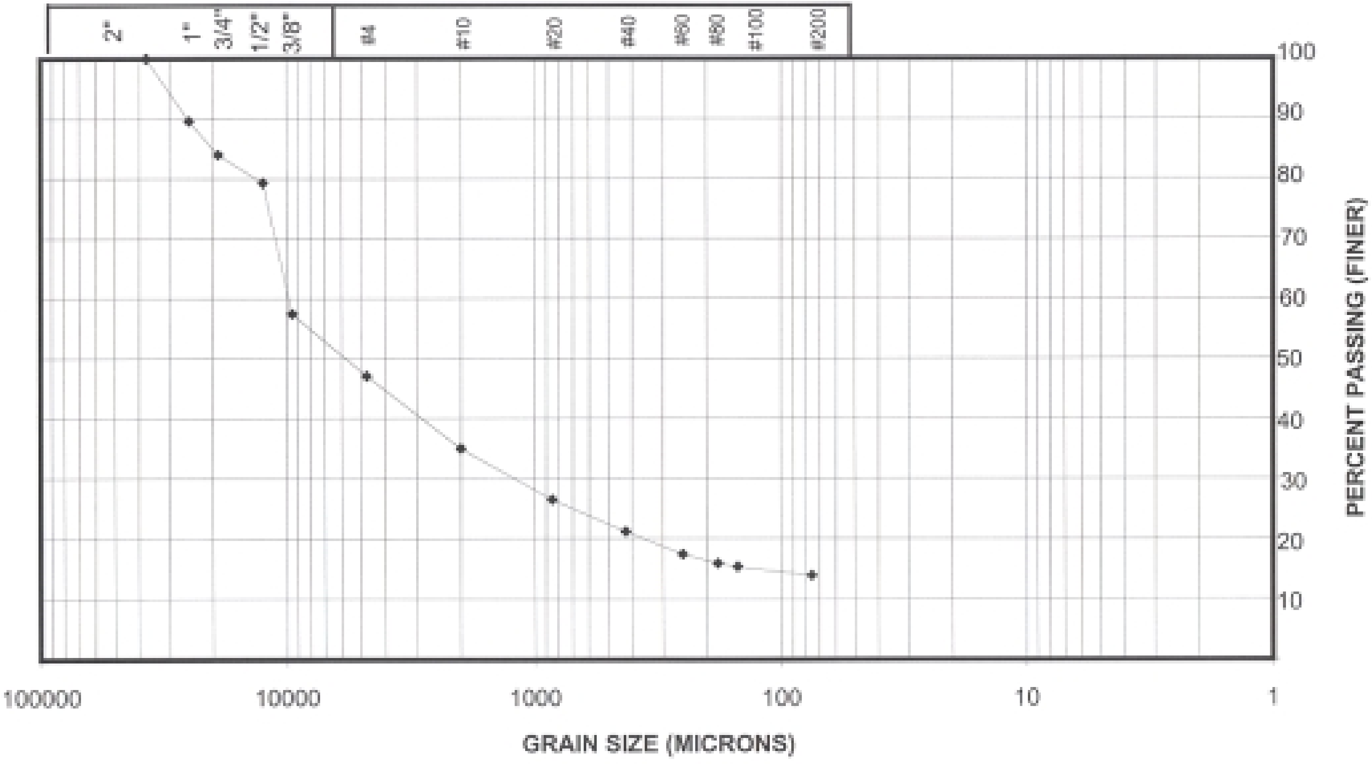


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8181

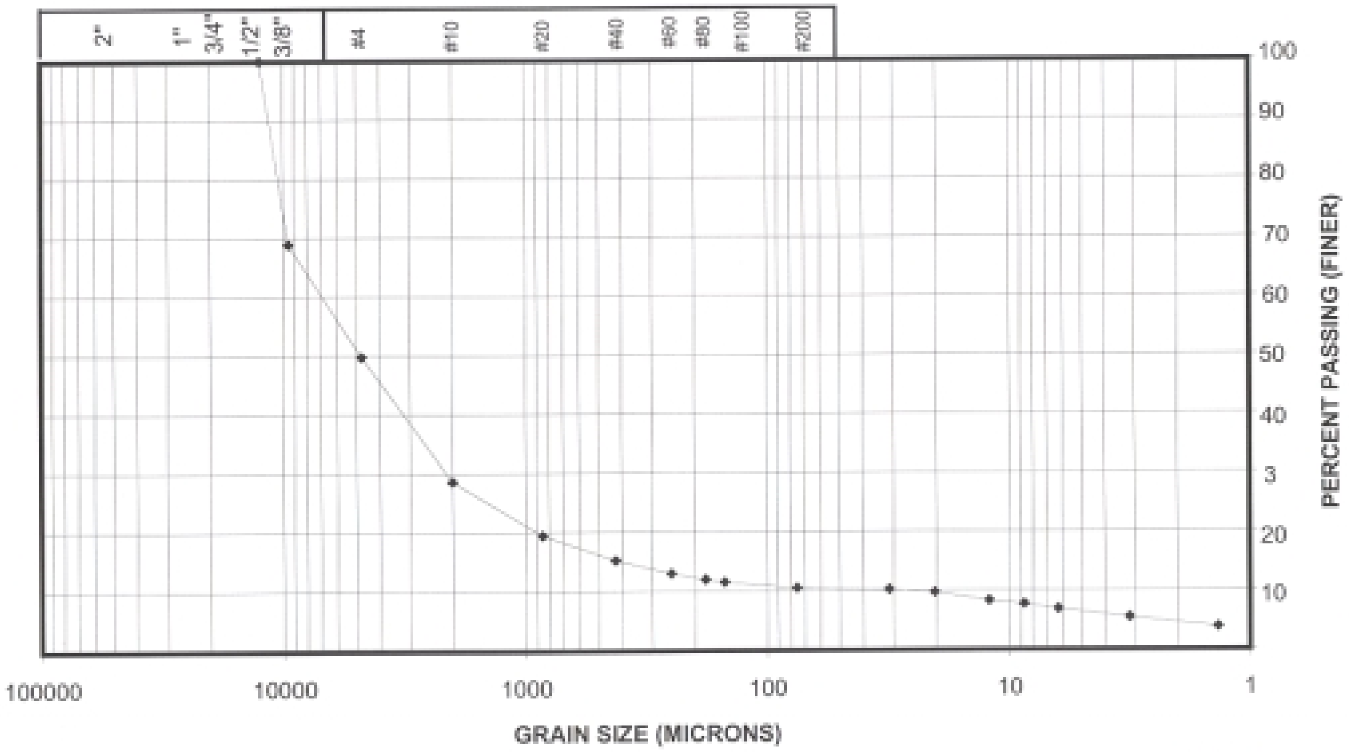


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8182

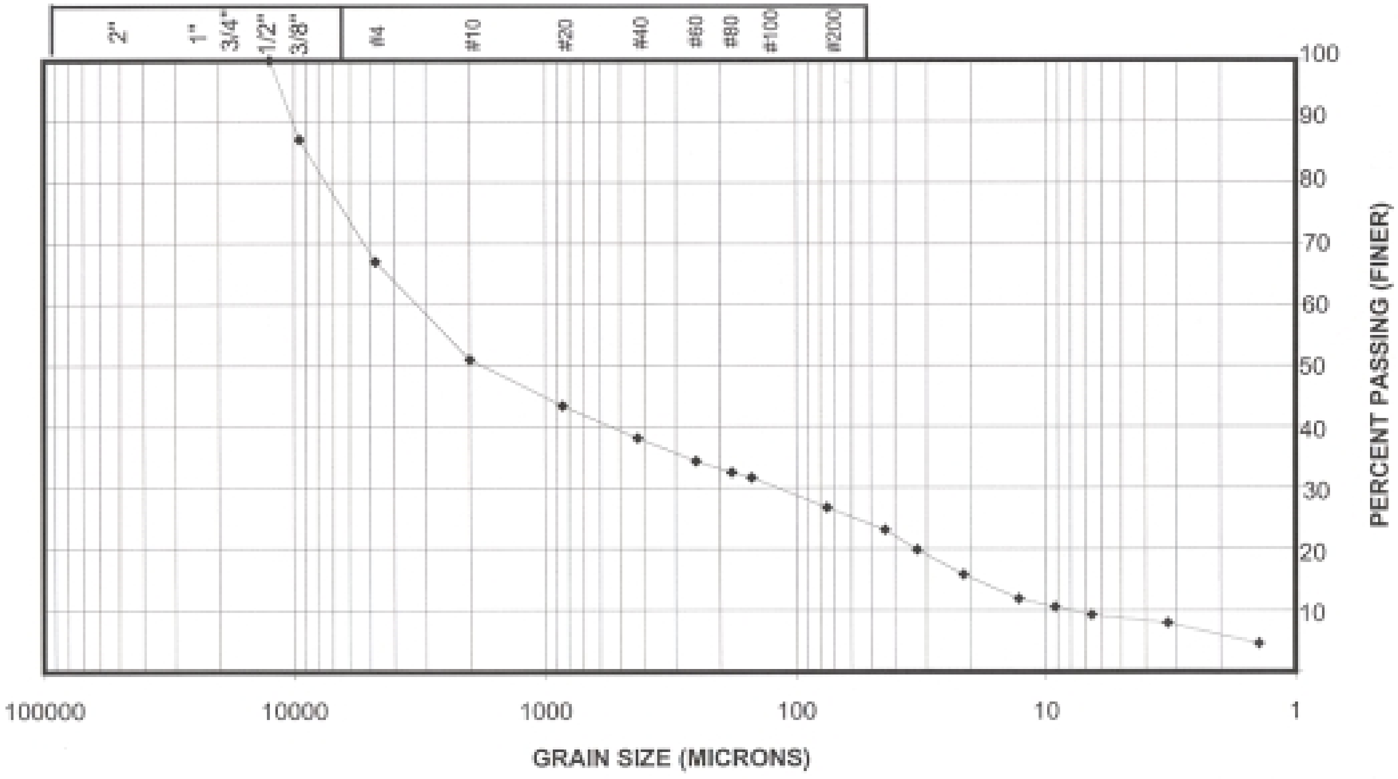


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8183

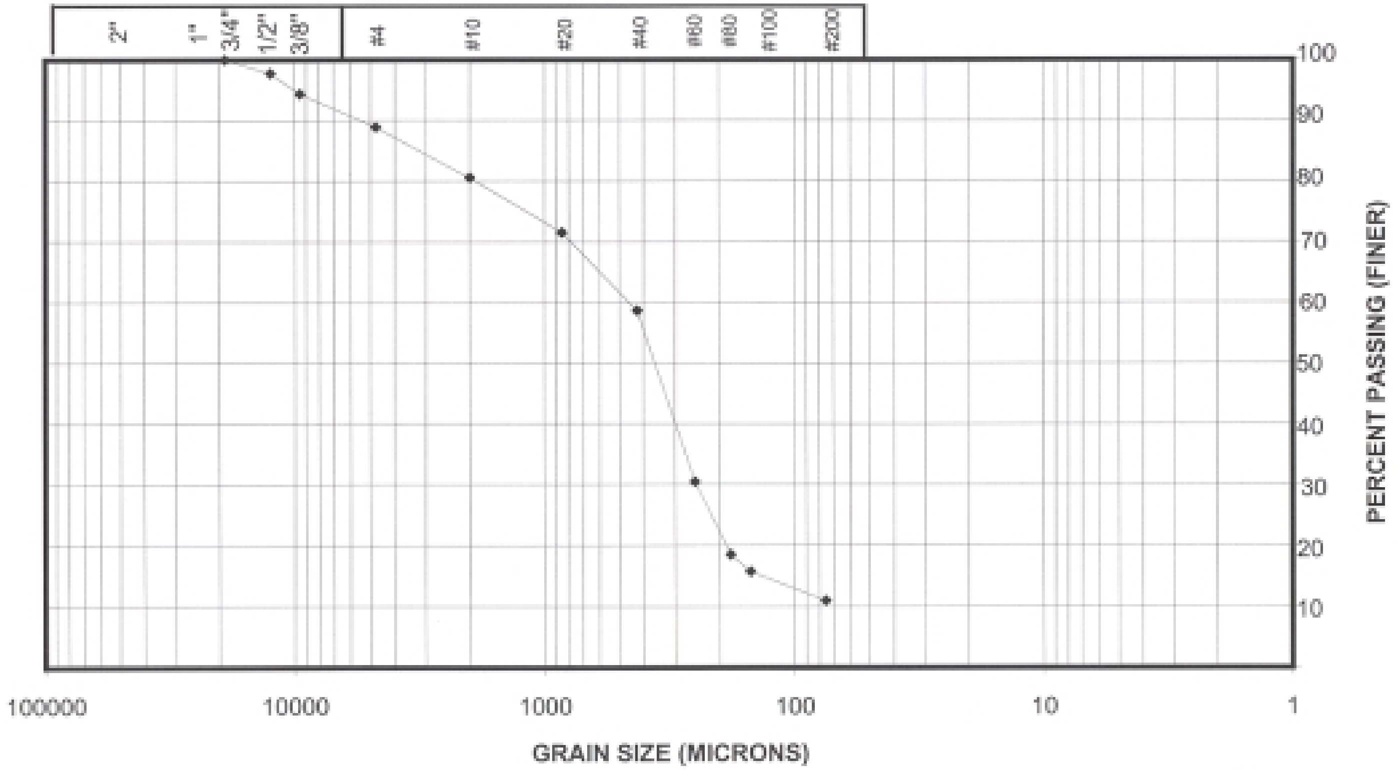


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8184

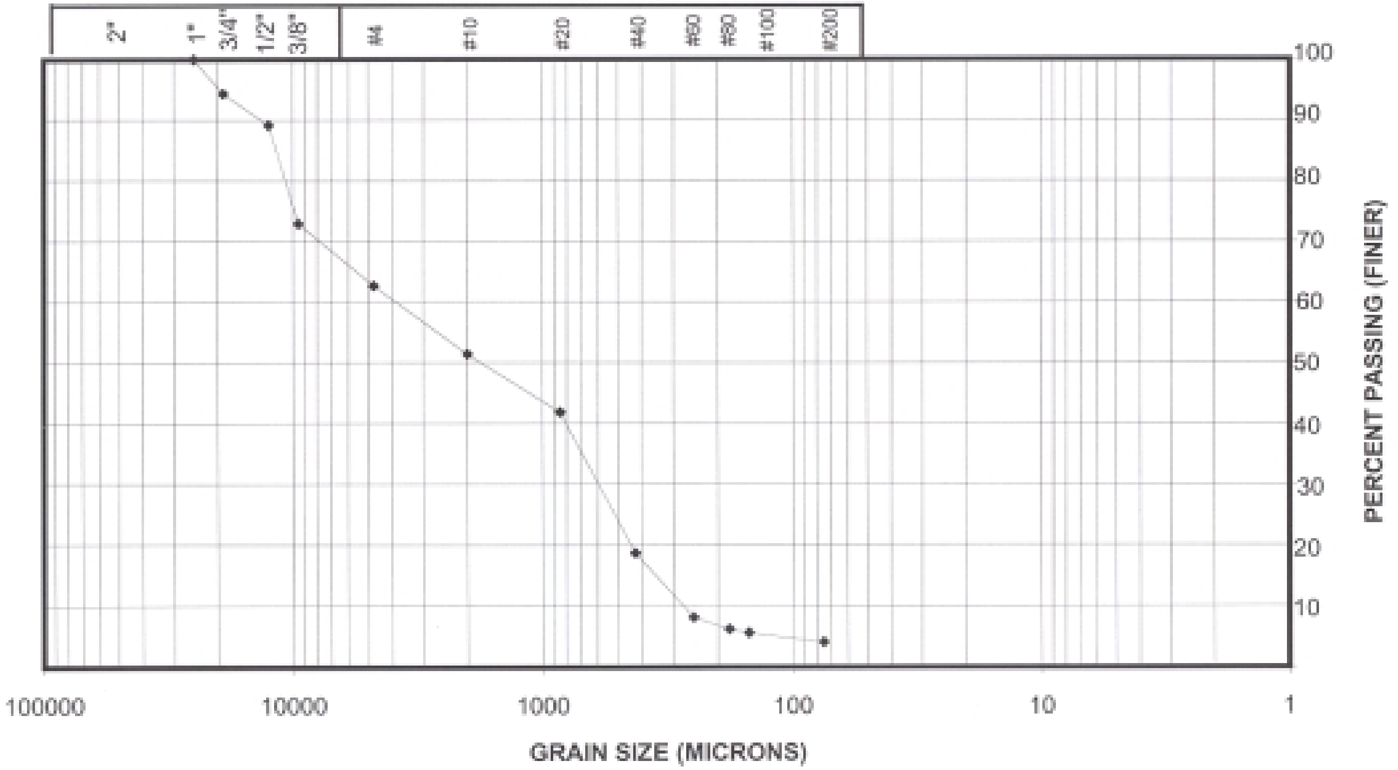


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8185

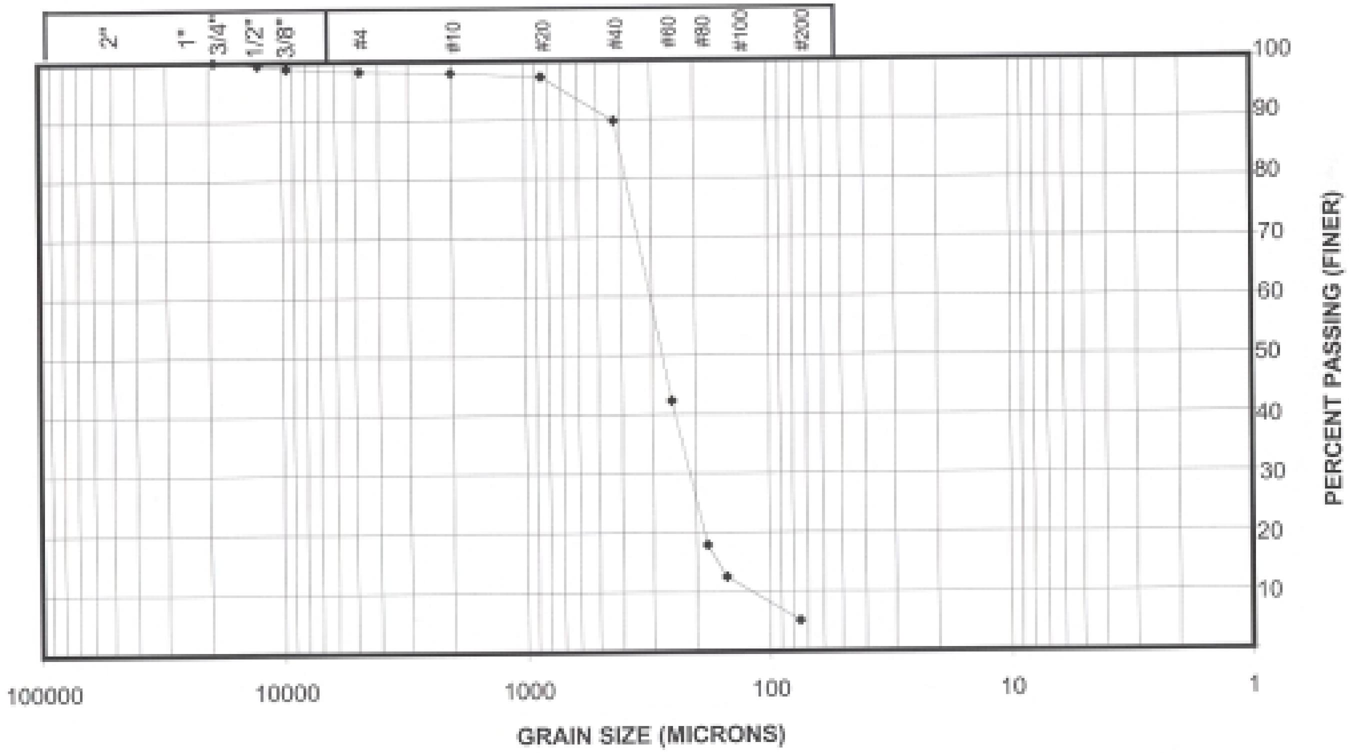


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8186

