DESIGN ANALYSIS REPORT

DRAFT FINAL 100 PERCENT DESIGN SUBMITTAL HOLLY STREET LANDFILL CLEANUP/ WHATCOM CREEK ESTUARY RESTORATION PROJECT

Prepared for

City of Bellingham
Office of Neighborhoods and Community Development

In Cooperation with:

U.S. Environmental Protection Agency,
Brownfields Assessment Program
and
Washington State Department of Ecology,
Toxics Cleanup Program

Prepared by

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Table of Contents

List of Tables

List of Figures

List of Photos

List of Appendices

1 INTRODUCTION

The purpose of this Design Analysis Report (DAR) is to provide a narrative discussion of the methods and assumptions used in developing the design of the Holly Street Landfill Cleanup/Whatcom Creek Estuary Restoration Project (henceforth the “Project”) in Bellingham, Washington. This DAR is one part of an overall draft final (100 percent level) design submittal package which also contains design plans, specifications, and associated documents. The remedial actions selected for the site will occur under the legal framework of a recently entered Consent Decree between the City of Bellingham (City) and the Washington State Department of Ecology (Ecology). Preparation of this DAR was funded by a Supplemental Grant from the U.S. Environmental Protection Agency (EPA) Brownfields Assessment Demonstration Pilot Program. Work was carried out in a manner consistent with the Cooperative Agreement between the City and EPA, and also consistent with the terms of the Consent Decree between the City and Ecology.

2 EXISTING CONDITIONS

2.1 General Description of Site

The Holly Street Landfill site is a 13-acre historic municipal solid waste landfill located in the City's Old Town district. The general location and layout of the site is shown on Figures 2-1 and 2-2. Municipal solid waste is located on both sides of Whatcom Creek, with the landfill divided into a northern unit and a southern unit. Both the northern landfill unit on the northwest bank, and the southern landfill unit encompassing Maritime Heritage Park and the southeast bank of Whatcom Creek, are listed and ranked by Ecology as contaminated sites subject to the investigation and cleanup requirements of the Washington State Model Toxics Control Act (MTCA). Since these sites are essentially one site bisected by Whatcom Creek, Ecology has combined the sites into one site known as the Holly Street Landfill.

The current ground surface of the landfill consists predominantly of silty sand and gravel of variable thickness, overlain in many areas by asphalt (predominantly over the northern landfill unit) and landscaping (predominantly over the southern landfill unit). Cover material thickness ranges from approximately 1 to 20 feet, and is generally thicker in the southeast portion of the site (Maritime Heritage Park), where it ranges from about 3 to 20 feet thick.

2.2 Site Use and Landfilling History

In the late 1800s, the Holly Street Landfill site was part of the original Whatcom Creek estuary and mudflat. Around 1905, private property owners began filling portions of the site with dredge spoils and other materials to increase usable upland areas. From 1937 to 1953, and possibly continuing to as late as 1959, municipal waste was disposed on private tidelands within the former Whatcom Creek Estuary. Wastes disposed at the site included debris and scrap materials, consistent with landfill disposal practices of the time.

With the acquisition of the Sash & Door property, the City currently owns 8.3 acres of the 13-acre landfill site, including all landfill properties located along the Whatcom Creek shoreline. Various private property owners own land around the upland/inland perimeter of the landfill.

Insert Figure 2-1 here

Insert Figure 2-2 here

Most of the wastes disposed at the site are generally described in the historical documents as inorganic materials, largely devoid of putrescible wastes or flammable items, which were disposed at other locations. Specific descriptions of waste materials disposed at the Holly Street Landfill site have included glass, concrete, household debris, metal scrap, soil, coal slag, ashes, and woody debris consistent with landfill disposal practices of the time. Few of the waste materials are currently exposed at the surface, but are largely covered by soil fills, gravel, buildings, and asphalt.

2.3 Nature and Extent of Site Contamination

A Remedial Investigation/Feasibility Study (RI/FS) was prepared by Anchor and Aspect (2003) for this site, including collection of data needed to evaluate the nature and extent of contamination. Soil, sediment, surface water, and groundwater conditions were characterized during the RI/FS. As set forth in Ecology's Cleanup Action Plan (CAP) for the site (included as Exhibit A to the Consent Decree), based on the findings of the RI/FS, controls are needed at the site to continue to prevent future human and environmental exposure to buried (subsurface) refuse and associated soil contaminants. Moreover, although contaminants have not been detected in groundwater at the site at levels of potential concern, metals such as copper and zinc present in landfill refuse are mobilized by tidal processes affecting the shoreline landfill zone. These processes result in seepage to Whatcom Creek along a localized reach of the northern landfill unit shoreline that poses a potential risk to sensitive aquatic species in this area.

2.4 Stability of Existing Landfill Side Slopes

The existing landfill side slopes are marginally stable along the shoreline of Whatcom Creek. Evidence of ongoing sloughing and shoreline erosion can be found in several areas behind existing wooden bulkheads, where loss of ground has resulted in gaps between the bulkhead and the shoreline. Stability of the landfill slopes could be a future source control concern at the site, as the bulkhead continues to deteriorate and the wood piles supporting the bulkhead provide decreasing support for the slope.

Stability analyses (presented below and detailed in Appendix D) indicate that the existing slope in many areas of the site has a factor of safety against sliding on the order of 1.0, which indicates a marginal to low level of stability. This is particularly true where the slope has been oversteepened and the bulkhead is deteriorating. The analysis suggests that if the existing slopes are not further supported or otherwise stabilized, continued sloughing may occur, particularly along portions of the Maritime Heritage Park shoreline. If the site remains in its existing condition, additional loss of ground may occur along the slope face in the event of an earthquake, possibly accompanied by exposure of refuse. Accordingly, source controls to stabilize landfill side slopes are incorporated into the Project design.

3 SELECTED REMEDY

3.1 Cleanup Remedy Required to Comply with Consent Decree

The RI/FS and CAP developed and evaluated three potential remedial alternatives for the site. As set forth in the Consent Decree, the selected cleanup alternative for the site is a cap constructed along the northern landfill area (the former Sash & Door property shoreline) and localized upland areas, institutional controls, and monitoring of localized surface water seeps. Based on a consideration of geochemical processes controlling copper and zinc mobility at the site, the identified shoreline capping system would be designed to restrict tidal mixing and associated oxygen transfer into nearshore refuse deposits of the northwest landfill lobe. Such a cap system is expected to be effective in controlling the release of copper and zinc into Whatcom Creek. Furthermore, as described in the next section, it offers a concurrent opportunity to improve the quality of intertidal habitat in this area.

3.2 Contingent Remedy - Integrated Cleanup and Habitat Restoration

Contingent upon continuing participation by ecosystem restoration funding sources as described in the CAP, the selected cleanup alternative may be modified by combining habitat restoration, public access, and land use elements into a single integrated cleanup remedy (also incorporating source control elements as discussed above). While the habitat restoration component is not necessary to achieve cleanup goals, it is fully consistent with remedial action objectives and the Bellingham Bay Comprehensive Strategy (Ecology 2000). The integrated plan includes:

- Excavating wedges of shoreline solid waste within and adjacent to the "B" Street right-of-way, and along limited oversteepened/bulkhead areas of the Maritime Heritage Park shoreline, and disposing the excavated material off-site;
- Backfilling the excavation areas with a clean cap graded to relatively flat slopes, concurrently providing slope stabilization and restoring historically lost aquatic habitat in this important estuary;
- Enhancing the existing soil cap in portions of the Maritime Heritage Center to be consistent with other landfill areas already capped to ensure that humans and the environment are protected from buried solid waste; and
- Incorporating public access into the overall project design to address existing community open space goals and planning objectives.

The final site layout and grades that would result from this integrated plan are shown on Figure 3-1.

The habitat restoration component of this contingent integrated action includes conversion of approximately 0.3 acres of existing uplands to aquatic habitat via excavation of refuse and capping. This will restore critical estuarine riparian buffer, marsh, and mudflat banks that existed historically in this area of Bellingham Bay. This action has also been designed to provide a park-like setting allowing citizens trail access along this stretch of Whatcom Creek to the Maritime Heritage Center, potentially linked into the larger Whatcom Creek Trail Master Plan. Incorporating public access design with cleanup and habitat restoration will help meet community open space goals and planning objectives, leverage additional community support and funding, and provide an opportunity to educate the public about critical estuarine environments. Future site plans are consistent with maintaining long-term habitat restoration and public access benefits.

This DAR is based on the assumption that the integrated cleanup and habitat restoration remedy will be carried forward by the City, consistent with the terms of the recently entered Consent Decree with Ecology. During the final design review period, the City will endeavor to secure the required habitat funding sources; the City remains optimistic that sufficient habitat restoration funding will be obtained to allow the Project to proceed on schedule. However, in the unlikely event that the required habitat restoration funding is not secured in time to facilitate implementation of the integrated remedy (as set forth in the Schedule incorporated into the Consent Decree), the City will notify Ecology of this condition, and will propose an alternate plan of action to allow the terms of the Consent Decree to be met. In this event, a revised design submittal may be required.

Insert Figure 3-1 here

4 REMEDIATION DESIGN

This section describes the development of the Project's remedial design elements. As described in the previous section, the cleanup remedy involves placement of a stable engineered cap over localized areas of the landfill and the banks of Whatcom Creek. In addition, a wedge of stabilizing rock and gravel fill will be placed along the southern bank of the creek to mitigate against slope instability and refuse exposure during a design-level seismic event.

4.1 Refuse Excavation and Disposal

As generally described in the RI/FS and CAP, and consistent with the Comprehensive Strategy (Ecology 2000), refuse within a nominal 0.3-acre area within the existing B Street right-of-way (ROW) will be removed as part of the integrated cleanup and habitat restoration project, and the excavation area backfilled with a clean cap graded to relatively flat slopes. This will result in a net conversion of uplands into aquatic habitat, providing a substantial net gain in habitat area and function.

As part of this Project, fill and refuse material will be removed (likely using an upland excavator) and transported to and disposed at a permitted landfill (e.g., Roosevelt Regional Landfill) or whenever possible, recycled. Most of the excavation is targeted along the north bank of Whatcom Creek. Localized excavation will also be required for some areas along the south bank. Based on a review of soil and solid waste boring logs of the Holly Street Landfill Site (Appendix A), there are likely to be significant variations in density within the landfill debris; voids may also be present. During excavation some of the softer spots may slough when exposed. However, such behavior is expected to occur in isolated areas (not on a widespread basis). Moreover, as discussed in Appendix D, research indicates that the strength of landfill refuse is largely a function of strain, or the amount of movement during failure (Gabr and Valero 1995). Increasing strain leads to higher strengths — a counterintuitive phenomenon that reflects the tendency of larger debris particles to interlock with one another during movement. Thus, the effect of sloughing is anticipated to be mitigated by the fact that the waste strength tends to increase with movement.

Careful controls will be implemented during construction as described in the accompanying Construction Quality Assurance Project Plan (CQAP) to ensure control of waste releases during the remedial action. The project specifications require that excavation be restricted to periods when water levels are at least one foot below the elevation of work activity. The only potential exception to this requirement is for areas along the south bank where excavation is required at elevations below elevation +3 feet Mean Lower Low Water (MLLW). In these cases, the Contractor will be allowed to perform in-water excavation only if they can demonstrate to the City, the City's Engineer, and Ecology that doing otherwise is infeasible. Furthermore, if in-water excavation is done in these areas, it will be subject to water quality monitoring and to observation by the City and Ecology.

Overall stability of excavated slopes will be maintained by limiting the proximity of equipment storage and soil stockpiling from the edges of excavated side slopes. There are also limitations on how long excavated slopes can remain exposed before backfilling is required. Freshly excavated surfaces will need to be rolled smooth before the next tidal inundation to reduce potential for erosion.

4.2 Control of Shoreline Seepage

The groundwater flow system at the Holly Street Landfill Site consists of a shallow unconfined aquifer within the refuse and underlying Recent Alluvial sediment (Anchor and Aspect 2003). Groundwater flow within this unconfined aquifer is generally directed from the upland areas toward Whatcom Creek. Fine-grained silts and clays present beneath the aquifer function as confining layers, restricting downward groundwater flow into deeper units.

Leachate within the refuse is generated from infiltration of incidental precipitation and from lateral inflow of groundwater into the landfill area. Tidal influence creates a sinusoidal groundwater flow path as the groundwater approaches the point of discharge into Whatcom Creek, and oscillates in response to tidally propagated waves. These groundwater oscillations are most pronounced within approximately 20 feet of the shoreline.

Monitoring conducted during the RI/FS, along with supplemental monitoring conducted as a part of the pre-remedial design evaluation (Appendix B) indicate that surface water cleanup levels set forth in the CAP for dissolved metals (copper and zinc) are currently exceeded in shoreline seeps along portions of the northwest lobe of the Holly Street Landfill. The geochemical data suggest that water within the Whatcom Creek estuary, high in dissolved oxygen, migrates into the shallow groundwater zone during high tides, creating oxidizing conditions within the saturated refuse. The oxidizing conditions promote mobilization of copper and zinc present within the refuse.

The Project includes removal of that portion of the refuse that encounters oxygenated water infiltrating from Whatcom Creek during high tides and placement of a sufficient thickness of semi-permeable shoreline cap. This design is intended to reduce concentrations of copper and zinc discharging to Whatcom Creek by displacing the zone of mixing outward from the refuse. Such displacement would separate the low dissolved oxygen environment within the refuse from oxidizing surface water, thereby reducing the release of dissolved copper and zinc.

For the purpose of Project design, a numerical groundwater flow model and integrated numerical groundwater contaminant transport model was developed to assess migration of dissolved oxygen (DO) inland from Whatcom Creek, considering advection, dispersion, and diffusion processes. Groundwater flow and transport model development and calibration are discussed in Appendix C; conservative model assumptions were incorporated to ensure the protectiveness of the remedy. The shoreline cap performance was evaluated by specifying a constant DO concentration boundary in cells representing Whatcom Creek. Two cap design scenarios were evaluated: 1) a medium sand cap with a uniform hydraulic conductivity of 0.02 cm/sec (the same as specified for the RI/FS); and 2) a less permeable silty sand cap with a uniformly lower hydraulic conductivity of 0.005 cm/sec. Multi-year transport simulations were performed with both configurations until a steady-state concentration profile was developed. These scenarios evaluated the relative effectiveness of the shoreline cap over a reasonable range of cap permeability values that may be specified in the design.

The cap performance scenarios indicated that a shoreline cap with a 5-foot effective thickness and a hydraulic conductivity of 0.02 cm/sec or less will greatly reduce oxygen flux from Whatcom Creek to adjacent shoreline solid waste deposits, relative to existing conditions. As shown in Figure C-5 (in Appendix C), the modeling analyses indicate that a medium sand (0.02 cm/sec) shoreline cap will result in at least a 95 percent reduction in DO concentrations encountering solid waste, as compared to existing conditions where no capping material is present. A less permeable silty sand, with a hydraulic conductivity of 0.005 cm/sec, would attenuate the influx of DO from Whatcom Creek by more than 99 percent, providing a substantially higher factor of safety for this design, with little impact on Project costs or constructability. Therefore, the less permeable material was selected as cap material for the project. With the shoreline cap in place, DO concentrations of groundwater in contact with the refuse will decrease substantially. Consequently, concentrations of zinc and copper in groundwater within the refuse will also decrease substantially, since both metals are less mobile at lower DO concentrations. As generally discussed in Appendix C, the predicted level of reduction in metals concentration is sufficient to achieve compliance with surface water standards set forth in the CAP.

4.3 Shoreline Cap Design and Construction

Consistent with the results of groundwater transport modeling described above, the total thickness of cap material to be placed during the Project must be 5 feet, measured in the general direction of groundwater flow. The flow direction is expected to be essentially horizontal. In order to provide an additional 50 percent factor of safety on cap protectiveness, the cap has been designed to provide an effective thickness of at least 7.5 feet in the groundwater flow direction. The desired 7.5-foot thickness of cap material in the horizontal direction of groundwater flow can be achieved by placing 2 to 2.5 feet of cap material on the proposed site grades, depending on the inclination of the capped grade. This geometric principle is illustrated in Figure 4-1.

The groundwater modeling demonstrated that 2 feet of cap material is more than sufficient for cap performance on relatively flat slopes of 4H:1V to 15H:1V (as will be present on the salt marsh bench area of the north bank). For steeper slopes of 3H:1V that will be constructed behind the rock berm on the north bank, a 2.5-foot-thick cap will be required.

The shoreline cap will be constructed in separate layers. The first layer will consist of 2 to 2.5 feet of clean, relatively fine-grained capping material, such as a slightly silty to silty fine sand or equivalent, which will have a permeability at or below approximately 0.005 cm/sec, as indicated by modeling results (Appendix C). The second layer will consist of a sand/gravel component of suitable grain size to resist erosive forces (see Section 4.5), and the final (surface) layer will consist of an imported topsoil.

In general, construction of the cap on the north bank of the creek will be limited to periods when water levels are at least one foot below the elevation of construction subgrade, and when there is no standing water present at the location of cap lift placement. Since the lowest elevation of cap material placement is +4 feet MLLW, the Contractor will need to sequence their operations with daily tidal fluctuations. An alternative approach will be allowed for placement of rock spalls and gravel at elevations below +3 feet MLLW. In these cases, the Contractor may elect to place the specified rock materials through the water, but subject to water quality monitoring by the City and Ecology. Furthermore, based on this monitoring, the Contractor may be required to employ Best Management Practices (BMPs) for turbidity control as well (i.e., silt fencing).

The Contractor will be required to achieve a nominal degree of compaction on each lift of cap material underlying the topsoil layer by rolling each lift with a roller or heavy construction equipment. The topsoil layer will receive only a light tamping, since this compaction could adversely affect its ability to support vegetation.

The upper bank area will be covered with a biodegradable coir erosion control fabric and planted with woody riparian vegetation (native trees and shrubs) since it is above the area of normal tidal inundation.

4.4 Softening and Stabilization of South Bank

As part of remedial measures for the Holly Street Landfill, a rock and gravel “buttress” will be placed along the south bank slopes of Whatcom Creek with a design grade of 2H:1V or flatter. This will serve to both “soften” the currently eroded escarpment geometry of this bank, and increase its overall stability, including increased stability against failure during seismic events. Where existing bulkheads are present, this will require a maximum of about 10 feet of rock and gravel material (measured vertically at the slope face), which will supplement the wooden piles in providing support for the slope. In some areas, excavation and off-site disposal of solid waste from the South Bank is included in the Project design, in part to maximize habitat-related benefits (see accompanying Project Plans).

As discussed in the previous section, rock and gravel placement will generally be sequenced to occur above water levels. However, the Contractor may elect to place the initial lifts of rock and gravel through the water, subject to specified monitoring requirements.

Stability analyses of the slope with the proposed buttress (Appendix D) indicate that the buttress will increase the slope factor of safety by about 40 to 50 percent. These analyses assume that the wooden piles have been left in place (cut off at the mudline) as part of the remedial measure. It is important that the existing piles not be pulled during construction for two reasons:

- The piles currently provide additional stability for the slope, particularly for potential seismic events and will continue to do so after the sand and gravel buttress is placed; and
- Pulling the piles would tend to cause additional unnecessary stress within the slope that could precipitate localized sloughing during removal.

Insert figure 4-1 here

4.5 Erosion Protection

Under current conditions, the site experiences erosion and periodic flooding due to stream flows and tidal influence. Design of the reconfigured site needs to account for such forces by incorporating armor materials that can resist anticipated erosive forces. This section presents the basis for selection of suitable armoring materials for the cap and reconfigured banks.

4.5.1 Evaluation of Erosive Forces at the Site

The site is located at the mouth of Whatcom Creek, upstream of the Whatcom Waterway (Figure 2-1). Typically, the types of potential erosive forces that are evaluated to ensure long-term cap stability in aquatic environments include stream flows, tidal flows, and wind or vessel-generated waves. However, because of the sheltered and non-navigable setting of the site, wind and vessel-generated waves are not significant, and are therefore unlikely to influence cap stability. Furthermore, wind waves coming in from Bellingham Bay cannot reach the location of this site because of the constriction at the Holly Street bridge and the relatively shallow depths of this area. Therefore, stream and tidal flows have been identified as the main factors contributing to potential erosive forces at the site.

4.5.2 Calculation Procedure

The required particle size gradation for cap and surface protection was determined using velocities computed within the creek channel for three different tide levels: mean low water level, mean tide level, mean higher high water level. These velocities were increased by a factor of 50 percent to provide an additional factor of safety (consistent with cap design methodology) to allow for higher velocities on the outside bends (U.S. Army Corps of Engineers 1991).

This design-level erosion analysis is expected to be additionally conservative because it does not expressly account for the fact that shallower side slopes tend to result in dissipation of velocity through turbulence, eddy formation, and friction. Above an elevation of +6 feet MLLW, the north bank at the site will generally be constructed at a shallower angle than below this elevation. The change of the slope creates a bench with a relatively shallow water depth, which will experience slower velocities, since most of the velocity will occur in the deeper portion of the main channel. Thus, this conservative analysis provides an additional factor of safety in the design.

For each design velocity, four different methods and diagrams were used to compute stable sediment size: Plate B-28 from the Engineering Manual EM 1110-2-1601 (later referenced as *Method 1*), the Hjulström (1935) and Shields (1936) diagrams (*Method 2* and *Method 3*), and Figure 5-5 of the Engineering Manual EM 1110-2-1418 (*Method 4*). All these diagrams are presented in Appendix E. For the Shields diagram, a dimensionless shear stress of 0.03 was used, and bottom shear stress was computed using the following formula:

$$\tau_b = \frac{1}{2}\rho f V^2$$

where ρ represents water density

f is a friction factor, equal to 0.03

V represents the design velocity

The results obtained with the different analyses were then compared to determine a stable rock size for each elevation range.

4.5.3 Flow Data and Calculations

Whatcom Creek inflow at the site is a combination of water originating in Lake Whatcom, tributary creeks, the adjacent fish hatchery, stormwater, and from tidal flows originating in the Whatcom Waterway. Currently, no gage has been installed at the site to record flow data. The peak stream flow measured at U.S. Geological Service (USGS) gage 12203500 on Whatcom Creek (upstream of the site) was 1,350 cubic feet per second (cfs) in 1950. The flow used by the Federal Emergency Management Agency (FEMA) for a 100 year flood condition on Whatcom Creek is 1,429 cfs (FEMA, 1982). This 100-year flow rate was used for the purpose of cap design.

Tidal flow contributions were also considered in the computation of potential flows and resultant bed velocities within the Whatcom Creek channel. The maximum flow velocity was computed for different water levels, since the river cross-sectional area changes with water surface elevation at different tidal stages, with a corresponding effect on bed velocity. The post-construction grading plan was used to determine cross-sectional areas.

Because tidal flows vary substantially over the tidal cycle, peak ebb and flood tide currents were calculated to correspond with maximum tidal exchange period. The maximum tidal flow velocity at ebb tide was found to be approximately 0.1 feet per second, which was added to the peak measured flow velocity in Whatcom Creek to determine the design velocity. Clearly, at this site, flood flows were determined to be more significant than tidal flows as contributors to erosional force.

4.5.4 Armor Requirements

The cap armor analyses were performed using the methods described above for three different tidal conditions and their corresponding water levels and velocities. The calculated water velocities at three tide levels in the design flood event are presented in Table 4-1. The four different methods led to different sediment sizes, as presented in Table 4-2.

Table 4-1
Design Velocities in Whatcom Creek

Peak River Flow (feet^3/second)[a]	Tide Level (feet)[b]	Average Cross-Secondtional Area (feet^2)[c]	V_{River} (feet/second)[d]	V_{Tide} (feet/second) [e]	V_{Total} (feet/second)[f]	V_{Design} (feet/second)[g]
1,429	MHHW: 8.5	854	1.67	0.14	1.81	2.7
1,429	MTL: 5.1	464	3.07	0.08	3.15	4.7
1,429	MLW: 2.5	221	6.44	0.04	6.48	9.7

Table 4-2
Stable Sediment Size and Type in Whatcom Creek

Tide Level (feet)[b]	V_{Design} (feet/second) [g]	Method 1 D_{50} (inches)	Method 2 D_{50} (inches)	Method 3 D_{50} (inches)	Method 4 D_{50} (inches)	Design D_{50} (inches)	Elev. Range (feet)
MHHW	854	0.6	0.4	0.2	—	0.6	8.5 and above
MTL	464	1.6	0.7	0.6	0.4	1.6	5.1 to 8.5
MLW	221	7.0	3.2	2.7	3.2	7.0	Bed to 5.1

a Peak River Flow is 100 year flood event as defined by FEMA.

b Tide level is shown for Mean Higher High Water (MHHW), Mean Tide Level (MTL), and Mean Lower Low Water (MLLW) conditions.

c This column gives the average post-construction cross-sectional area of Whatcom Creek in the site area for the three different tide elevations.

d V_{River} is the velocity of the water at the three different tide stages. This velocity was computed using the Peak Flow and the cross-sectional area, for different tide elevations.

e V_{Tide} is the ebb tide water velocity for the different tide elevations.

f V_{Total} is the sum of V_{River} and V_{Tide}.

g V_{Design} was computed by multiplying V_{Total} by 1.5

The erosion analyses indicate that the banks may need to be protected with large cobble or spalls at and below approximately +5.1 feet MLLW in order to ensure their stability during the 100-year flood condition. Above this elevation, the required armor size becomes smaller with increasing elevation, with a coarse gravel required at an elevation at and below approximately +8.5 feet MLLW. At upper intertidal elevations (+8.5 feet MLLW and above), a fine gravel was determined to be stable.

Potential erosive forces were further addressed in this design by specifying construction of a rock berm along the north bank, which will protect the adjacent north bank shoreline from both tidal and flood-induced peak flows. The lower elevations of the rock berm (at and below roughly +5 feet MLLW) require armoring with a spall-sized material.

4.5.5 Incorporation of Armor Into Cap Design

The rock armoring described above has been incorporated into the constructed caps on the north and south banks. On the north bank, placing the required rock armor directly on the cap surface would conflict with the goal of establishing vegetation. Therefore the armoring material will be placed below the topsoil and cap layers, in a (minimum) 6-inch-thick layer between the cap material and the surface topsoil layer. This buried layer of armoring material will act as a protective barrier against erosion of the cap in the event of a design-level flood event, thus cap preventing erosion and potential exposure of refuse should the flood erode the overlying topsoil layers. It is expected that the surficial topsoil layer will remain stable during most conditions, particularly after the stand of vegetation has been established.

Additional protection against erosion of the north bank will be provided by the following design features:

- Construction of a rock berm along that portion of the bank that encounters the highest flows
- Establishment of a stable stand of vegetation in the surfacial cap topsoil
- Placement of a biodegradable erosion control fabric (coir) on the surface of slopes inclined at 4H:1V or steeper

On the south bank, the constructed rock buttress will be composed of a rock size sufficient to resist erosion, as described above. The surface of the rock buttress will be covered by a layer of gravel that will be more amenable to safe public access. If a design-level flood event removes some of this gravel layer, then the remaining armoring rock will remain to resist further erosion of the south bank.

4.6 Upland Cap Design

The potential for human and environmental exposure to refuse and associated soil contaminants will be controlled through construction and maintenance of a minimum 2-foot-thick permeable cap or equivalent direct contact exposure barrier. A soil cap meeting this specification is already in place throughout the southeast lobe of the landfill (Maritime Heritage Park) and in most of the northwest lobe of the site.

However, based on pre-remedial design sampling data, in limited areas of the site, the existing cap is insufficient (i.e., less than 2-feet-thick and also not overlain by asphalt or concrete barriers), and requires augmenting to meet containment specifications set forth in the CAP. Localized areas within the Maritime Heritage Center (fish hatchery) contain only a thin cover (less than 2 feet thick) and therefore will require a cap amendment. The delineated capping area is depicted on the accompanying Project plans. The upland cap will be constructed concurrent with the shoreline remedy.

Below elevation +10 feet MLLW, the upland cap area will be first excavated and then capped so that the minimum 2-foot-thick cap thickness is achieved without modifying currently existing grades, thereby incurring no net loss of aquatic area. The cap will be carried down to elevation +6 feet MLLW. Above elevation +10 feet MLLW, minor regrading will be accomplished to provide trail continuity.

4.7 Water Quality Protection

Water quality controls will be implemented as a part of this action. Dredge elutriate testing conducted on composited sediment from the site (see Appendix B) indicated that the only possible exceedances of screening levels would be from the particulates generated by turbidity releases. Therefore if turbidity is controlled, water quality standards will be met. Turbidity releases will be prevented by restricting in-water work windows to low tide conditions, and using erosion control BMPs such as rolling and smoothing freshly excavated surfaces. These controls are described in more detail in the accompanying specifications and CQAP.

5 HABITAT RESTORATION

5.1 Ecological Context of Site

The project site is located within the Whatcom Creek Estuary at the mouth of Whatcom Creek, immediately upstream of the Whatcom Waterway in Bellingham Bay. Whatcom Creek flows four miles from its origin in Lake Whatcom to its mouth at Bellingham Bay. The creek is located within Water Resource Inventory Area (WRIA) 1, which encompasses:

- The Nooksack River watershed
- Adjacent drainages that enter the Strait of Georgia, Bellingham Bay, Chuckanut Bay, the north portion of Samish Bay, and portions of the Sumas and Chilliwack River watersheds
- Associated estuarine, nearshore, and marine areas

Estuaries and nearshore marine habitat, such as the Whatcom Creek Estuary, typically provide juvenile salmonids with abundant prey during critical growth periods, and refuge from high stream flows and predators. Estuaries also provide both spawning adults and outmigrating juveniles transition or staging sites for the physiological shift from fresh to salt water (Simenstad et al. 1982).

Salmonids from multiple creek and river systems utilize inner Bellingham Bay and the Whatcom Creek Estuary. Chinook, coho, chum, and pink salmon, as well as steelhead and cutthroat trout have all been documented to spawn in Whatcom Creek (Whatcom Conservation District et al. 2001, City of Bellingham unpublished data). Subyearling juvenile chinook and chum salmon are the most estuarine-dependent salmon species, as they tend to have more extended estuary residence times and utilize the inner marsh areas more extensively than other species (Simenstad et al. 1982, Aitkin 1998).

The shoreline of the Whatcom Creek Estuary, however, is comprised of bulkheads or relatively steep banks of solid waste, resulting in substantially degraded habitat functions for juvenile salmonids. The vertical shoreline configuration reduces the surface area of habitat inundated and exposed during tidal cycles, hinders the establishment of marsh vegetation at middle and upper tidal elevations, and accelerates the velocity of stream and tidal flows (which flushes detritus and small fish downstream). This reduction in the extent and diversity of natural estuarine and nearshore marine habitats, such as tidal sloughs, mudflats/sandflats, sand/gravel beaches and salt marshes, has negatively impacted Bellingham Bay's capacity to support the variety of fish, bird, and crustacean species that were historically abundant. The Whatcom Creek Estuary has been degraded much more dramatically than Bellingham's other estuaries, significantly impairing critical habitat functions, including the loss of transition or staging sites for salmonids' critical physiological shift from fresh to salt water.

5.2 Restoration Needs and Objectives

Degraded nearshore and estuarine habitat in the Whatcom Creek Estuary impacts recovery of the eight species of salmonids that spawn in tributaries to Bellingham Bay—two of which (chinook salmon and bull trout) are federally listed as threatened. Detailed habitat assessments of the area performed by a range of federal, state, and local entities have documented the degraded functions of nearshore/estuarine habitat in the project area. For example, baseline benthic and epibenthic samples recently collected by Western Washington University's Shannon Point Marine Center within the project area documented an extremely low diversity of fauna in this area (populations were dominated by only three species) (Bingham 2002). The highly degraded nature of existing nearshore/estuarine habitat in the project area has significantly impaired the function of this habitat for salmonids and other important stocks documented within the estuary. The interagency Bellingham Bay Pilot Team identified restoration of nearshore and estuarine habitat in the Whatcom Creek Estuary as one of the highest priority actions for the larger Bellingham Bay area (Pacific International Engineering and Anchor Environmental 1999), and has worked to coordinate restoration of the estuary with source control, cleanup, and land use plans, and with other restoration projects performed both upstream in Whatcom Creek and downstream within the Whatcom Waterway.

The overall objective of the proposed restoration elements of this project is to re-establish critical ecological functions of the historical estuarine habitat targeted at juvenile salmonids that were lost as a result of prior filling practices within the Whatcom Creek Estuary. More specifically the project will provide higher functioning early estuarine rearing habitat for Whatcom Creek salmonid populations and estuarine rearing habitat for Nooksack River and other Bellingham Bay salmonid populations. The habitat restoration actions are designed to improve the estuary's ecological functions supporting juvenile salmonids by:

- Increasing availability of upper intertidal shallow water habitat for refuge from predators
- Providing habitat structure that creates refuge from high flow events (high energy refuge)
- Increasing the productivity and prey resources of nearshore habitat through substrate enhancement (benthic and epibenthic productivity) and establishment of fringing emergent salt marsh and fringing riparian vegetation (terrestrial insects)
- Increasing the residence time within the estuary for detritus and small fish (physiological refuge)

Excavating upland fill deposits from the shoreline and widening this stretch of the estuary, and also softening and re-vegetating the shorelines with native species, will restore habitat diversity and functions more typical of a tidally-influenced estuary. Specific restoration actions for the project area include:

- Bank Softening: approximately 1,000 lineal feet of shoreline on both banks of the estuary will be converted to more gently sloped conditions. On the north side the reconstructed shoreline will have a maximum slope of 3H:1V, with most of the intertidal area softened to less than 8H:1V, to facilitate incorporation and retention of fine-grained substrate. On the south side, the vertical bulkhead will be replaced by a 2H:1V sloped shoreline, which will also serve to stabilize the existing bank.
- Increase Aquatic Area: the acreage of intertidal, estuarine habitat within the project area will be increased (particularly on the northern landfill lobe at middle to upper intertidal zones) by converting existing uplands into aquatic lands.
- Increase Riparian Buffer: the acreage of native riparian buffer will be expanded by removal of non-native invasive species, particularly on the northwest bank of the estuary where this buffer is nearly absent.
- Improve public education: enhanced community stewardship to promote long-term habitat protection

The restoration action will be integrated with the overall landfill cleanup project to ensure both short- and long-term water quality protection and to maximize overall project efficiencies, among other elements. Long-term monitoring and adaptive management will also be implemented to ensure the success of the restoration action. Future site use plans are consistent with maintaining long-term habitat restoration benefits, including more controlled park use on both the north and south banks, and redevelopment of industrial and commercial uses on the north side to new mixed use development. Provisions for public access will be integrated into the restoration design in a manner that protects the restored habitat from intensive human use in this urban environment.