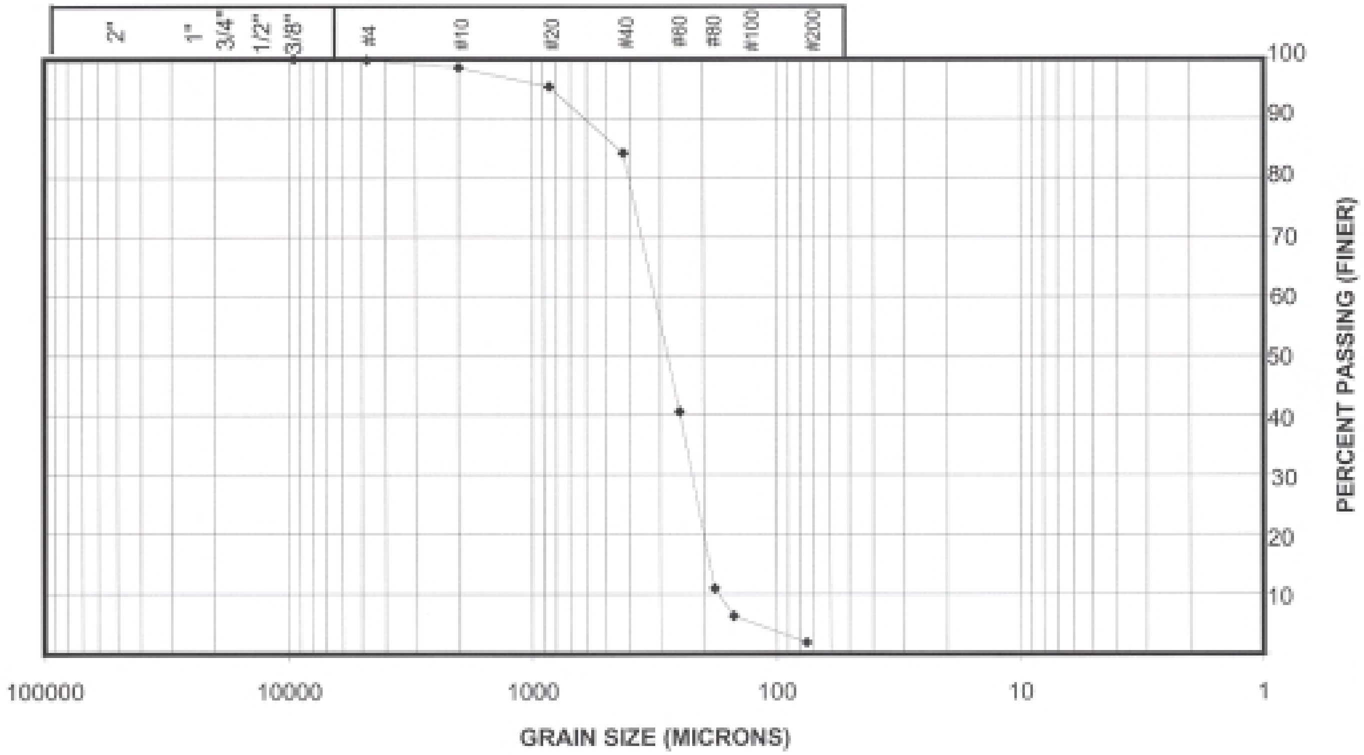


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8187

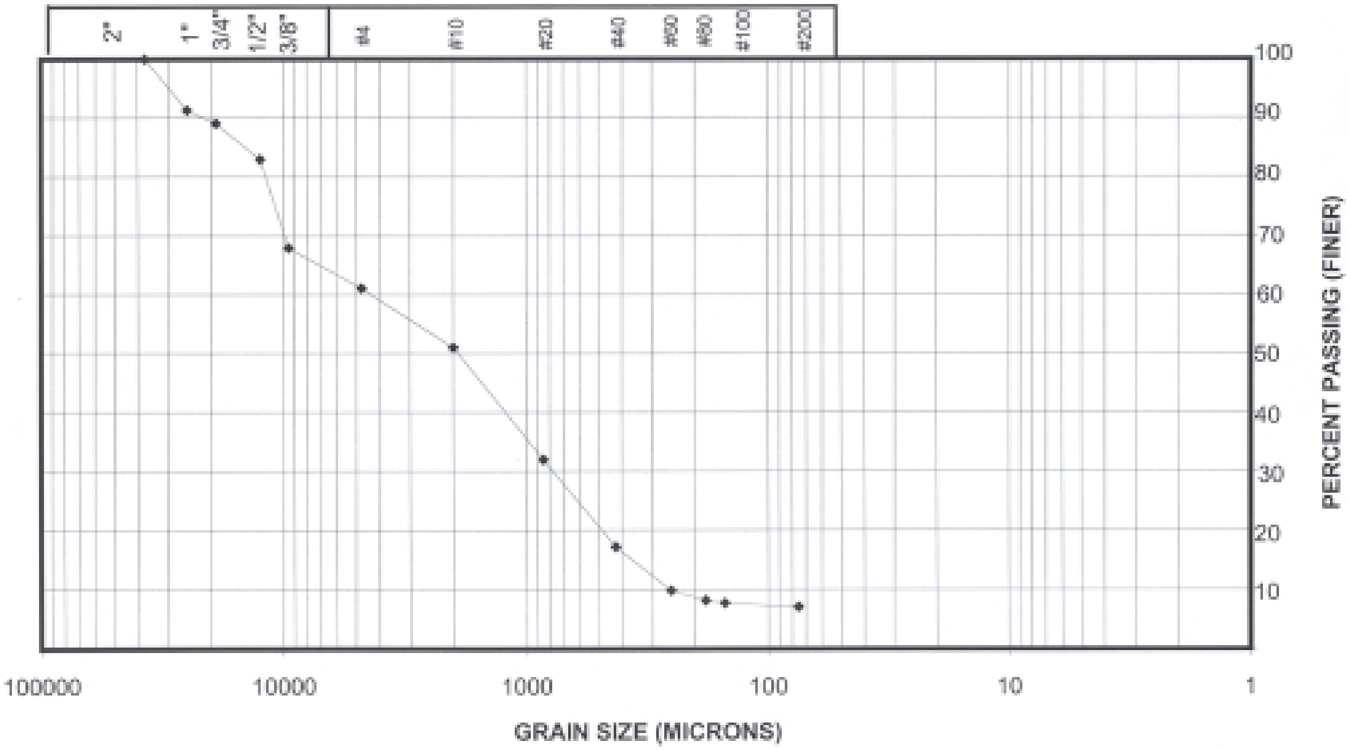


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8188

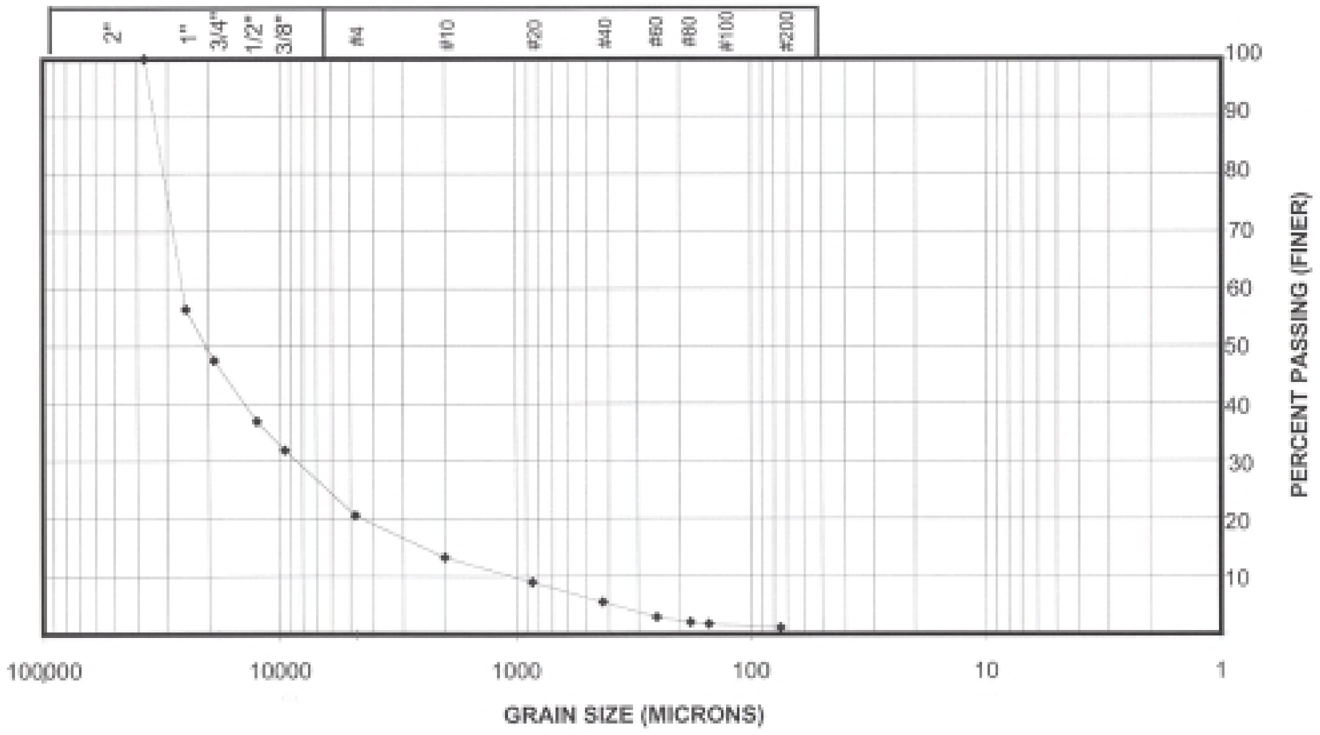


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8189

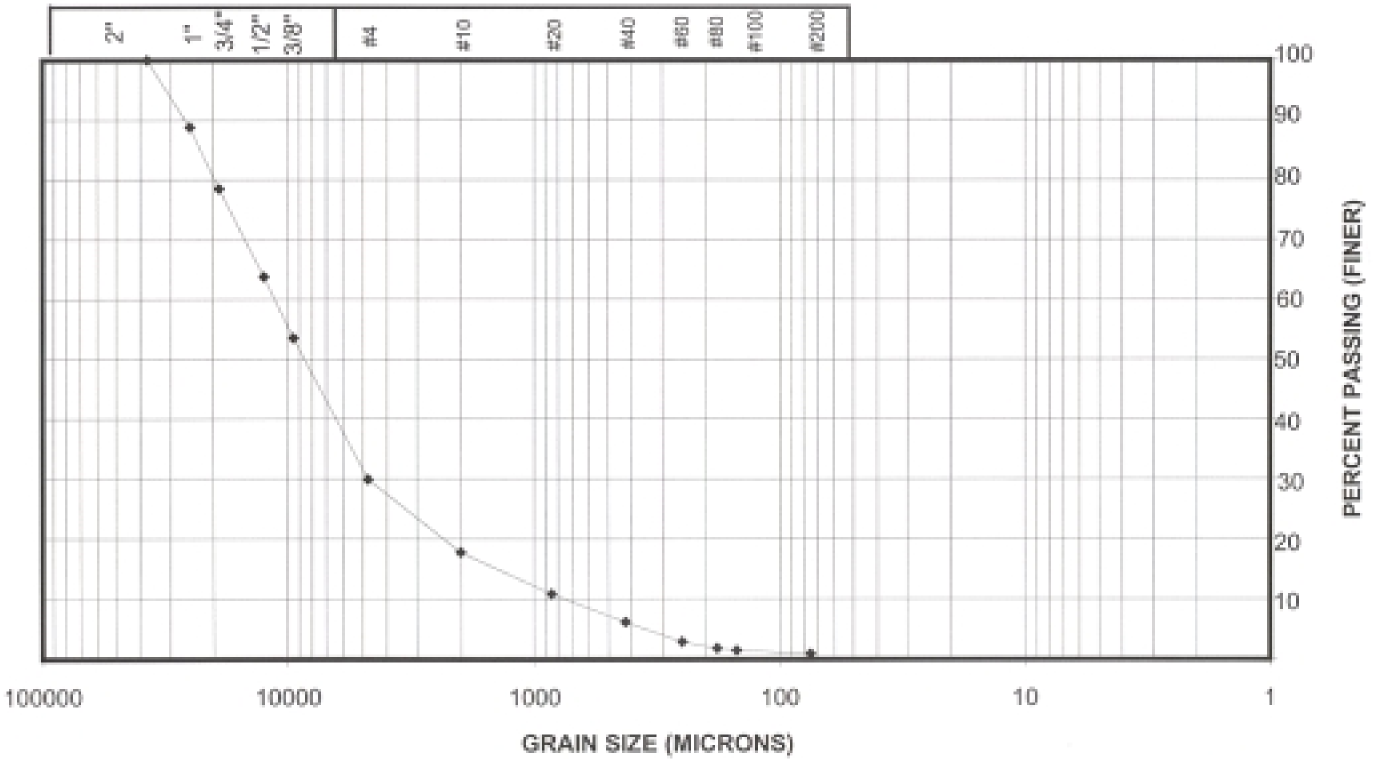


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8190

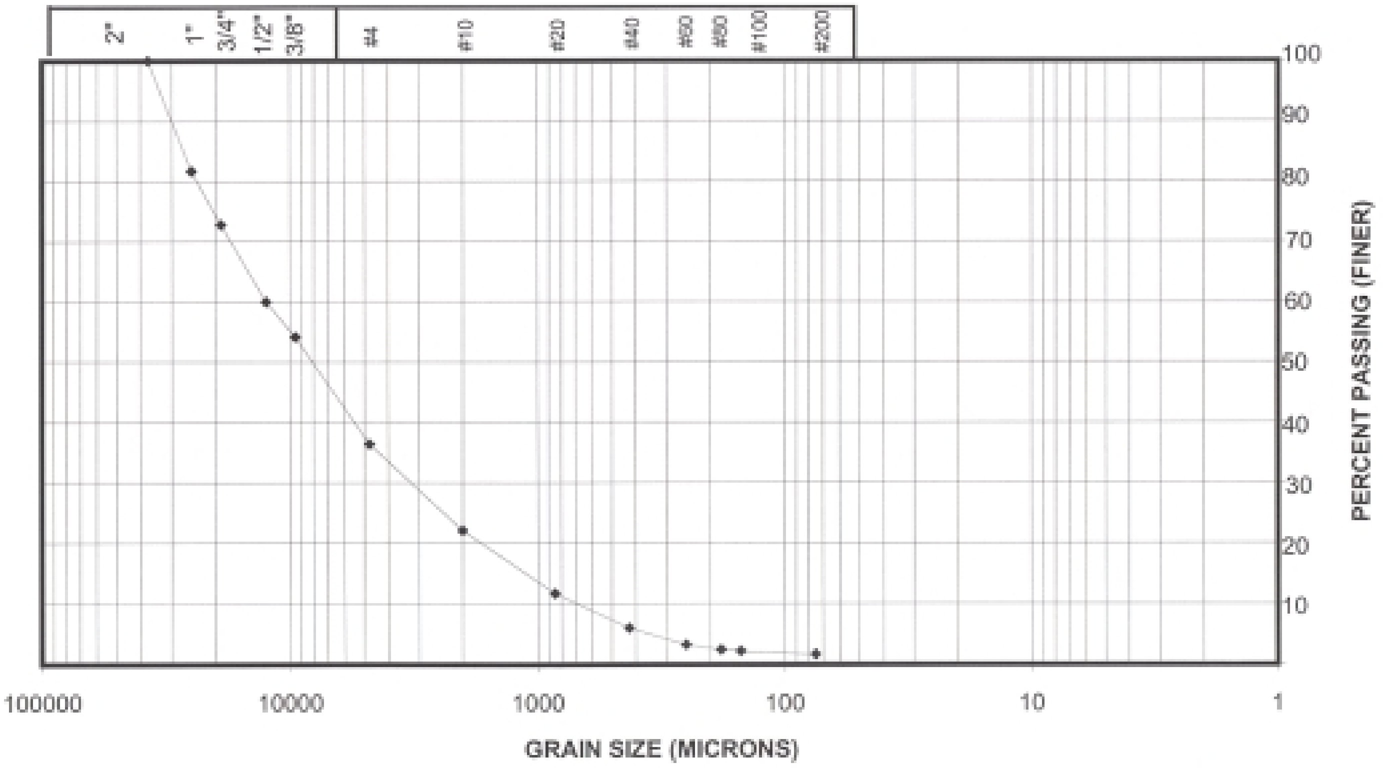


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8191

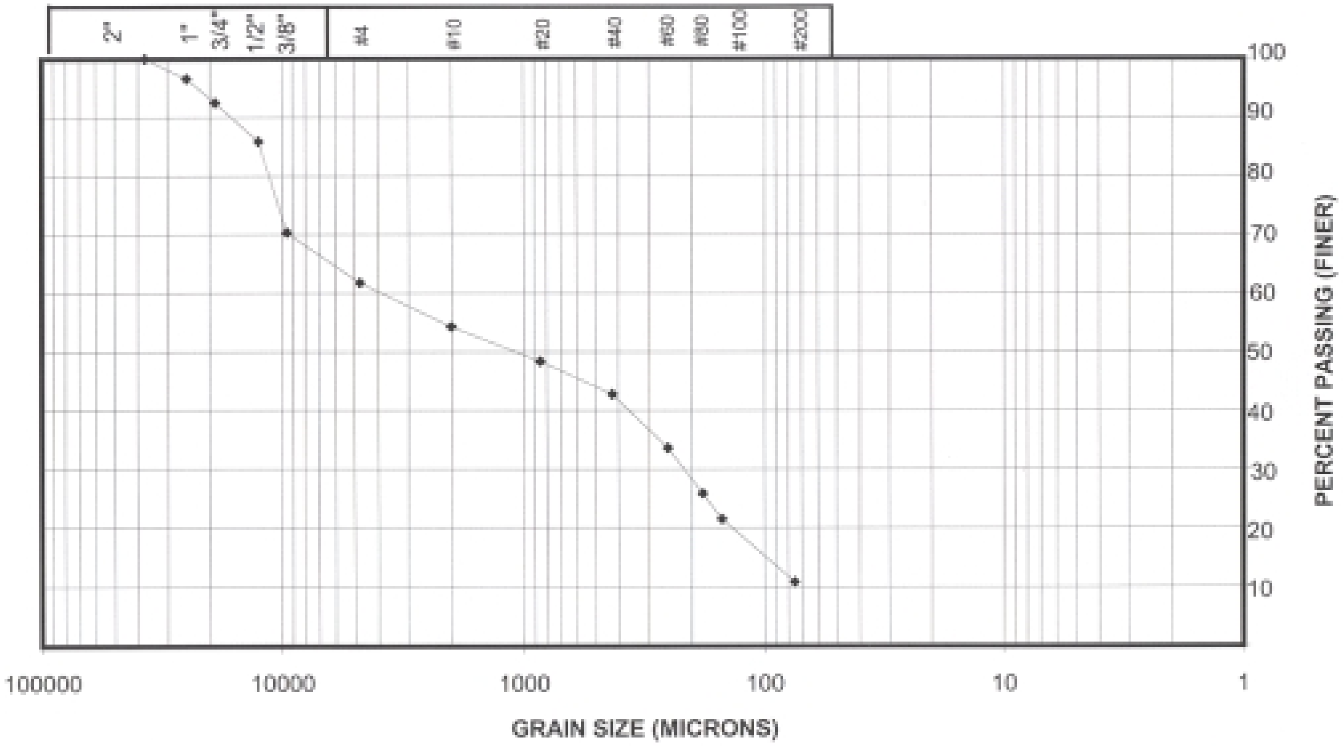


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8192