5.3 Northern Landfill Lobe

The northern landfill lobe is currently characterized by steep slopes along the shoreline, fill, and primarily invasive vegetation (Photo 5-1). Habitat diversity and functions more typical of a tidally-influenced estuary will be restored in this area by excavating upland areas to widen the estuary and remove upland fill deposits, and also by softening and planting the shoreline with marsh and riparian vegetation.

Photo 5-1. View of the existing shoreline slope and riparian vegetation along the north side of the Whatcom Creek Estuary.

5.3.1 Upper Slope/Riparian Habitat

The upper portions of the shoreline (above +10 feet MLLW) will be regraded and replanted to provide riparian buffer habitat that more closely resembles what was historically found near the site. Non-native invasive vegetation that currently grows along the shoreline will be removed and would be replaced with woody riparian vegetation (native trees and shrubs). Approximately one half of an acre of riparian buffer habitat will be created within the northern landfill lobe along 500 linear feet of shoreline. This expanded and enhanced riparian habitat will increase nutrient and terrestrial prey inputs into the estuarine system. In the long-term, this habitat will also be a source of detritus and small woody debris that can provide structure for juvenile salmonids, and additional organic inputs to the estuary. Views of the creek from the proposed boardwalk, along with considerations related to future upland development and personal safety, will influence the density and height of proposed woody vegetation.

The upper portions of the shoreline (above +10 feet MLLW) will be constructed in layers. The first two lifts will consist of clean, relatively fine-grained capping material, such as a moderately silty fine sand or equivalent material.. The third (surface) lift will consist of 12 inches of manufactured topsoil (60 percent sand and sandy loam, and 40 percent composted organic matter by volume). In areas that will have slopes inclined at 4H:1V or steeper, the upper bank area will be covered with a coconut fiber (coir) biodegradable erosion control fabric.

5.3.2 Lower Bench/Estuarine Marsh Habitat

The lower bench will be restored to support emergent marsh vegetation. Approximately one quarter of an acre of emergent marsh habitat will be created within the northern landfill lobe along 280 feet of shoreline. This emergent marsh habitat will provide prey resources for juvenile salmonids, refuge from predators, refuge habitat for outmigrating juvenile salmonids during their critical transition from fresh to saltwater, and potential refuge from Whatcom Creek's high flow events.

The lower bench of the shoreline begins at elevation +10 feet MLLW, where the surface would become a relatively flat slope (6H:1V or flatter) to the limit of excavation (+6 feet MLLW). The constructed shoreline between elevation +10 to +6 feet MLLW forms a bench that would be designed to recolonize with emergent marsh vegetation. Between elevation +10 feet MLLW and the Mean Higher High Waterline (MHHW) at elevation +8.5 feet MLLW, high marsh vegetation, consisting of a mixture of native grasses, herbaceous perennials, and a few tree and shrub species is proposed. Species colonizing this zone may include *Potentilla pacifica*, *Deschampsia cespitosa*, *Aster subspicatus*, *Malus fusca, Crataegus douglasii, Symphoricarpos albus*. Driftwood will be placed in this high marsh zone. This material will consist of logs, with or without root wads. This material could include piles removed from the project area if they are not treated with wood preservatives. This zone is the elevation range where this material naturally would "ground out" and accumulate. Placing this material adds habitat structure that meets the functional criteria for juvenile salmonids. Between elevations +8.5 feet MLLW (the Mean Higher High Waterline) and +6 feet MLLW low marsh vegetation will be planted. This type of vegetation is currently found on the north and south sides of the creek (primarily *Carex lyngbyei*). It grows in a narrow band of elevation based on the degree of tidal inundation it requires (Thom et al. 2000).

The substrate in this bench will be constructed in four separate lifts of material, similar to the cap structure used for the riparian zone. The first two lifts will each consist of 12 to 18 inches of clean, relatively fine-grained silty sand capping material, to achieve a total cap thickness of 2 to 2.5 feet. The third lift will consist of a 6-inch-thick (minimum) layer of armoring gravel to protect against erosion of underlying refuse in a design-level flood event. The final (surface) lift will consist of topsoil that is different than the topsoil used in the upland riparian zone. The topsoil for the marsh will be more moisture retentive and have a lower organic matter content than the topsoil used in the upper bank.

5.3.3 Intertidal Side Channel

Immediately upstream of the marsh bench, a side channel is proposed in the intertidal zone. This channel is approximately 180 feet long and will be constructed out of a gravel and spalls berm with a 2H:1V maximum slope and partly buried, anchored large woody debris. The top of the gravel berm will be set between +7 and +8 feet MLLW. The bottom of the channel will be two to three feet lower. The berm will also serve to protect the base of the newly re-graded planted slope from erosion by high flow events. Just upstream, Whatcom Creek enters the tidal basin at relatively steep gradient and is pinched by the presence of the fish hatchery concrete bulkhead. These two factors combined generate the highest velocities (and potential erosion) during peak stream flow events affecting the project area. The side channel is designed to create more diverse habitat structure in the intertidal zone within the northern landfill lobe. The channel bottom will trap fine-grained materials for the establishment of a benthic invertebrate community. Anchored large woody debris (18 to 24 inch diameter Douglas Fir or Western Red Cedar logs with rootwads attached) placed on the outboard side of the upstream 80 linear feet of the gravel berm in this intertidal zone will provide habitat structure and refuge, and will trap fine sediments and organic debris. The logs will be anchored in-place using a combination of structural anchors and through their burial within the berm.

5.4 Southern Landfill Lobe

The shoreline along the southern landfill lobe contains remnant portions of a failing wood bulkhead and derelict wooden piling (Photo 5-2).

Photo 5-2. View of the south shoreline section containing a failing wood bulkhead.

Habitat restoration in the southern landfill lobe will involve shoreline stabilization and softening of the slope. Along the downstream 170 feet of the shoreline the bulkhead is relatively intact, but in very poor condition. Along this section, a wedge constructed of spalls topped by gravel is proposed at a 2H:1V slope to buttress the landfill slope and eliminate the vertical bulkhead effect on the habitat. The toe of this buttress is the channel bottom, which varies in elevation (+2 to -4 feet MLLW), and the top is a maximum of +8 feet MLLW (set 0.5 feet below the Mean Higher High Waterline elevation). Along the upstream 280 feet of the south shoreline, the eroded bank will be softened by a combination of excavating near vertical lobes of landfill material and placing gravel and spalls at gentler slopes down to existing grades. The toe of this regraded slope is the channel bottom, which varies in elevation (+2 to –4 feet MLLW), and the top is a maximum of elevation +13 feet MLLW (the existing path edge). Gravel will be placed up to elevation +10 feet MLLW in this location due to the slope. No new riparian or marsh plantings are proposed on the south lobe of the landfill since extensive riparian plantings exist and the new grades are too steep for marsh plantings. Overall, no loss of aquatic area is proposed in this location.

5.5 Public Access

One of the objectives of this project is to improve public education and stewardship in order to promote long-term habitat protection. Public access has been incorporated into the overall project design to address existing community open space goals and planning objectives. Habitat restoration within the Whatcom Creek Estuary will provide an opportunity to educate the public about critical estuarine environments as a result of these public access components.

Within the northern landfill lobe, a new shoreline boardwalk trail is proposed in the middle to upper level of the bank in the riparian zone, and above the lower bench/marsh zone. The trail will run parallel to the shoreline approximately 500 feet and link to Holly Street on the west and the fish hatchery path on the east. From there, the existing access route will ultimately connect to the Whatcom Creek Trail over an existing bridge.

The boardwalk foundation design will be compatible with the cap and refuse beneath it. This trail would be designed to allow for controlled public access and would be wheelchair accessible. Two viewpoint/lookouts will be located along the boardwalk at the Astor Street right-of-way and along the proposed side channel. These viewpoints will allow for better views of the creek and educational activities. The Astor Street viewpoint is intended to align with a future open space corridor/pathway in the future development planned by the City. This viewpoint is larger (15 feet by 30 feet) than the upstream viewpoint (10 feet by 20 feet). Both viewpoints include benches facing the creek.

The southern landfill lobe area is part of the City's Maritime Heritage Park, and already includes an extensive network of trails and interpretive exhibits, along with an environmental education classroom facility. These trails are linked into the larger Whatcom Creek Trail Master Plan. A 180 foot long, redundant segment of trail that will be disturbed by construction will be removed and restored to riparian vegetation. One viewpoint/lookout will be constructed on the upstream end of this segment of deleted trail. This viewpoint will have a similar design to the viewpoints on the north side and will provide controlled access for viewing and educational activities. This viewpoint is 20 feet by 10 feet. This portion of the creek is located in an urban area and currently receives heavy fishing pressure that needs to be accommodated to protect the restored habitat. The portion of the shoreline where the path is proposed to be removed is a good location to provide access for fishing from the shoreline. Construction of the viewpoint/lookout will not result in any permanent disturbance riparian vegetation. Handrails are included to protect existing riparian vegetation above the fishing access area and downstream of it where the band of vegetation is narrow. Access parallel to the shoreline will be provided by the existing trails to remain.

5.6 Future Plans for Site Use

Areas proposed for habitat restoration will remain in the uses described above. Adjacent to the north landfill lobe restoration area on the north side of the creek, future mixed use commercial/residential redevelopment is proposed by the City. Future adjacent redevelopment concepts will be consistent with the goals of maintaining the long-term viability of habitat restoration and public access benefits of this project.

5.7 Monitoring and Adaptive Management

The significant long-term habitat functional benefits expected to be provided by the project include:

- Increased benthic and epibenthic community production
- Expanded and enhanced rearing area for juvenile salmonids and other resources
- Enhanced migratory corridor for juvenile salmonids
- Improved habitat connectivity between Whatcom Creek and Bellingham Bay

A habitat monitoring plan will be used to investigate, quantify, and verify these improvements to habitat function, by documenting benthic and epibenthic macroinvertebrate re-colonization and juvenile salmonid utilization in the Whatcom Creek Estuary. Details of the habitat monitoring plan were presented in the Project's Compliance Monitoring and Contingency Response Plan (Anchor 2002a)

6 MONITORING

Compliance monitoring will be conducted during and following the remedial construction work at the site, in accordance with WAC 173-340-410, in order to confirm that cleanup requirements and long-term effectiveness have been achieved by the work. The three types of compliance monitoring to be conducted include the following:

- **Protection Monitoring** to confirm that human health and the environment are adequately protected during the construction period of the cleanup action.
- **Performance Monitoring** to confirm that the cleanup action has attained cleanup standards and other performance standards.
- **Confirmation Monitoring** to confirm the long-term effectiveness of the cleanup action once performance standards have been attained.

The compliance monitoring activities are documented in the Compliance Monitoring and Contingency Response Plan (Anchor 2002a), previously approved by Ecology. More detailed requirements of the Compliance Monitoring and Contingency Response Plan for the site, consistent with the Consent Decree, are documented in the CQAP, included as a companion document to this DAR in the Draft Final design submittal package.

The CQAP incorporates relevant sections of the Consent Decree concerning protection monitoring to confirm that human health and the environment are adequately protected during construction, and performance monitoring to confirm that the construction action attains cleanup goals.

7 INSTITUTIONAL CONTROLS

Institutional controls are measures undertaken to limit or prohibit activities that may interfere with the integrity of a cleanup action or result in exposure to hazardous substances at the site. Such measures are required to assure continued protection of human health and the environment when a cleanup action results in residual concentrations of indicator hazardous substances that exceed cleanup levels set forth in the CAP, and where conditional points of compliance have been established. Installing temporary fencing around the active landfill removal area during construction will provide access restrictions.

Site uses would be constrained by restrictive covenants that are required by MTCA (WAC 170-340-440(4)(a)). Elements of the restrictive covenants for the site include prohibition of activities that would damage the integrity of the soil cover or equivalent structural cap placed over the waste material. Consistent with the requirements of the Consent Decree, the City and other settling landowners will add restrictive covenants to their property deeds that will restrict the property use and allow implementation of the remedial action proposed in this document. The City intends to obtain agreements from other owners of the site that they concur with placing a deed restriction on their property. The form and recording schedule for the Restrictive Covenants are set forth in the Consent Decree.

8 OPINION OF PROBABLE COST

The designer's Opinion of Probable Construction Cost is summarized in Table 8-1. Quantities and volumes of construction materials were determined from the Project Plans. Unit costs were developed from a combination of information provided by the City and local Contractors, and from experience with other local projects.

The unit cost of soil and refuse disposal is particularly significant in this overall cost estimate. The $30/ton unit rate for transport and disposal is based on recent discussions with the City's Public Works Department and with the Rabanco regional solid waste landfill, and is consistent with the City's existing solid waste disposal agreement with Rabanco. Excavated material is expected to be transported from the project site by truck to a transfer station and to the Rabanco facility by rail. Other solid waste facilities may also be considered during procurement.

The unit cost of capping material is based on an assumed upland source of the material, potentially as a truck back haul from the rail transfer facility (e.g., Rabanco).

A 15 percent contingency has been applied to the cost estimate to account for current unknowns in the final design and possible quantity increases in the field during construction.

The current total estimate cost for construction and construction monitoring is approximately $1.5 million. Other costs for construction administration and long term monitoring are as shown.

Insert Table 8-1 page 1

Insert Table 8-1 page 2

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Table 8-1
Opinion of Probable Cost of Construction