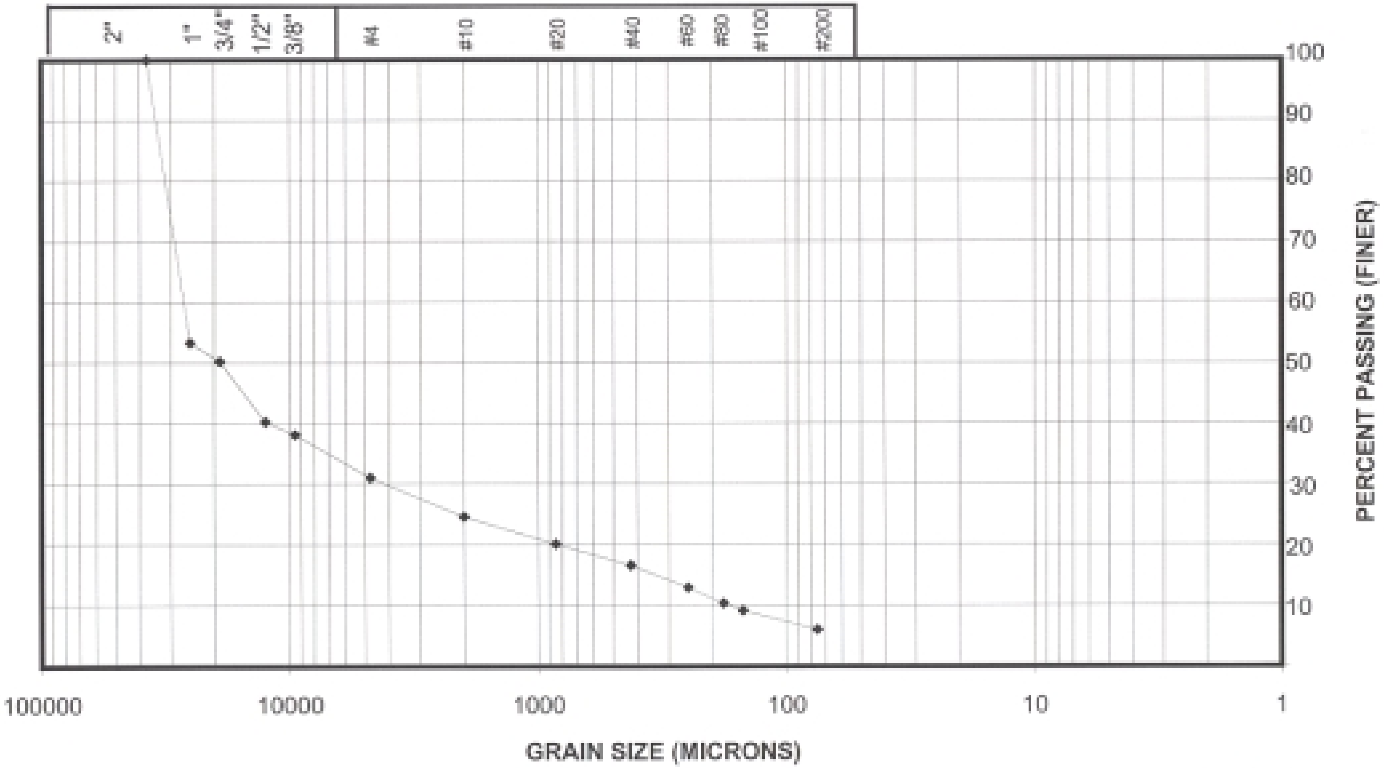


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8193

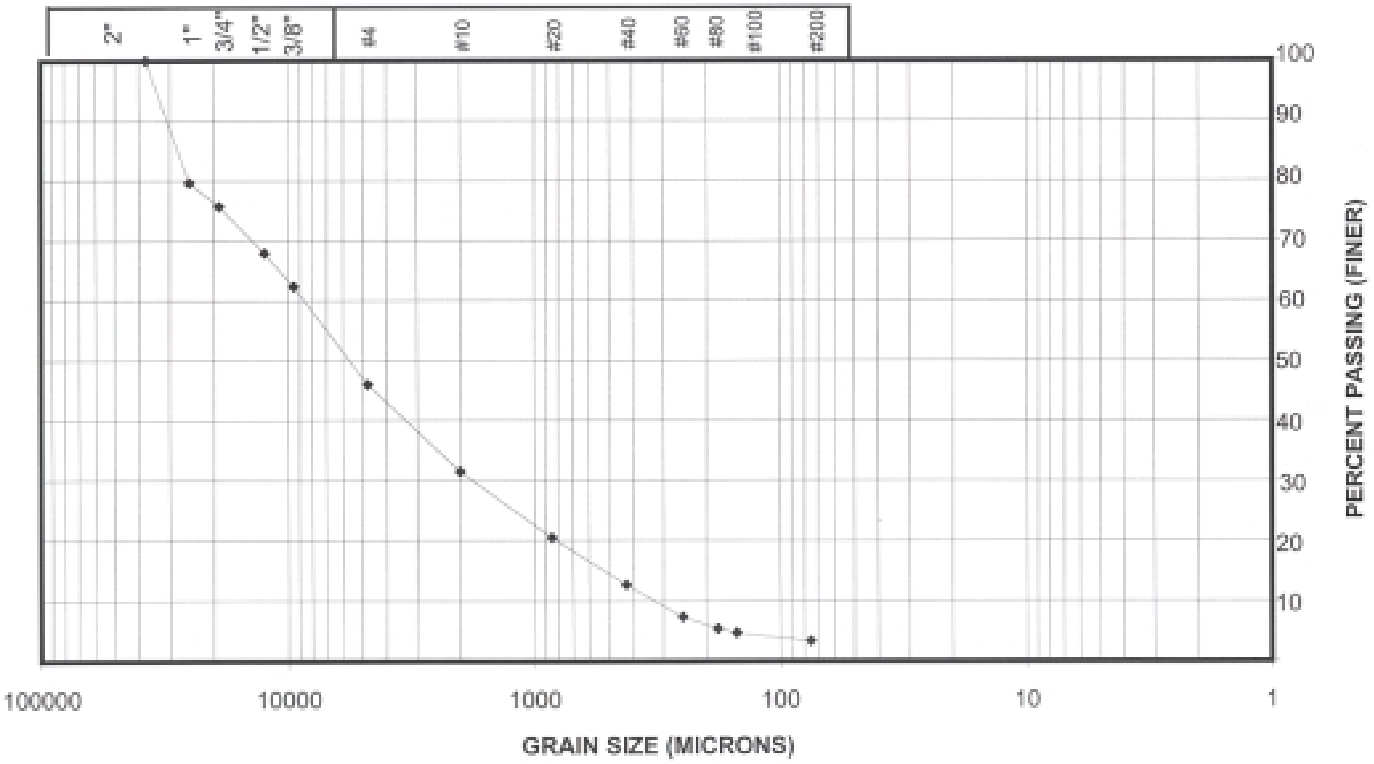


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8194

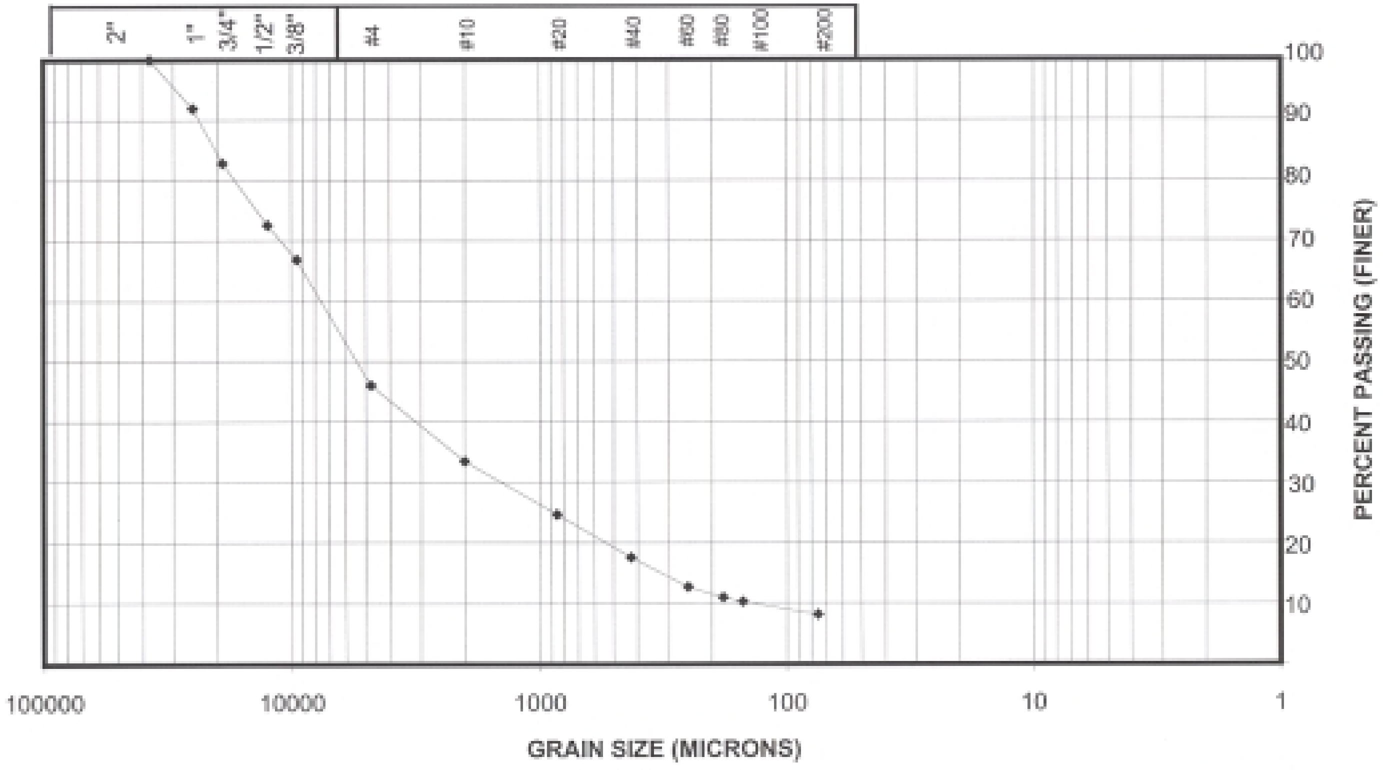


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8195

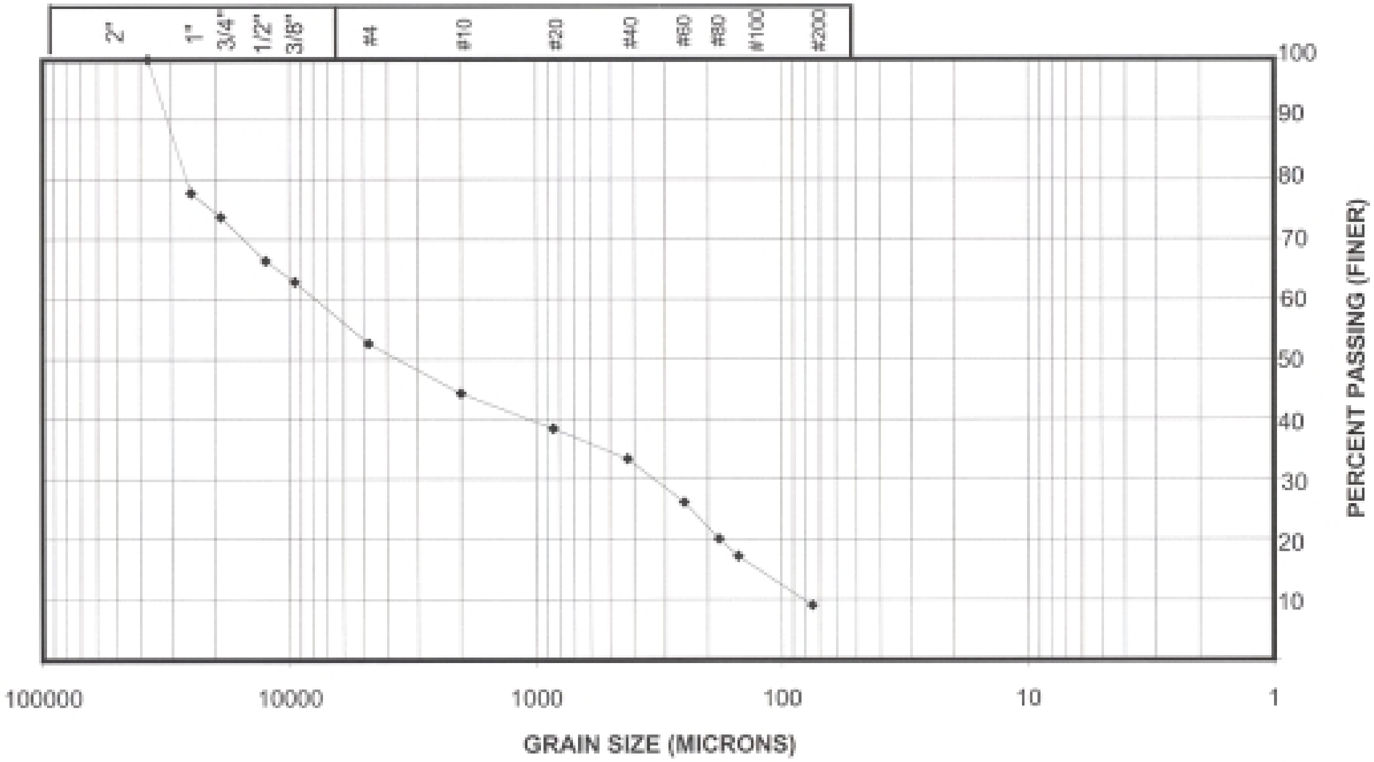


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8196

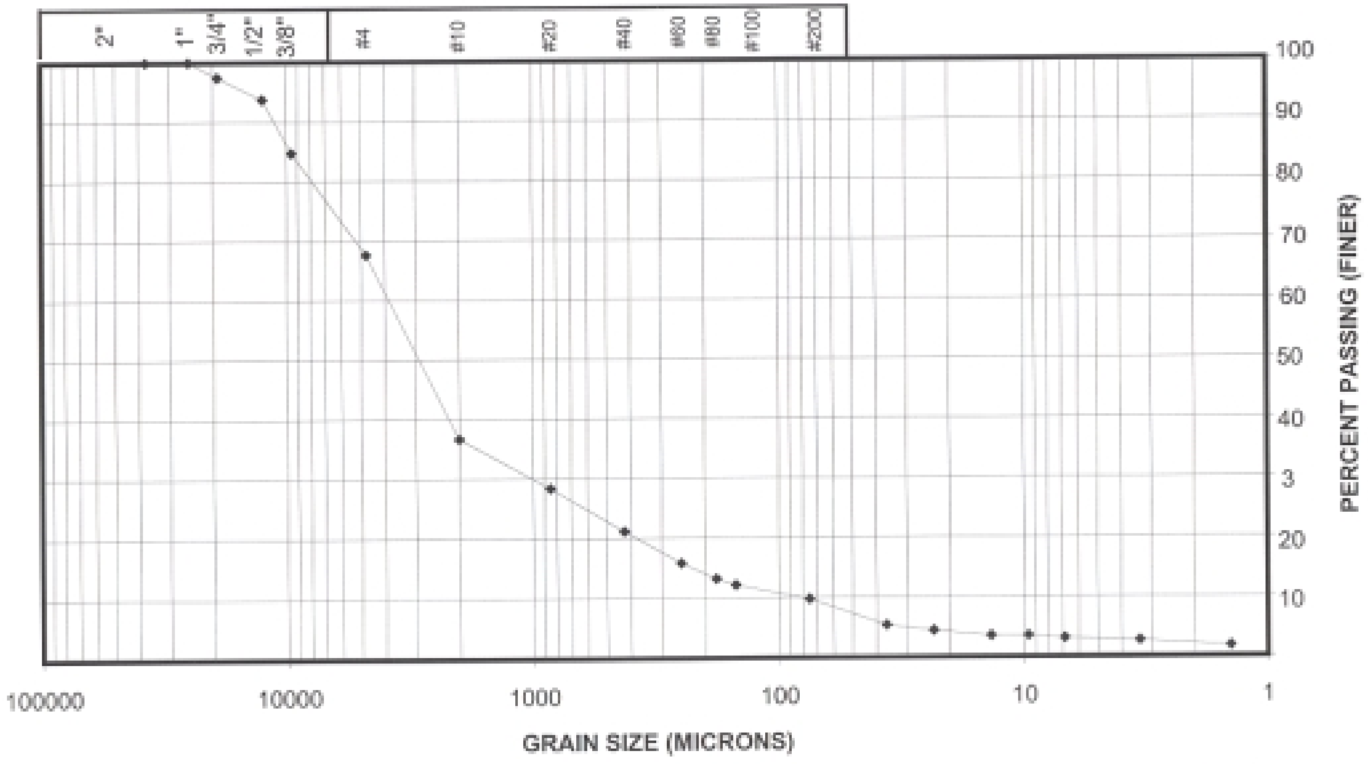


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8197

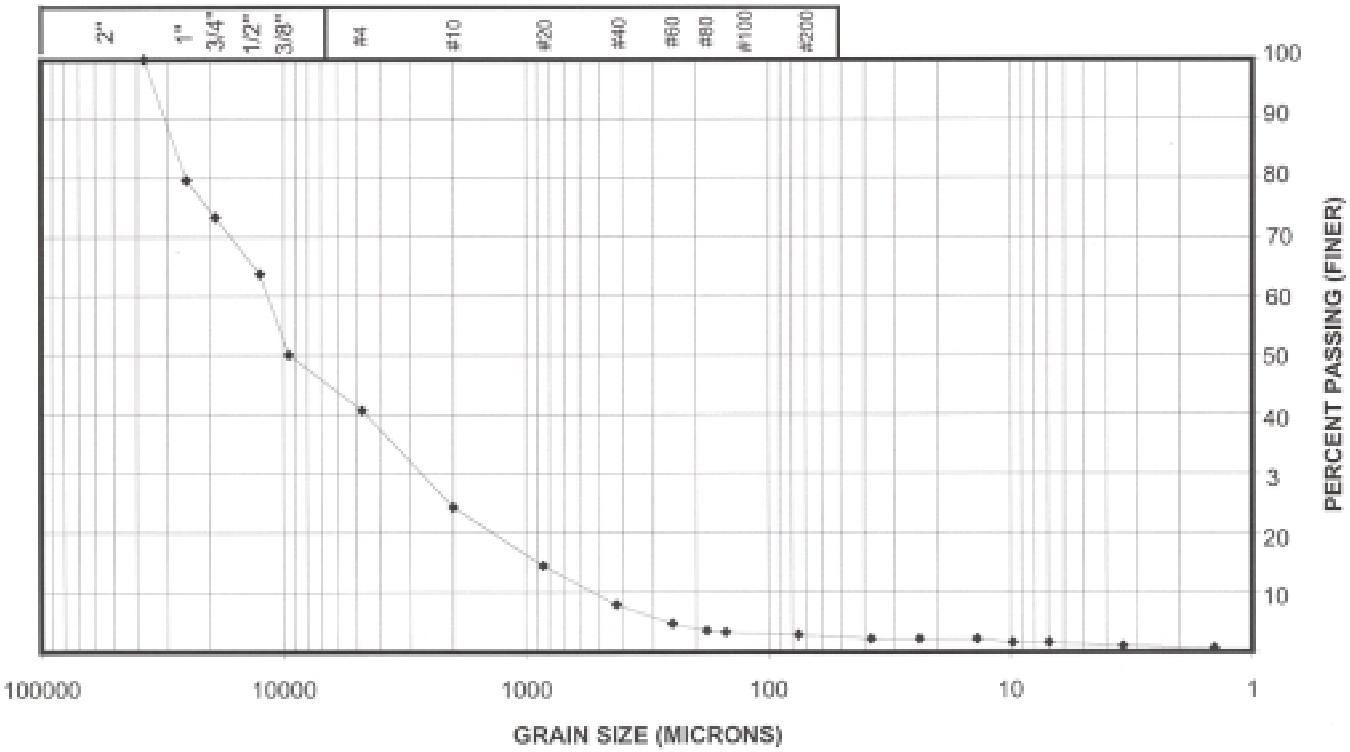


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8198

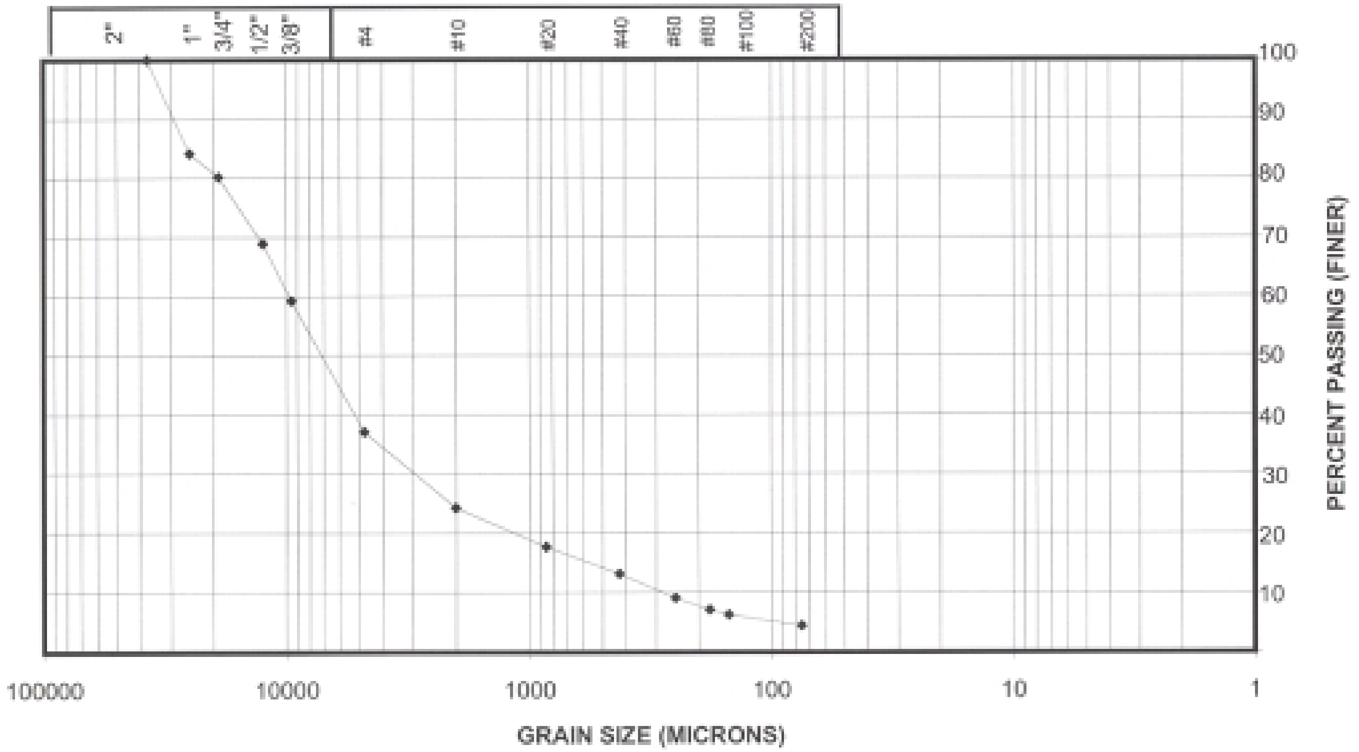


1004-026

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422   GRAIN SIZE DISTRIBUTION

Project: WDOE - Skokomish Study
Sample No.: 34-8199



1004-026

This page is purposely blank for duplex printing

Appendix D

Water table and ground surface elevations of the monitoring wells and wetland

Appendix D. Water table and ground surface elevations of the monitoring wells and wetland. Elevations are in feet above me
The elevation for Skok-4 was extrapolated from the USGS 7.5 minute quadrangle map as 45.00 feet.

	Ground surface elevations	Water table elevations (feet)												