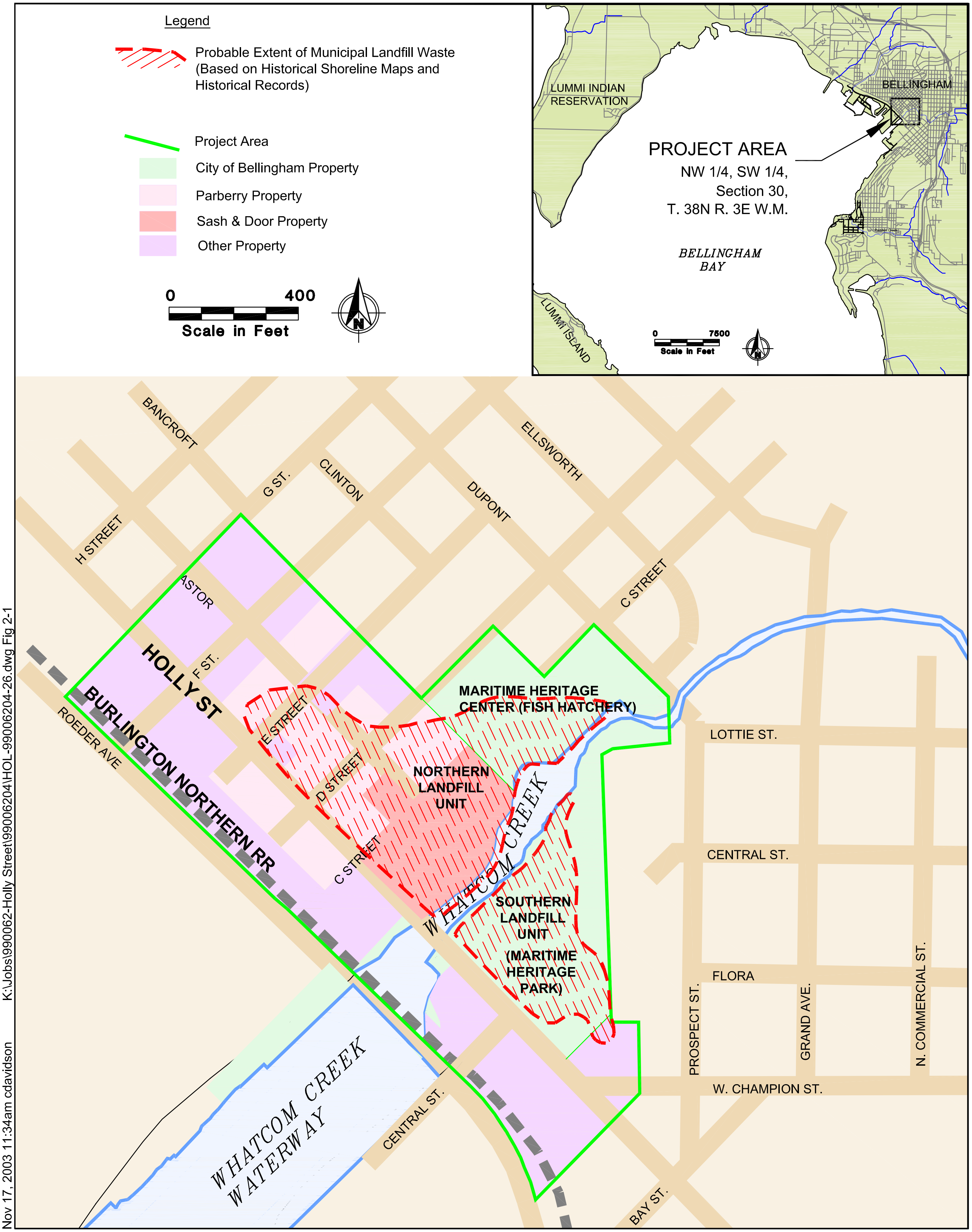
Item	Qty.	Unit	Unit Cost	Subtotal
1. Demolition and Clearing				
A. Mobilization	10,000	LS	$ 1.00	$ 10,000
B. Clear and grub site	21,000	SF	$ 0.10	$ 2,100
C. Remove and dispose of asphalt paving	23,500	SF	$ 1.10	$ 25,850
D. Remove and dispose of concrete blocks and rubble	250	CY	$ 25.00	$ 6,250
E. Remove and dispose of wood bulkhead	1	LS	$ 5,000.00	$ 5,000
F. Remove and dispose of wood piles	1	LS	$ 10,000.00	$ 10,000
G. Salvage park's items (benches, boulders, logs) for reuse	1	LS	$ 5,000.00	$ 5,000
H. Miscellaneous demolition	1	LS	$ 10,000.00	$ 10,000
Subtotal Demolition				**$ 74,200**
2. Temporary Facilities				
A. Temporary construction fencing: including staging area	1,200	LF	$ 6.00	$ 7,200
B. Tree protection fencing: north and south sides	700	LF	$ 6.00	$ 4,200
C. Temporary erosion control	1	LS	$ 10,000.00	$ 10,000
Subtotal Temporary Facilities				**$ 21,400**
3. Earthwork				
A. Excavation of refuse to subgrade	12,400	Ton	$ 7.00	$ 86,800
B. Off-site disposal of excavated refuse	12,400	Ton	$ 30.00	$ 372,000
C. Purchase, deliver, and install cap material	3,300	Ton	$ 20.00	$ 66,000
D. Purchase and install Type A topsoil (above el. +10 MLLW)	600	CY	$ 30.00	$ 18,000
E. Purchase and install Type B topsoil (below el. +10 MLLW)	500	CY	$ 30.00	$ 15,000
F. Purchase and install well-graded gravel for cap protection	400	CY	$ 25.00	$ 10,000
G. Purchase and install spalls	1,300	CY	$ 35.00	$ 45,500
H. Purchase and install riprap	20	CY	$ 40.00	$ 800
I. Purchase and install surficial gravel	600	CY	$ 25.00	$ 15,000
J. Purchase and install geotextile	2,000	SY	$ 10.00	$ 20,000
Subtotal Earthwork				**$ 649,100**
4. Cast-in-Place Conc.				
A. Concrete grid paving at entry points	1,133	SF	$ 10.00	$ 11,330
B. Concrete sidewalks and paths	623	SF	$ 5.00	$ 3,115
C. Concrete seatwalls	52	LF	$ 50.00	$ 2,600
D. Concrete thickened edge	25	LF	$ 30.00	$ 750
Subtotal Cast-in-Place Concrete				**$ 17,795**
5. Boardwalk and Viewpoints				
A. 8' wide boardwalk with handrail and bullrail on pipe pile foundation	4,065	SF	$ 44.20	$ 179,673
B. Viewpoints/lookout with handrail on pipe pile foundation	673	SF	$ 55.25	$ 37,183
C. South Bank vegetation protection handrail	285	LF	$ 41.65	$ 11,870
C. Viewpoint 5' benches	8	EA	$ 750.00	$ 6,000
E. Reinstall salvaged benches, boulders and logs at upland viewpoint (next to hatchery)	1	LS	$ 5,000.00	$ 5,000
Subtotal Boardwalk and Viewpoints				**$ 239,727**
6. Planting and Irrigation				
A. Temporary irrigation: riparian planting	20,690	SF	$ 0.60	$ 12,414
B. Coir fabric	1,000	SY	$ 9.00	$ 9,000
C. Planting: habitat restoration				
1.Trees				
Large 5'-6' ht. B&B	10	EA	$ 102.00	$ 1,020
Small 5 gal. 10' O.C.	25	EA	$ 54.00	$ 1,350
2. Shrubs				
2 gal. 5' O.C.	303	EA	$ 18.00	$ 5,454
1 gal. 3' O.C.	861	EA	$ 13.50	$ 11,624
1 gal. 2' O.C.	1,613	EA	$ 13.50	$ 21,776
Live stakes 2' O.C.	203	EA	$ 2.00	$ 406
3. Grasses 4" pot 2' O. C.	6,500	EA	$ 7.50	$ 48,750
D. Large woody debris placement	21	EA	$ 200.00	$ 4,200
E. Driftwood placement	1	LS	$ 8,000.00	$ 8,000
F. Goose exclosure	10,500	SF	$ 1.50	$ 15,750
G. Hydroseed: Ecology lawn	1,303	SF	$ 0.25	$ 326
H. Mulch: riparian area	170	CY	$ 25.00	$ 4,250
Subtotal Planting and Irrigation				**$ 144,319**

Table 8-1
Opinion of Probable Cost of Construction

Item	Qty.	Unit	Unit Cost	Subtotal
7. Monitoring				
A. Surveying	1	LS	$ 20,000.00	$ 20,000
B. Water quality monitoring	1	LS	$ 40,000.00	$ 40,000
Subtotal Monitoring				**$ 60,000**
8. Integrated Art Budget	1	LS	$ 20,000.00	**$ 20,000**
Subtotal Construction				**$ 1,206,540**
Contingency (15%)				**$ 180,981**
Subtotal				**$ 1,387,521**
Sales Tax (8.1%)				**$ 112,389**
TOTAL ESTIMATED COST				**$ 1,499,911**
Other Costs:				
Construction administration / documentation 10%				$ 138,752
Contract administration 5%				$ 69,376
Year 2 long-term monitoring and reporting				$ 60,000
Year 5 long-term monitoring and reporting				$ 50,000
Year 10 long-term monitoring and reporting (if needed)				$ 40,000

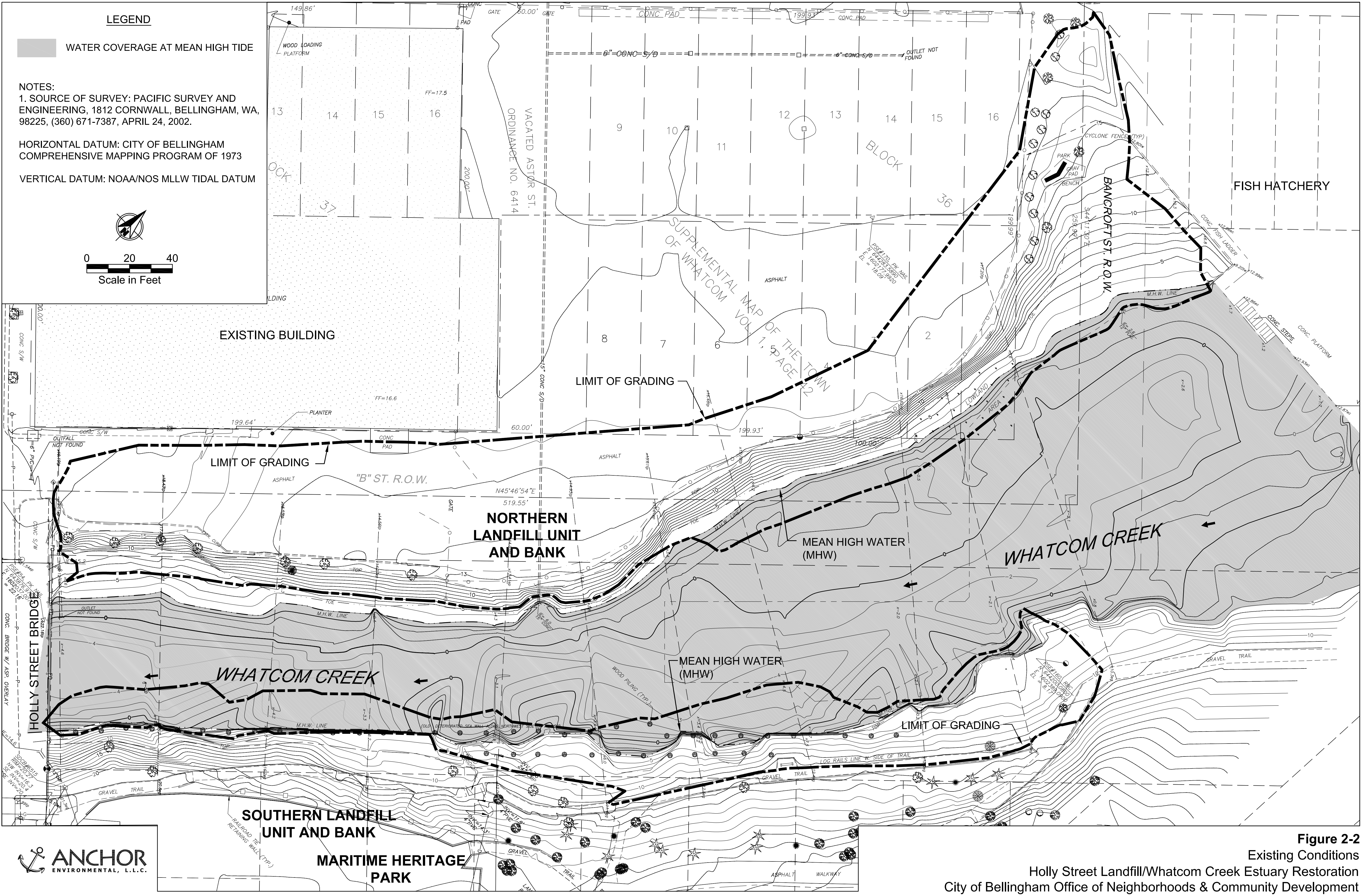
Note: This Opinion of Probable Cost is made on the basis of the Consultant's professional judgement and experience. The Consultant has no control over the cost or availability of labor, equipment, or materials, nor over market conditions that might affect the bidders' method(s) of pricing. The Consultant therefore makes no warranty, express or implied, that the bids or negotiated cost of the Work will not vary from this, the Consultant's opinion of the probable construction cost.

Nov 17, 2003 11:34am cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-26.dwg Fig 2-1



ANCHOR
ENVIRONMENTAL, L.L.C.

Figure 2-1
Project Area
Holly Street Landfill/Whatcom Creek Estuary Restoration
City of Bellingham Office of Neighborhoods & Community Development



LEGEND

▨ WATER COVERAGE AT MEAN HIGH TIDE

NOTES:

1. SOURCE OF SURVEY: PACIFIC SURVEY AND ENGINEERING, 1812 CORNWALL, BELLINGHAM, WA, 98225, (360) 671-7387, APRIL 24, 2002.

HORIZONTAL DATUM: CITY OF BELLINGHAM COMPREHENSIVE MAPPING PROGRAM OF 1973

VERTICAL DATUM: NOAA/NOS MLLW TIDAL DATUM

Feb 18, 2004 11:39am cadtemp K:\Jobs\990062-Holly Street\99006204\HOL-99006204-22.dwg Fig 2-2

ANCHOR ENVIRONMENTAL, L.L.C.

Figure 2-2

Existing Conditions

Holly Street Landfill/Whatcom Creek Estuary Restoration

City of Bellingham Office of Neighborhoods & Community Development

Feb 19, 2004 3:39pm cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-48.dwg fig 3-1

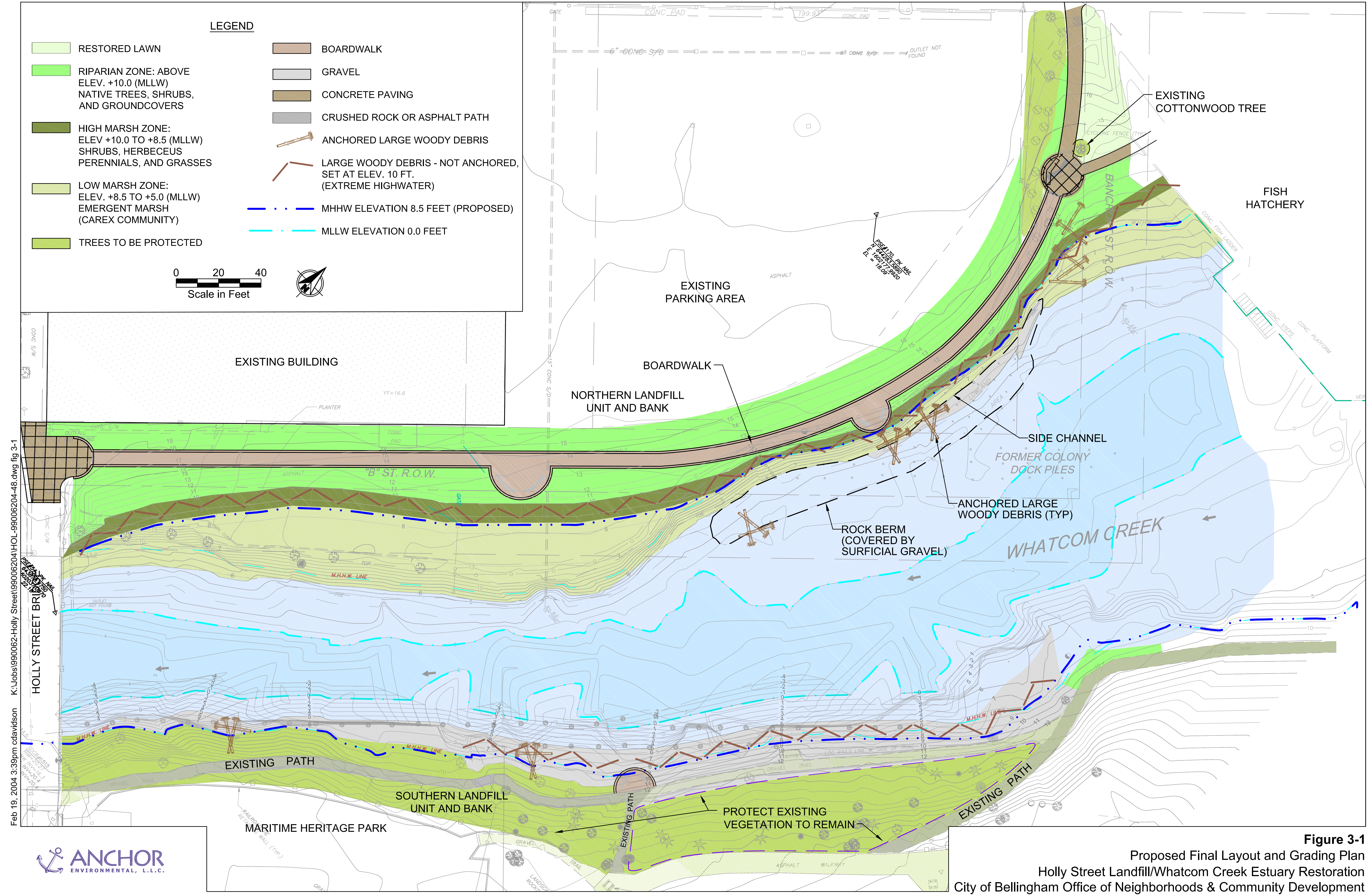
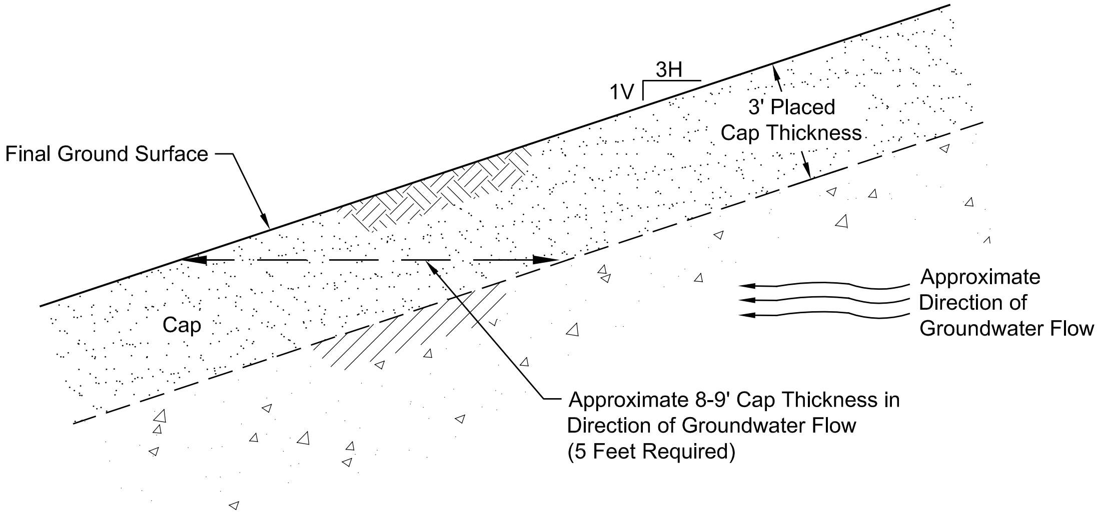
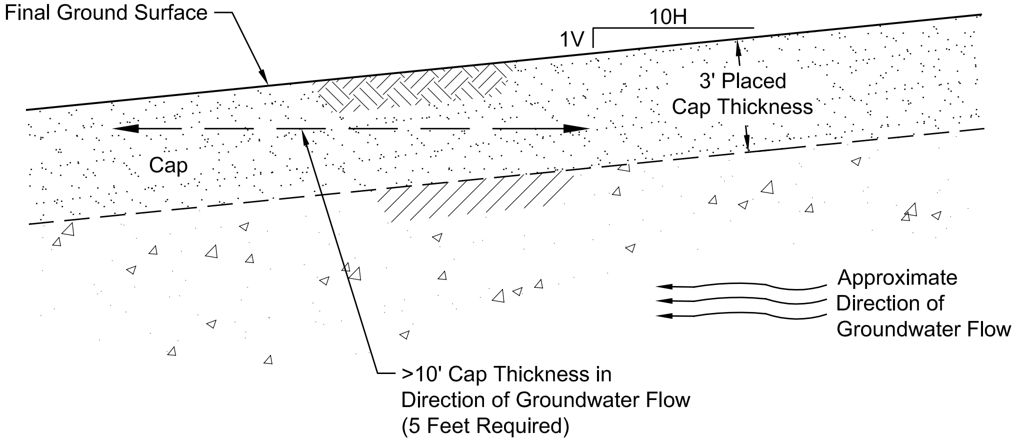


Figure 3-1
Proposed Final Layout and Grading Plan
Holly Street Landfill/Whatcom Creek Estuary Restoration
City of Bellingham Office of Neighborhoods & Community Development



A 3H:1V Slope



B. 10H:1V Slope

Plotted: Nov 17, 2003 11:51am cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-27.dwg FIG 4-1

ANCHOR
ENVIRONMENTAL, L.L.C.

Figure 4-1
Illustration of Cap Design Thickness
Holly Street Landfill/Whatcom Creek Estuary Restoration
City of Bellingham Office of Neighborhoods & Community Development

APPENDIX A

SUBSURFACE SOILS DATA

This appendix presents the results of geotechnical explorations and laboratory testing accomplished on the site by various parties. Results from the following exploration programs are included herein:

- Anchor Environmental, L.L.C., Geotechnical Explorations for Boardwalk Design, 2003.
- GeoEngineers, Geotechnical Exploration for Holly Street Bridge, 2003.
- AESI, Inc., Monitoring Wells for Holly Street Landfill Remediation, 2000.
- BEK Engineering and Environmental, Inc., Monitoring Wells at Maritime Heritage Park, 2000.

Base maps, field exploration logs, and laboratory results for each of these exploration programs are provided in this Appendix, arranged in the same order as the list above.

FIELD AND LABORATORY METHODS
Geotechnical Explorations for Boardwalk Design, Anchor Environmental L.L.C., 2003

Anchor performed a geotechnical subsurface investigation program for design of the boardwalk element of this project. Field explorations consisted of four hollow-stem auger borings, drilled on October 6, 2003. The explorations were completed using a 3-3/8-inch inside diameter hollow-stem auger mounted on a truck-mounted drill rig subcontracted by Anchor. The borings were continuously observed by a field representative from Anchor.

Anchor's field representative prepared logs of each boring and the samples taken. Field descriptions were verified through visual observation and index testing in a geotechnical laboratory. Soil samples were obtained every five feet using a split spoon sampler and following sampling protocol for the Standard Penetration Test (SPT, per ASTM D 1587). The number of hammer blows required to drive the sampler the final 12 inches of an 18-inch sampling length constitutes the Standard Penetration Resistance, or "blow count", which serves as an approximate measure of soil density and consistency.

In some cases, very dense or hard soils precluded the ability to drive the sampler the entire 18 inch interval. In this event, the recorded blow count is number of blows required to drive the sampler until refusal, not including the first six inches of penetration, combined with the number of inches driven after the first six. ("Refusal" is defined by ASTM D 1587 as 50 blows per six inches or less of penetration.) An example record would be 90/9", which indicates 90 blows to advance the sampler 9 inches (not including the first six inches of driving). In cases where the sampler meets refusal before six inches of penetration, the recorded blow count includes the total number of blows and the total number of inches driven.

Following Anchor's geotechnical field work, the samples obtained were sent to a geotechnical laboratory subcontracted to Anchor. This appendix includes the results of geotechnical laboratory testing on selected soil samples from our borings. The following is a brief description of the lab tests performed.

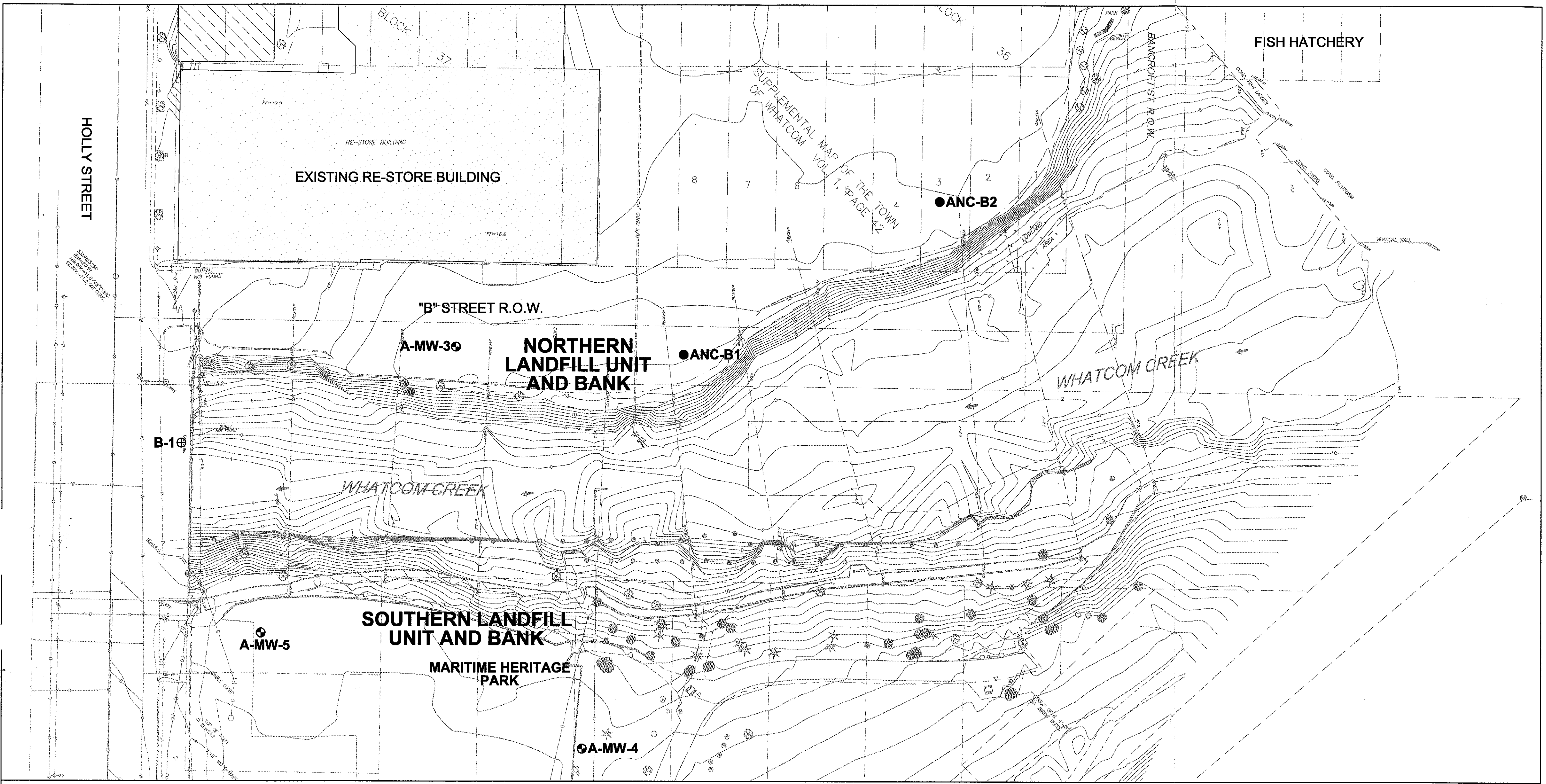
Moisture contents were determined for all samples in general accordance with ASTM D2216. The results are plotted at each sample's respective depth on the boring logs in Appendix A.

Grain-size analyses were performed in general accordance with ASTM D422. A hydrometer analysis was performed on the fines fraction (finer than the U.S. No. 200 sieve) for selected samples. The resulting plots of grain-size distribution are presented in this appendix. The results of these tests indicate the samples classify as the following:

Table A1
Soil Sample Classifications

Sample ID	Depth in Feet	Classification
ANC-B1-S6	28	SAND
ANC-B2-S4	18	Slightly gravelly, silty SAND
ANC-B2-S8	38	Silty SAND and GRAVEL

Nov 21, 2003 2:22pm cdavidson K:\Jobs\990062-Holly Street\990 HOL-9900 Fig 1-HSt



ANC-B1 ● GEOTECH EXPLORATION BORING LOCATION AND NUMBER (THIS INVESTIGATION)

A-MW-3⊙ MONITORING WELL LOCATION AND NUMBER (AESI, 2000)

B-1 ⊕ PREVIOUS GEOTECHNICAL EXPLORATION LOCATION AND NUMBER (GEOENGINEERS, 2003)

NOTES:
1. SOURCE OF SURVEY: PACIFIC SURVEY AND ENGINEERING, 1812 CORNWALL, BELLINGHAM, WA, 98225, (360) 671-7387, APRIL 24, 2002.

HORIZONTAL DATUM: CITY OF BELLINGHAM COMPREHENSIVE MAPPING PROGRAM OF 1973

VERTICAL DATUM: NOAA/NOS MLLW TIDAL DATUM

0 50
Scale in Feet

ANCHOR ENVIRONMENTAL, L.L.C.

Figure 1
Site and Exploration Plan
Holly Street Landfill Redevelopment

Sample Description

Classification of soils in this report is based on visual field and laboratory observations which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field nor laboratory testing unless presented herein. Visual–manual classification methods of ASTM D 2488 were used as an identification guide.

Soil descriptions consist of the following:
Density/consistency, moisture, color, minor constituents, MAJOR CONSTITUENT, additional remarks.

Density/Consistency

Soil density/consistency in borings is related primarily to the Standard Penetration Resistance.
Soil density/consistency in test pits is estimated based on visual observation and is presented parenthetically on the test pit logs.

SAND or GRAVEL Density	Standard Penetration Resistance (N) in Blows/Foot	SILT or CLAY Consistency	Standard Penetration Resistance (N) in Blows/Foot	Approximate Shear Strength in TSF
Very loose	0 – 4	Very soft	0 – 2	<0.125
Loose	4 – 10	Soft	2 – 4	0.125 – 0.25
Medium dense	10 – 30	Medium stiff	4 – 8	0.25 – 0.5
Dense	30 – 50	Stiff	8 – 15	0.5 – 1.0
Very dense	>50	Very stiff	15 – 30	1.0 – 2.0
		Hard	>30	>2.0

Moisture

Dry	Little perceptible moisture
Damp	Some perceptible moisture, probably below optimum
Moist	Probably near optimum moisture content
Wet	Much perceptible moisture, probably above optimum

Minor Constituents

	Estimated Percentage
Not identified in description	0 – 5
Slightly (clayey, silty, etc.)	5 – 12
Clayey, silty, sandy, gravelly	12 – 30
Very (clayey, silty, etc.)	30 – 50

Legends

Sampling Test Symbols

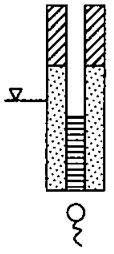
BORING SAMPLES

☒	Split Spoon
⧅	Shelby Tube
▥	Cuttings
◫	Core Run
*	No Sample Recovery
P	Tube Pushed, Not Driven

TEST PIT SAMPLES

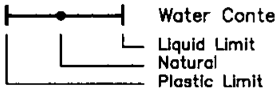
☒	Grab (Jar)
⧄	Bag
⧅	Shelby Tube

Groundwater Observations



Test Symbols

NS	No Sheen
SS	Slight Sheen
MS	Moderate Sheen
HS	Heavy Sheen
TCD	Triaxial Consolidated Drained
QU	Unconfined Compression
DS	Direct Shear
K	Permeability
PP	Pocket Penetrometer Approximate Compressive Strength in TSF
TV	Torvane Approximate Shear Strength in TSF
CBR	California Bearing Ratio
MD	Moisture Density Relationship
AL	Atterberg Limits



PID	Photoionization Detector Reading
CA	Chemical Analysis
DT	*In Situ* Density Test

Nov 21, 2003 2:20pm cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-44.dwg FIG A-1_HST

1=1 BORING.DWG

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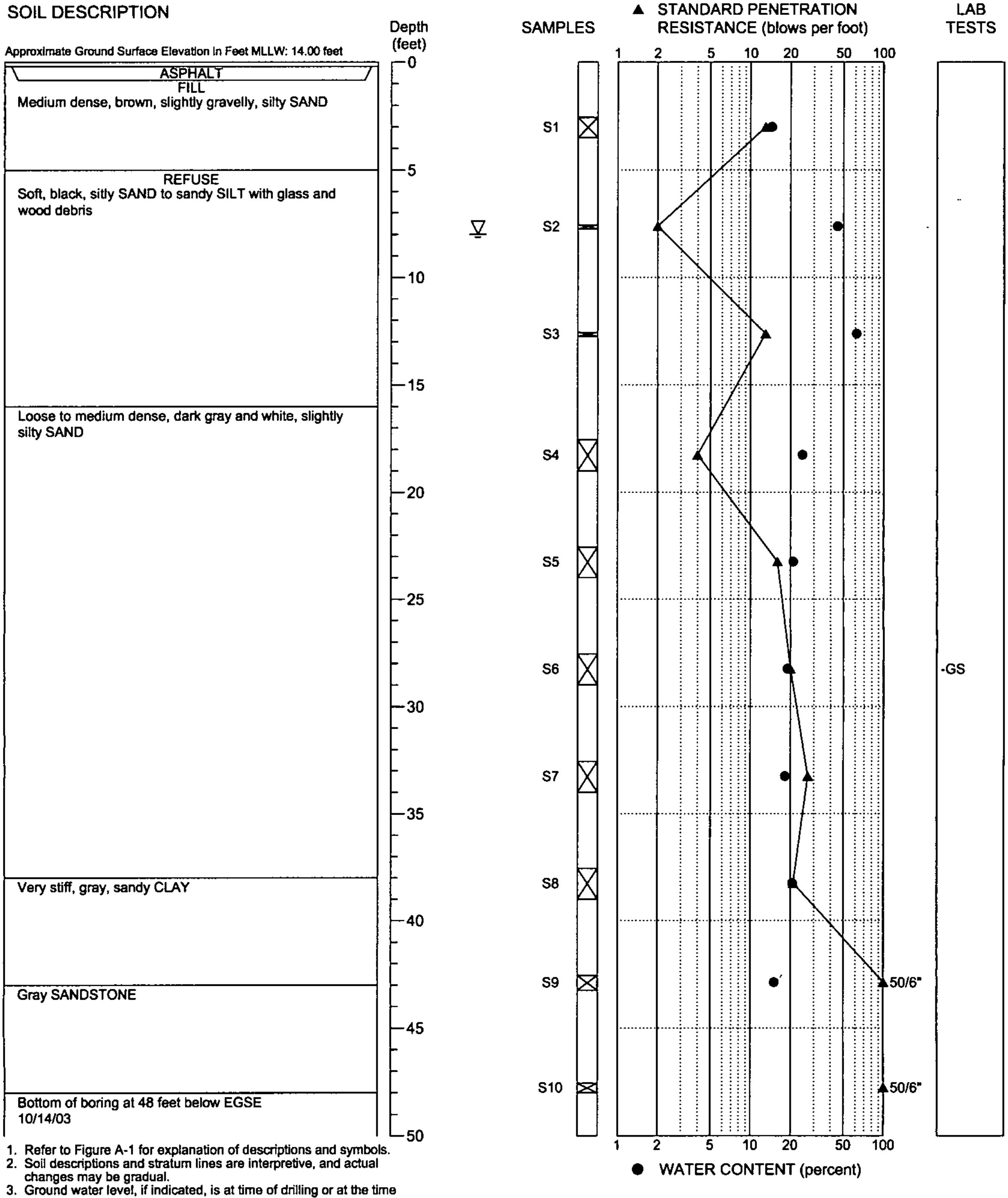
Figure A-1
Key to Exploration Logs
Holly Street Landfill Redevelopment

BORING: ANC-B1



1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive, and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling or at the time and date specified. Ground water level may vary with time.