Well	(feet)	6/16/99	7/2/99	7/28/99	8/17/99	9/15/99	10/15/99	11/8/99	12/8/99	1/19/00	2/11/00	3/7/00	4/3/00	5/9/00
SK-1	48.03	20.20	NA	19.63	19.46	19.10	18.95	19.16	22.53	22.46	21.71	21.26	20.62	19.88
SK-2	30.97	14.74	14.75	14.59	14.61	14.43	14.57	15.03	15.83	15.65	15.37	15.27	14.41	14.42
SK-3	44.57	14.73	NA	14.58	14.52	14.35	14.43	14.90	15.86	15.64	15.11	15.17	14.36	14.34
SK-4	45.00	14.52	14.47	14.31	14.34	14.19	14.27	14.79	15.86	15.61	15.18	15.15	14.09	14.06

	Water table elevations (feet)							
	10/15/99	11/8/99	12/8/99	1/19/00	2/11/00	3/7/00	4/3/00	5/9/00
Wetland	14.57	15.03	15.83	15.65	15.37	15.27	14.41	14.42

Appendix E

Water quality data

This page is purposely blank for duplex printing

Appendix E. Water quality data. Concentrations are in mg/L unless otherwise specified.

Laboratory Analytes											Field Parameters			
Well	Date	NH3-N	NO2+NO3-N	TPN	Total P	Chloride	TDS	Conductivity (umhos/cm)	Fecal coliform (No./100ml)	Hydrocarbon ID	Temp	pH (SU)	Conductivity (umhos/cm)	Dissolved Oxygen
Skok-1	8/2/99	0.031	0.576	0.529	0.214	2.07	105	127	1 U			7.60		
	11/8/99	0.010 U	0.120	0.205	0.052	1.81	75	104			9.9	7.05	103	9.45
	2/11/00	0.010 U	1.99	2.080	0.420	2.32	93				9.6	6.56	124	10.6