Nov 21, 2003 2:21pm cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-38.dwg ANC-B1_HST

ANCHOR ENVIRONMENTAL, L.L.C.

Figure A-2
Boring ANC-B1
Holly Street Landfill Redevelopment

BORING: ANC-B2

SOIL DESCRIPTION

Approximate Ground Surface Elevation in Feet MLLW: 17.00 feet

ASPHALT

FILL

Medium stiff, dark gray, slightly sandy SILT

REFUSE

Medium stiff, dark gray to black, silty SAND to sandy SILT with glass and wood debris

-Sheen and petroleum odor observed in sample S-4

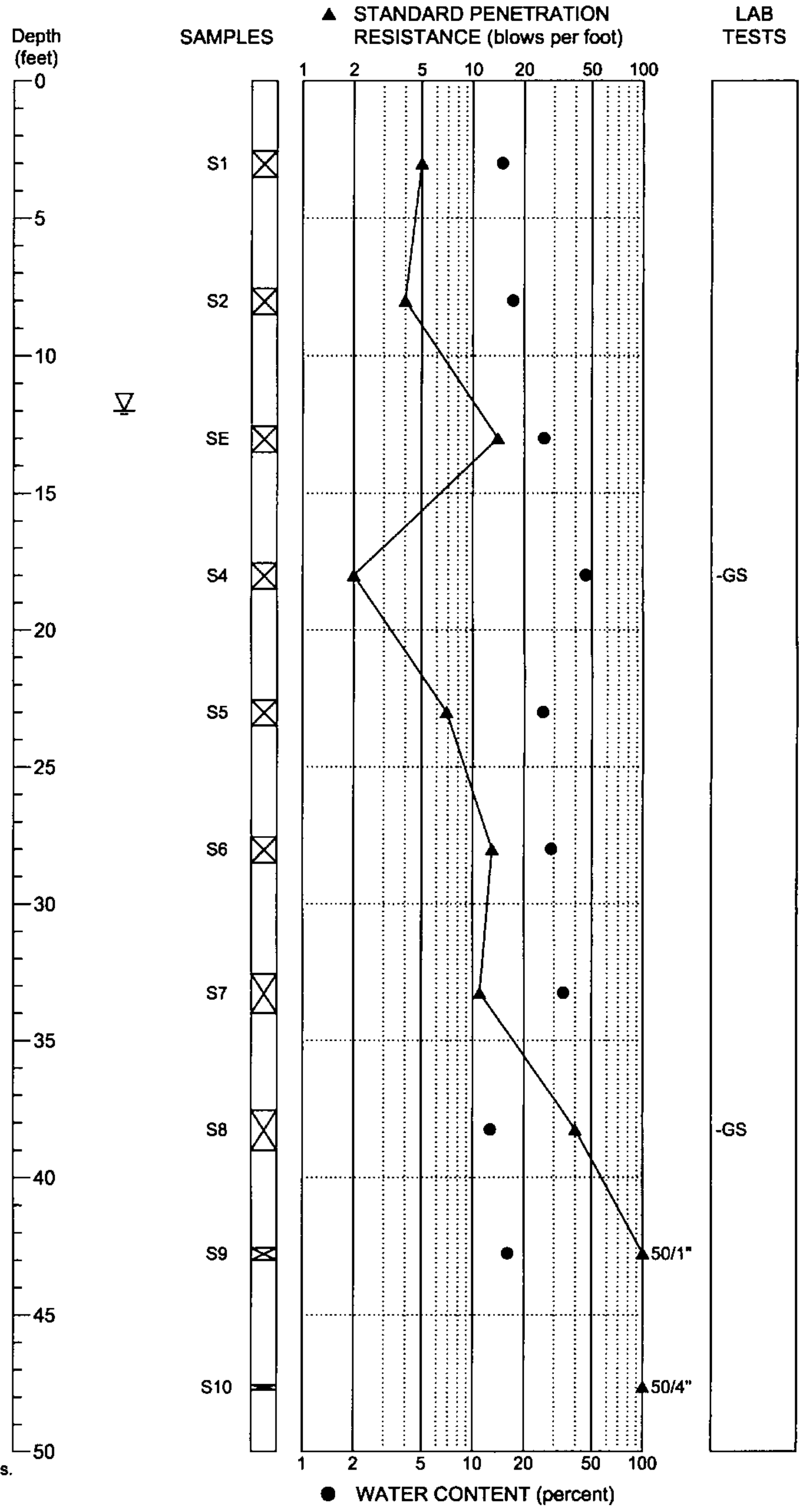
Loose to medium dense, dark gray and white SAND

Stiff, gray, silty CLAY

Dense, gray, clayey SAND and GRAVEL

Gray SANDSTONE

Bottom of boring at 48 feet below EGSE
10/14/03

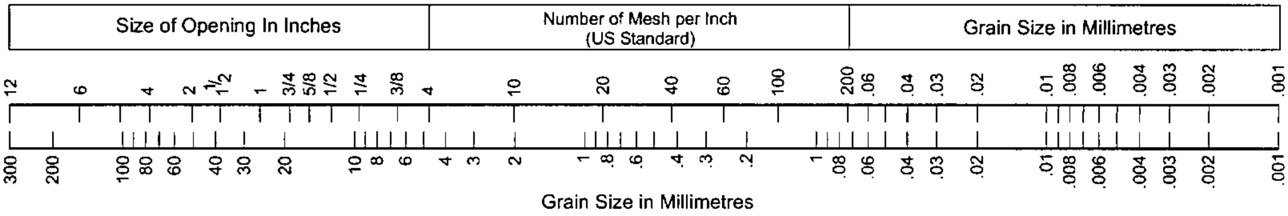


1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive, and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling or at the time and date specified. Ground water level may vary with time.

Nov 21, 2003 2:21pm cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-38.dwg ANC-B2_HST

ANCHOR
ENVIRONMENTAL, L.L.C.

Figure A-3
Boring ANC-B2
Holly Street Landfill Redevelopment



COBBLES	GRAVEL	SAND	SILT and CLAY
Coarse-Grained Soils			Fine-Grained Soils

Coarse-Grained Soils

G W	G P	G M	G C	S W	S P	S M	S C
Clean GRAVEL <5% fines		* GRAVEL with >12% fines		Clean SAND <5% fines		* SAND with >12% fines	
GRAVEL >50% coarse fraction larger than No. 4				SAND >50% coarse fraction smaller than No. 4			
Coarse-Grained Soils >50% larger than No. 200 sieve							

G W and S W $\left(\frac{D_{60}}{D_{10}}\right)$ >4 for G W, >6 for S W & $1 \leq \left(\frac{(D_{30})^2}{D_{10} \times D_{60}}\right) \leq 3$

G P and S P Clean GRAVEL or SAND not meeting requirements for G W and S W

G M and S M Atterberg limits below A line with PI <4

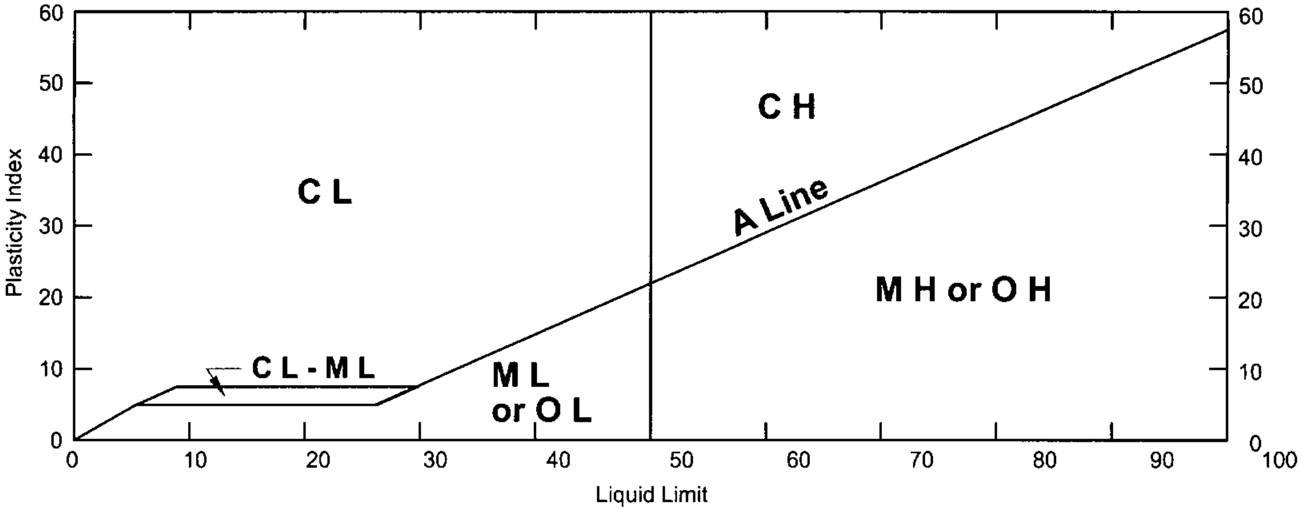
G C and S C Atterberg limits above A Line with PI >7

* Coarse-grained soils with percentage of fines between 5 and 12 are considered borderline cases required use of dual symbols.

D_{10}, D_{30}, and D_{60} are the particles diameter of which 10, 30, and 60 percent, respectively, of the soil weight are finer.

Fine-Grained Soils

M L	C L	O L	M H	C H	O H	Pt
SILT	CLAY	Organic	SILT	CLAY	Organic	Highly Organic Soils
Soils with Liquid Limit <50%			Soils with Liquid Limit >50%			
Fine-Grained Soils >50% smaller than No. 200 sieve						

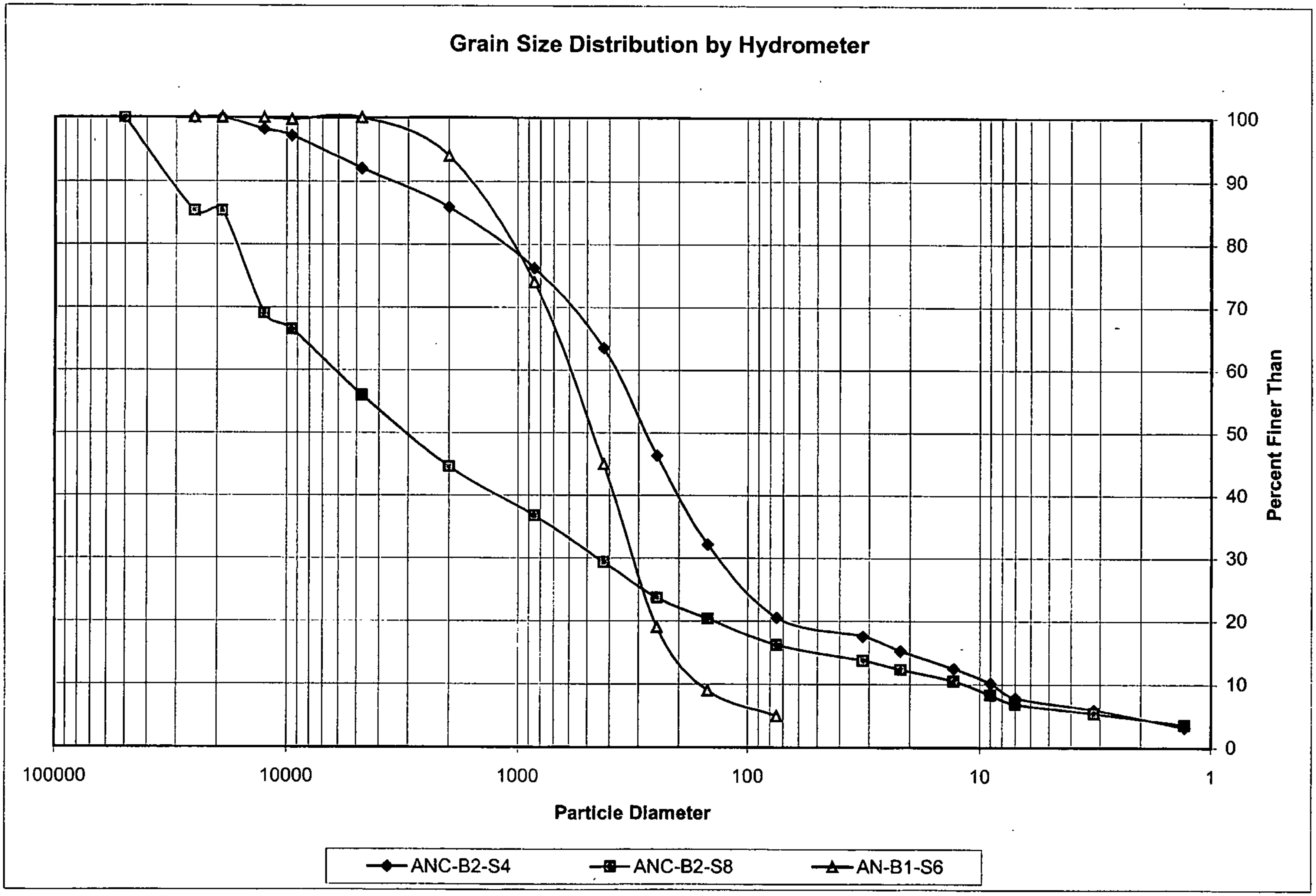


11/12/03 CVD K:\Jobs\990062-Holly Street\99006204\FIG B-1-GRAIN SIZE.cdr

ANCHOR ENVIRONMENTAL, L.L.C.

Figure B-1
Unified Soil Classification (USC) System
Soil Grain Size
Holly Street Landfill Redevelopment

ANALYTICAL
RESOURCES
INCORPORATED



SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GROUP SYMBOL	GROUP NAME
COARSE GRAINED SOILS More Than 50% Retained on No. 200 Sieve	GRAVEL More Than 50% of Coarse Fraction Retained on No. 4 Sieve	CLEAN GRAVEL	GW	WELL-GRADED GRAVEL, FINE TO COARSE GRAVEL
			GP	POORLY-GRADED GRAVEL
		GRAVEL WITH FINES	GM	SILTY GRAVEL
			GC	CLAYEY GRAVEL
	SAND More Than 50% of Coarse Fraction Passes No. 4 Sieve	CLEAN SAND	SW	WELL-GRADED SAND, FINE TO COARSE SAND
			SP	POORLY-GRADED SAND
		SAND WITH FINES	SM	SILTY SAND
			SC	CLAYEY SAND
FINE GRAINED SOILS More Than 50% Passes No. 200 Sieve	SILT AND CLAY Liquid Limit Less Than 50	INORGANIC	ML	SILT
			CL	CLAY
		ORGANIC	OL	ORGANIC SILT, ORGANIC CLAY
	SILT AND CLAY Liquid Limit 50 or More	INORGANIC	MH	SILT OF HIGH PLASTICITY, ELASTIC SILT
			CH	CLAY OF HIGH PLASTICITY, FAT CLAY
		ORGANIC	OH	ORGANIC CLAY, ORGANIC SILT
HIGHLY ORGANIC SOILS			PT	PEAT

NOTES:

1. Field classification is based on visual examination of soil in general accordance with ASTM D2488-93.
2. Soil classification using laboratory tests is in general accordance with ASTM D2487-98.
3. Descriptions of soil density or consistency are based on interpretation of blow count data, visual appearance of soils, and/or test data.

SOIL MOISTURE MODIFIERS:

Dry -	Absence of moisture, dusty, dry to the touch
Moist -	Damp, but no visible water
Wet -	Visible free water or saturated, usually soil is obtained from below water table

GeoEngineers

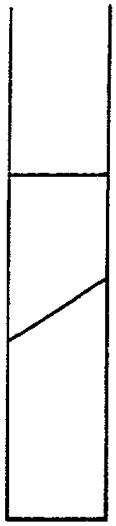
SOIL CLASSIFICATION SYSTEM

FIGURE 3

LABORATORY TESTS

AL	Atterberg Limits
CP	Compaction
CS	Consolidation
DS	Direct shear
GS	Grain size
%F	Percent fines
HA	Hydrometer Analysis
SK	Permeability
SM	Moisture Content
MD	Moisture and density
SP	Swelling pressure
TX	Triaxial compression
UC	Unconfined compression
CA	Chemical analysis

SOIL GRAPH:



SM Soil Group Symbol (See Note 2)

Distinct Contact Between Soil Strata

Gradual or Approximate Location of Change Between Soil Strata.

▽ Water Level

Bottom of Boring

BLOW COUNT/SAMPLE DATA:

Blows required to drive a 2.4-inch I.D. split-barrel sampler 12 inches or other indicated distances using a 300-pound hammer falling 30 inches.

- 22 ■ Location of relatively undisturbed sample
- 12 ☒ Location of disturbed sample
- 17 ☐ Location of sampling attempt with no recovery

Blows required to drive a 1.5-inch I.D. (SPT) split-barrel sampler 12 inches or other indicated distances using a 140-pound hammer falling 30 inches.

- 10 ◨ Location of sample obtained in general accordance with Standard Penetration Test (ASTM D-1586) procedures
- 25 ◫ Location of SPT sampling attempt with no recovery

☰ Location of grab sample

"P" indicates sampler pushed with weight of hammer or against weight of drill rig.

NOTES:

1. The reader must refer to the discussion in the report text, the Key to Boring Log Symbols and the exploration logs for a proper understanding of subsurface conditions.
2. Soil classification system is summarized in Figure 3.

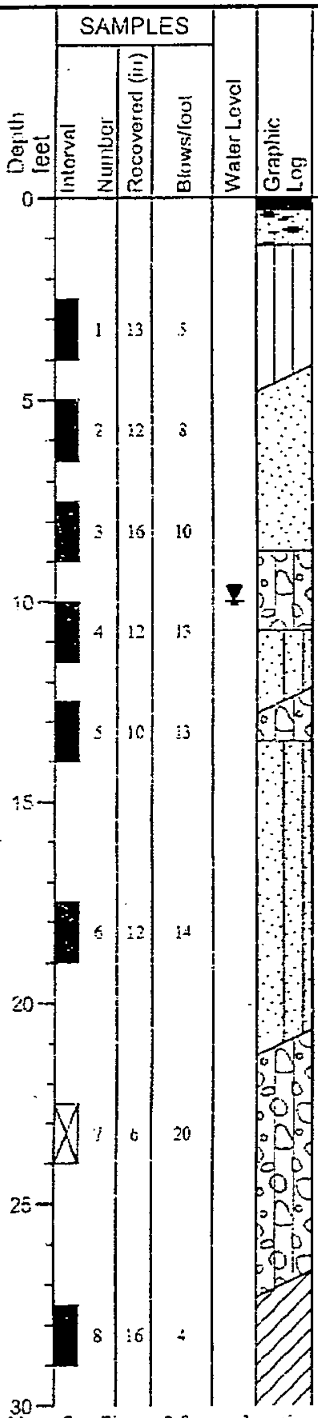
Geo Engineers

KEY TO BORING LOG SYMBOLS

FIGURE 4

Date(s) Drilled	3/24/03	Logged By	EMG	Checked By	EMG
Drilling Contractor	Subterranean, Inc.	Drilling Method	D&M	Sampling Methods	Mud Rotary
Auger Data		Hammer Data	300 (lb) hammer/ (in) drop Tri-Cone Bit	Drilling Equipment	B-61 Truck Mounted Drill Rig
Total Depth (ft)	89	Surface Elevation (ft)		Groundwater Level (ft. bgs)	
Datum/ System					

Number	Recovered (in)	Blows/foot	Water Content, %	Dry Unit Weight, lbs/ft³	OTHER TESTS AND NOTES
1	13	5	18	110	Su = 800psf (torvane)
2	12	8	11	103	
3	16	10	15	110	
4	12	13	10	113	
5	10	13	9	109	
6	12	14	15		%F=5,GS
7	6	20	15		
8	16	4	31	92	Su = 500psf (torvane)



Group Symbol	MATERIAL DESCRIPTION
AC	4 inches asphalt
CC	Concrete
ML	Brown sandy silt with occasional gravel (soft, moist) (fill)
SP	Tan and gray fine to medium sand with occasional gravel (fill)
GM	Gray silty fine gravel with sand and occasional sea shells (medium dense, wet) (fill)
SP-SM	Orangish brown fine to medium sand with occasional gravel (medium dense, wet)
GM	Fine to coarse gravel with silt and sand (loose, wet)
SP-SM	Light brown fine to medium sand with silt and occasional gravel (medium dense, moist)
GM	Grey fine to coarse gravel with sand (loose, wet)
CL	Gray clay with occasional sand (soft, moist)

Note: See Figure 2 for explanation of symbols

LOG OF BORING B-1

GeoEngineers

Project: City of Bellingham-Holly Street Bridge
Project Location: Bellingham, Washington
Project Number: 0356-073-00

Figure: 5
Sheet 1 of 3

0356-073-00 GEI G1BORING 2.1.0 C:\WINDOWS\DESKTOP\0356073.GPJ GEIV2_2.GDT 6/10/03

Depth feet	SAMPLES Interval	Number	Recovered (in)	Blows/foot	Water Level	Graphic Log	Group Symbol	MATERIAL DESCRIPTION	Water Content, %	Dry Unit Weight, lbs/ft^3	OTHER TESTS AND NOTES
30											
	▮	9	17	9				Note: Becomes medium stiff	19		AL (PI=19)
35											
								Note: Becomes sandy, very stiff			
	▮	10	18	24					34		AL (PI=34)
							SP	Black and white fine to medium sand (dense, wet)			
40							RX	Large boulder			
							SP	Gray and white fine to medium sand (very dense, wet)			
	▮	11	9	63					13	120	%F=6,GS
45											
								Note: Easier drilling from 45 to 47 feet			
	▮	12	10	71					17	117	%F=4,GS
50											
							CH	Gray clay with occasional sand (medium stiff to stiff, moist)			
	▮	13	17	7					33		AL (PI=35)
55											
	☐	14	0	20							No recovery
60											
	▮	15	18	11							
65								Note: Grades with occasional gravel			

LOG OF BORING B-1 (continued)

GeoEngineers

Project: City of Bellingham-Holly Street Bridge
Project Location: Bellingham, Washington
Project Number: 0356-073-00

Figure: 5
Sheet 2 of 3

0356-073-00 GEI GTBORING 2.1.0 C:\WINDOWS\DESKTOP\0356073.GPJ GEIV2_2.GDT 6/10/03

Depth feet	SAMPLES Interval	Number	Recovered (in)	Blows/foot	Water Level	Graphic Log	Group Symbol	MATERIAL DESCRIPTION	Water Content, %	Dry Unit Weight, lbs/ft^3	OTHER TESTS AND NOTES
70											
	■	16	18	7					37	98	AL (PI=41)
75											
80											
	☐	17	0	16							No recovery
85											
							RX	Gray sandstone			
	☒	18	5	60/.75							

Boring completed at 89 feet on 3/24/03
Groundwater encountered at 10 feet during drilling

LOG OF BORING B-1 (continued)

Geo Engineers

Project: City of Bellingham-Holly Street Bridge
Project Location: Bellingham, Washington
Project Number: 0356-073-00

Figure: 5
Sheet 3 of 3

Legend

Conceptual ground water flow direction based on data collected during the RI/FS.

Soil Boring/Well Installation Location

Well Points and/or Surface Sediment Sampling Locations

Surface Water Sampling Location

Probable Extent of Municipal Landfill Waste (Based on Historical Shoreline Maps and Historical Records)

Brownfield Project Area

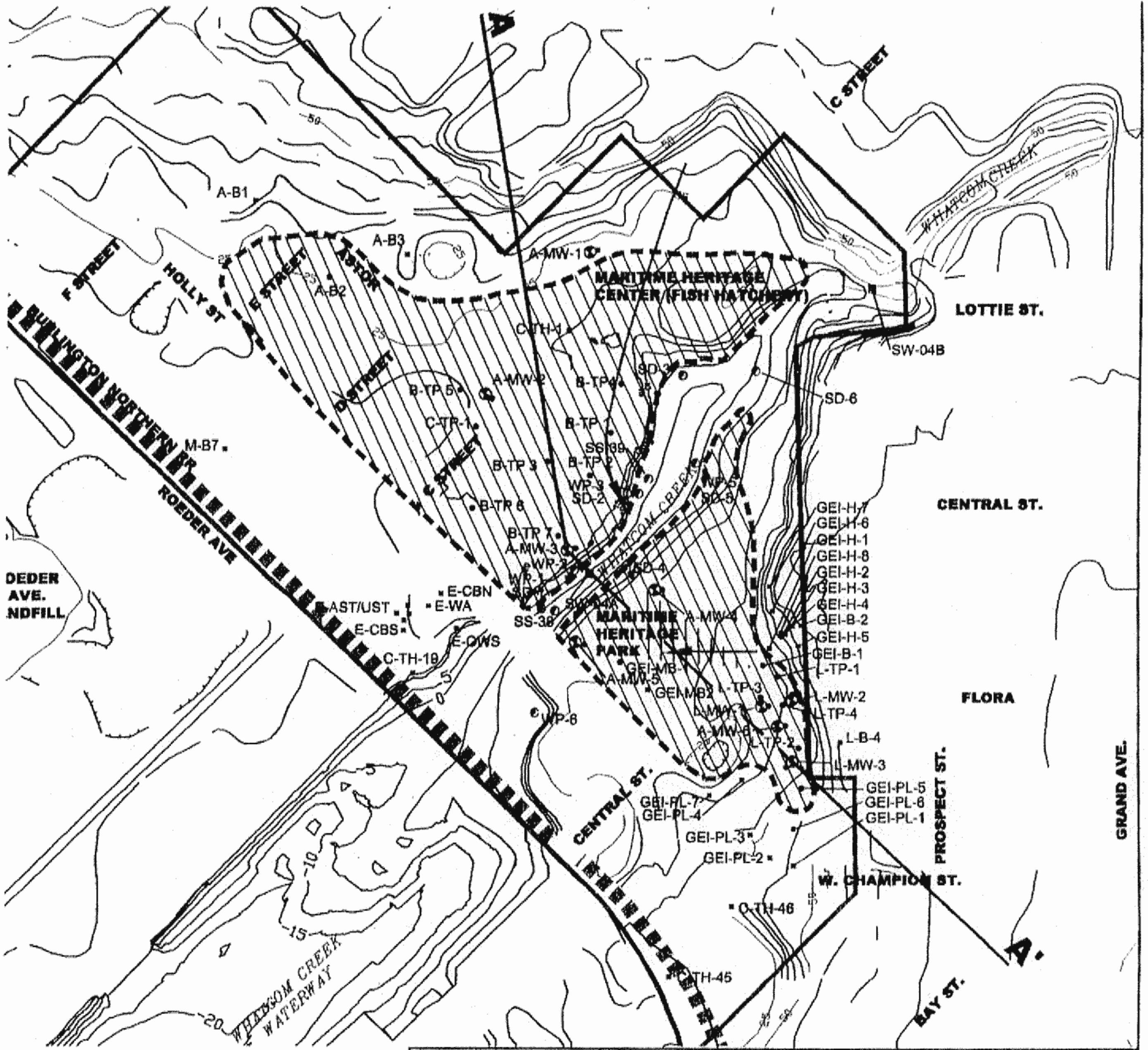
Solid Waste in Exploration

No Solid Waste in Exploration

A-MW-	Monitoring well sampled in 2000
WP-	Well point sampled in 2000
SD-	Surface sediment sampled in 2000
B-TP-	Test pit reported in BEK Purnell (1993)
C-TP/TH-	Test pit or test boring reported in City of Bellingham (1972)
E-	Soil boring reported in Entrix (1999)
GEI-H/B-	Hand boring or test hole boring reported in GeoEngineers (1998-2001)
L-TP/MW-	Test pit or soil boring/monitoring well sampling reported in Landau (1993)
GEI-PL-	GeoEngineers (1998-2001)
GEI-MB	GeoEngineers (1998-2001)

A — A' Line of Cross Section

0 200
Scale in Feet



Associated Earth Sciences, Inc.

Conceptual Ground Water Flow

Holly Street Landfill
Bellingham, Washington

PROJECT NO. BV00139
FIGURE NO. 4-1

ANCHOR ENVIRONMENTAL, L.L.C.

Coarse-Grained Soils - More than 50%(1) Retained on No. 200 Sieve	Gravels - More than 50%(1) of Coarse Fraction Retained on No. 4 Sieve	≤5% Fines(5)	**GW**	Well-graded gravel and gravel with sand, little to no fines
			GP	Poorly-graded gravel and gravel with sand, little to no fines
		≥15% Fines(5)	**GM**	Silty gravel and silty gravel with sand
			GC	Clayey gravel and clayey gravel with sand
	Sands - 50%(1) or More of Coarse Fraction Passes No. 4 Sieve	≤5% Fines(5)	**SW**	Well-graded sand and sand with gravel, little to no fines
			SP	Poorly-graded sand and sand with gravel, little to no fines
		≥15% Fines(5)	**SM**	Silty sand and silty sand with gravel
			SC	Clayey sand and clayey sand with gravel
Fine-Grained Soils - 50%(1) or More Passes No. 200 Sieve	Silts and Clays Liquid Limit Less than 50		**ML**	Silt, sandy silt, gravelly silt, silt with sand or gravel
			CL	Clay of low to medium plasticity; silty, sandy, or gravelly clay, lean clay
			OL	Organic clay or silt of low plasticity
	Silts and Clays Liquid Limit 50 or More		**MH**	Elastic silt, clayey silt, silt with micaceous or diatomaceous fine sand or silt
			CH	Clay of high plasticity, sandy or gravelly clay, fat clay with sand or gravel
			OH	Organic clay or silt of medium to high plasticity
Highly Organic Soils			**PT**	Peat, muck and other highly organic soils

Terms Describing Relative Density and Consistency

	Density	SPT(2) blows/foot
Coarse-Grained Soils	Very Loose	0 to 4
	Loose	4 to 10
	Medium Dense	10 to 30
	Dense	30 to 50
	Very Dense	>50
	Consistency	**SPT(2) blows/foot**
Fine-Grained Soils	Very Soft	0 to 2
	Soft	2 to 4
	Medium Stiff	4 to 8
	Stiff	8 to 15
	Very Stiff	15 to 30
	Hard	>30

Test Symbols

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

Component Definitions

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

(3) Estimated Percentage

Component	Percentage by Weight
Trace	<5
Few	5 to 10
Little	15 to 25
With	- Non-primary coarse constituents: ≥ 15% - Fines content between 5% and 15%

Moisture Content

Dry - Absence of moisture, dusty, dry to the touch

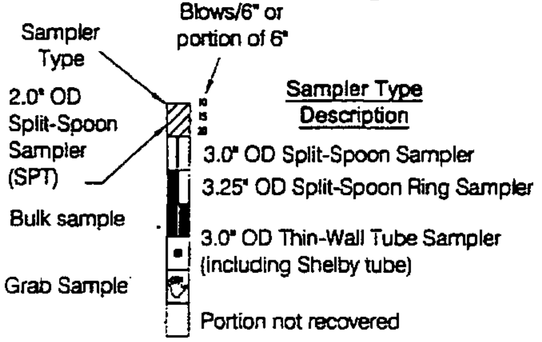
Slightly Moist - Perceptible moisture

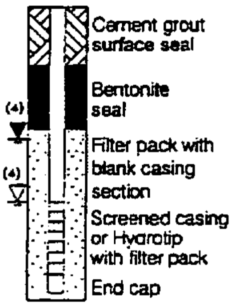
Moist - Damp but no visible water

Very Moist - Water visible but not free draining

Wet - Visible free water, usually from below water table

Symbols





(1) Percentage by dry weight
(2) (SPT) Standard Penetration Test (ASTM D-1586)
(3) In General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
(4) Depth of groundwater
▼ ATD = At time of drilling
▽ Static water level (date)
(5) Combined USCS symbols used for fines between 5% and 15%