	5/9/00	0.010 U	1.30	1.350	0.039	2.05	92	137	1 U		9.2	5.79	137	
Skok-2	8/2/99	0.040	0.096	0.100	0.067	1.76	60	77.0	1 U		10.3	7.66	63	
	11/8/99	0.010 U	0.037	0.045	0.032	1.67	48	70.0		NC	9.6	6.33	69	9.35
	2/11/00	0.010 U	0.086	0.082	0.028	2.64	58				9.5	6.53	76	7.91
	5/9/00	0.010 U	0.053	0.057	0.030	1.60	55	69.8	1 U		8.7	5.10	68	
Skok-3	8/2/99	0.036	0.184	0.172	0.280	1.59	67	68.4	1 U					
	08/02/99(dup)	0.032	0.187	0.186	0.080	1.53	61	68.5	1 U					
	11/8/99	0.010 U	0.802	0.843	0.072	2.52	72	100			10.2	5.74	98	6.96
	2/11/00	0.110	0.851	0.918	0.106	2.17	71				9.7	6.49	72	9.57
	02/11/00(dup)	0.010 U	0.870	0.944	0.077	2.19	64							
	5/9/00	0.010 U	0.394	0.410	0.045	1.61	55	73.6	1 U		9.4	5.18	70	
	05/09/00(dup)	0.010 U	0.410	0.407	0.033	1.61	63	74.2	1 U					
Skok-4	8/2/99	0.031	0.293	0.306	0.308	1.73	83	96.6	1 U				91	
	11/8/99	0.010 U	0.103	0.110	0.034	1.79	68	98.3			10.2	6.42	97	8.10
	11/08/99(dup)	0.010 U	0.102	0.109	0.036	1.67	65	98.3						
	2/11/00	0.010 U	0.342	0.356	0.034	1.97	81				10.1	6.36	106	7.82
	5/9/00	0.010 U	0.274	0.254	0.035	1.79	73	112	1 U		9.8	6.13	109	8.03

U: Below detection limit.
NC: No detectable petroleum hydrocarbons or products, or any other gas chromatographic compounds.