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

log_key.dwg 03/29/00 1:1

ASSOCIATED
EARTH
SCIENCES, INC

Exploration Log Key

FIGURE
A-1

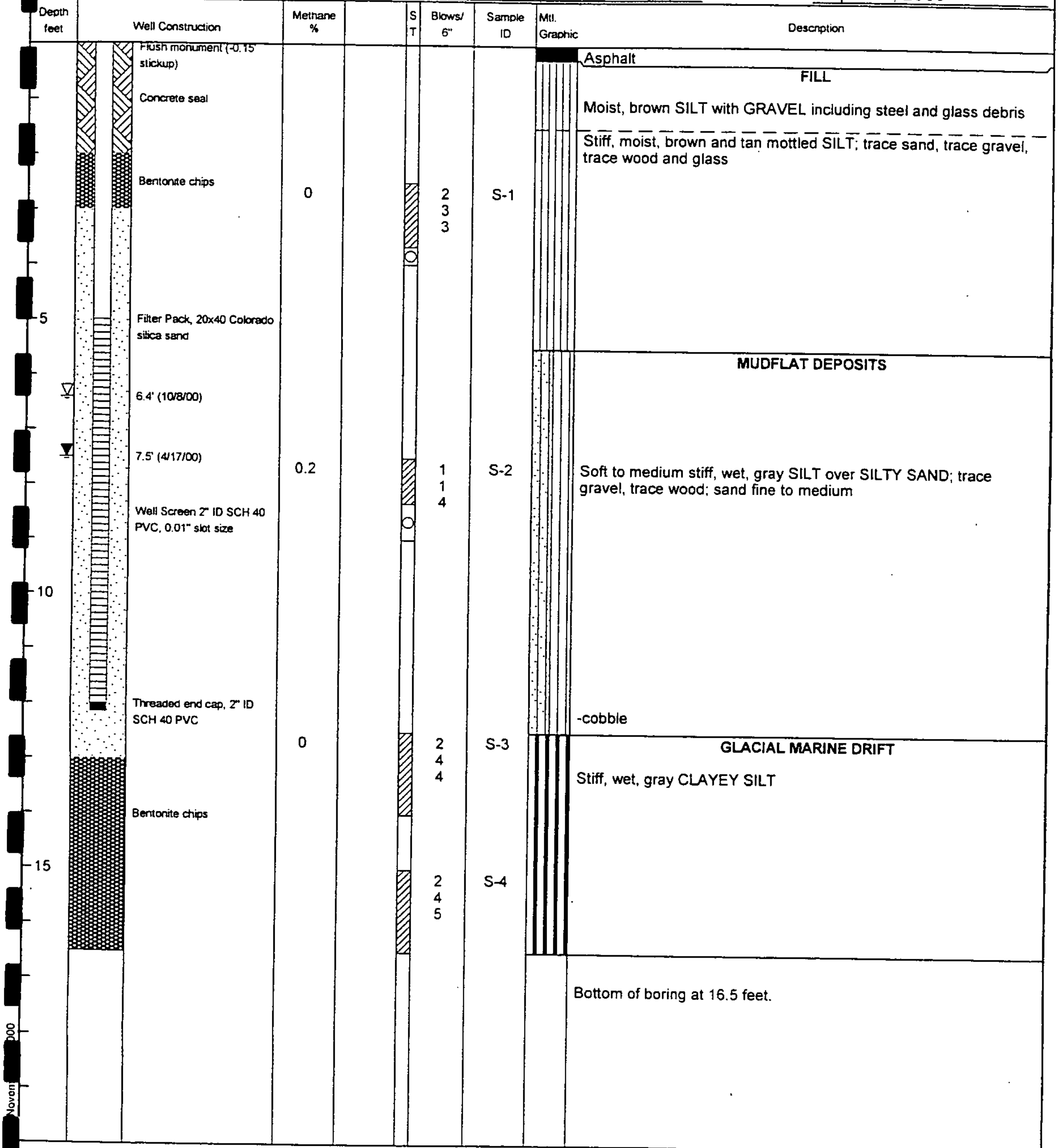
ASSOCIATED EARTH SCIENCES, INC

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
BV99139	A-MW-1	1 of 1

Project Name: Holly Street Landfill
Location: Bellingham, Washington
Drilling Method: Hollow Stem Auger 8" OD/ 4.5"ID
Sampling Method: 2" diameter, Split Spoon Sampler

Surface Elevation: 21.51
Water Depth (ft bgs): 6.4
Start Date: April 17, 2000
Finish Date: April 17, 2000



Depth feet	Well Construction	Methane %		S T	Blows/ 6"	Sample ID	Description
	Flush monument (-0.15' stickup)						Asphalt
	Concrete seal						**FILL** Moist, brown SILT with GRAVEL including steel and glass debris
							Stiff, moist, brown and tan mottled SILT; trace sand, trace gravel, trace wood and glass
	Bentonite chips	0		▨ ○	2 3 3	S-1	
5	Filter Pack, 20x40 Colorado silica sand						
							MUDFLAT DEPOSITS
	▽ 6.4' (10/8/00)						
	▼ 7.5' (4/17/00)	0.2		▨ ○	1 1 4	S-2	Soft to medium stiff, wet, gray SILT over SILTY SAND; trace gravel, trace wood; sand fine to medium
	Well Screen 2" ID SCH 40 PVC, 0.01" slot size						
10							
	Threaded end cap, 2" ID SCH 40 PVC						-cobble
		0		▨	2 4 4	S-3	**GLACIAL MARINE DRIFT** Stiff, wet, gray CLAYEY SILT
	Bentonite chips						
15				▨	2 4 5	S-4	
							Bottom of boring at 16.5 feet.

Sampler Type (ST):
- B Bag Sample
- ○ No Recovery
- ▨ 2" OD Split-Spoon Sampler

Lab Tests:
- G - Grain Size
- P - Permeability
- M - Moisture Content

▼ Water Level (ATD) ▽ Static Water Level

Logged by: RRH
Approved by: TJF

Figure No. A - 2

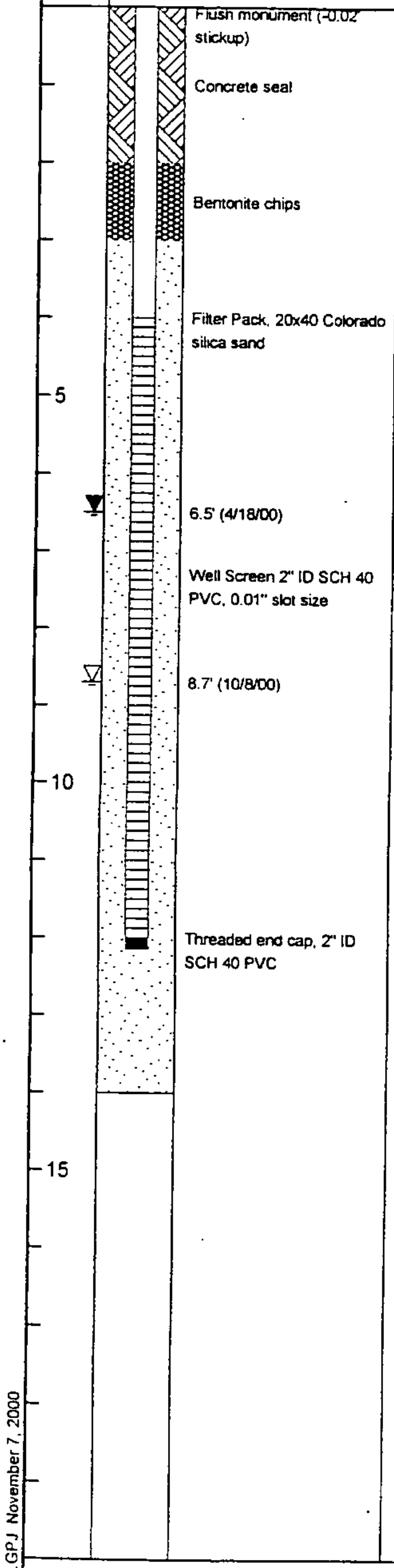
ASSOCIATED EARTH SCIENCES, INC

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
BV99139	A-MW-2	1 of 1

Project Name: Holly Street Landfill
Location: Bellingham, Washington
Drilling Method: Hollow Stem Auger 8" OD/ 4.5"ID
Sampling Method: 2" diameter, Split Spoon Sampler

Surface Elevation: 19.57
Water Depth (ft bgs): 8.7
Start Date: April 18, 2000
Finish Date: April 18, 2000



Depth feet	Well Construction	Methane %	S T	Blows/ 6"	Sample ID	Mtl. Graphic	Description
	Flush monument (-0.02 stickup)						Asphalt
							FILL Dark brown SILTY SAND with GRAVEL
	Concrete seal						
							LANDFILL DEBRIS Medium dense, moist to wet, brown SANDY GRAVEL with glass, rusted metal, and ash-like material
	Bentonite chips	0.2	▨ ○	5 6 14	S-1		
	Filter Pack, 20x40 Colorado silica sand						-cobble or large piece of debris
5		0.4	○	14 15 7	S-2		
	▼ 6.5' (4/18/00)						
	Well Screen 2" ID SCH 40 PVC, 0.01" slot size	0.4	▨ ○	1 0.5 0.5	S-3		-grades loose, wet and gray
	▽ 8.7' (10/8/00)						
10		0.4	▨ ○	1 1 1	S-4		-grades black; debris includes glass and metal
	Threaded end cap, 2" ID SCH 40 PVC						
		0.2	▨ ○	4 5 7	S-5		**MUDFLAT DEPOSITS** Medium dense, wet, dark gray to brown SILTY SAND with SILT interbeds; sand predominantly fine
15							Bottom of boring at 14 feet.

Sampler Type (ST):
- B Bag Sample
- ○ No Recovery
- ▨ 2" OD Split-Spoon Sampler

Lab Tests:
- G - Grain Size
- P - Permeability
- M - Moisture Content

▼ Water Level (ATD) ▽ Static Water Level

Logged by: RRH
Approved by: TJF
Figure No. A - 3

SPARKMW HOLLY.GPJ November 7, 2000

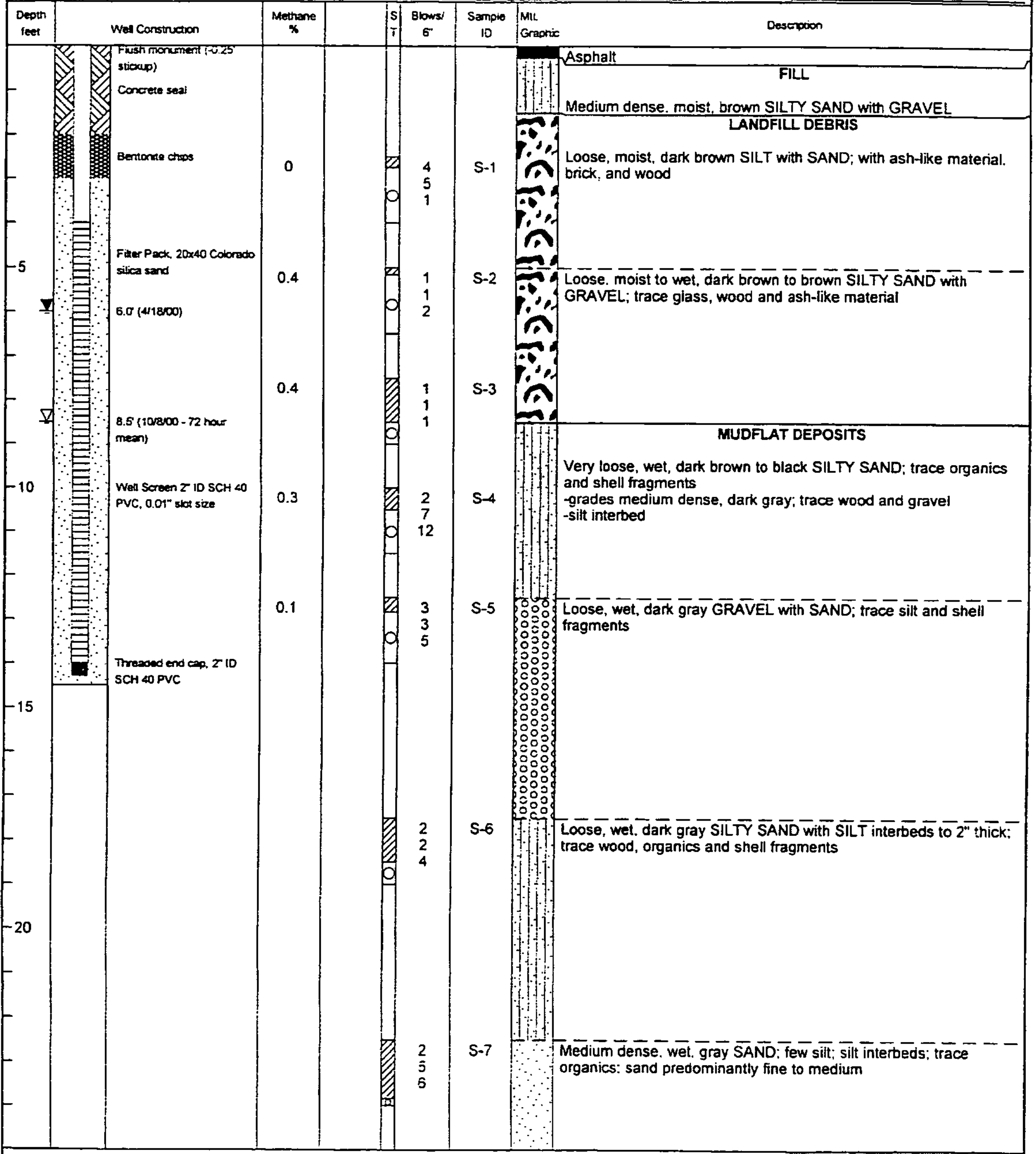
ASSOCIATED EARTH SCIENCES, INC

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
BV99139	A-MW-3	1 of 2

Project Name: Holly Street Landfill
Location: Bellingham, Washington
Drilling Method: Hollow Stem Auger 8" OD/ 4.5"ID
Sampling Method: 2" diameter, Split Spoon Sampler

Surface Elevation: 15.29
Water Depth (ft bgs): 8.5
Start Date: April 18, 2000
Finish Date: April 18, 2000



Depth feet	Well Construction	Methane %	ST	Blows/ 6"	Sample ID	Description
	Flush monument (-0.25' stickup) Concrete seal					Asphalt FILL Medium dense, moist, brown SILTY SAND with GRAVEL
	Bentonite chips	0		4 5 1	S-1	LANDFILL DEBRIS Loose, moist, dark brown SILT with SAND; with ash-like material, brick, and wood
5	Filter Pack, 20x40 Colorado silica sand 6.0' (4/18/00)	0.4		1 1 2	S-2	Loose, moist to wet, dark brown to brown SILTY SAND with GRAVEL; trace glass, wood and ash-like material
	8.5' (10/8/00 - 72 hour mean)	0.4		1 1 1	S-3	
10	Well Screen 2" ID SCH 40 PVC, 0.01" slot size	0.3		2 7 12	S-4	MUDFLAT DEPOSITS Very loose, wet, dark brown to black SILTY SAND; trace organics and shell fragments -grades medium dense, dark gray; trace wood and gravel -silt interbed
	Threaded end cap, 2" ID SCH 40 PVC	0.1		3 3 5	S-5	Loose, wet, dark gray GRAVEL with SAND; trace silt and shell fragments
15						
				2 2 4	S-6	Loose, wet, dark gray SILTY SAND with SILT interbeds to 2" thick; trace wood, organics and shell fragments
20						
				2 5 6	S-7	Medium dense, wet, gray SAND; few silt; silt interbeds; trace organics; sand predominantly fine to medium

Sampler Type (ST):
- B Bag Sample
- ○ No Recovery
- ▨ 2" OD Split-Spoon Sampler

Lab Tests:
- G - Grain Size
- P - Permeability
- M - Moisture Content

▼ Water Level (ATD) ▽ Static Water Level

Logged by: RRH
Approved by: TJF
Figure No. A - 4

SPARKMW HOLLY.GPJ November 7, 2000

ASSOCIATED EARTH SCIENCES, INC

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
BV99139	A-MW-3	2 of 2

Project Name Holly Street Landfill
Location Bellingham, Washington
Drilling Method Hollow Stem Auger 8" OD/ 4.5"ID
Sampling Method 2" diameter, Split Spoon Sampler

Surface Elevation 15.29
Water Depth (ft bgs) 8.5
Start Date April 18, 2000
Finish Date April 18, 2000

Depth feet	Well Construction	Methane %		S T	Blows/ 6"	Sample ID	Mtl. Graphic	Description
				▨ ○	4 5 7	S-8		-silty sand interbeds
30								
				▨ ○	4 5 8	S-9		-predominantly medium sand
35								
								GLACIAL MARINE DRIFT
				▨ ○	3 11 9	S-10		Very stiff, wet, gray CLAYEY SILT with 2" sand interbed
40								Bottom of boring at 39.5 feet. Original boring grouted with bentonite and cement. Moved 5 ft toward the creek and drilled to 14.5' with plug in auger then installed monitoring well
45								

Sampler Type (ST):
- B Bag Sample
- ○ No Recovery
- ▨ 2" OD Split-Spoon Sampler

Lab Tests:
- G - Grain Size
- P - Permeability
- M - Moisture Content

▼ Water Level (ATD) ▽ Static Water Level

Logged by: RRH
Approved by: TJF
Figure No. A - 4

UNIFIED SOIL CLASSIFICATION CHART (USCS)

MAJOR DIVISIONS			LETTER SYMBOL	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES) <5%	GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
			GP	POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES) >12%	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
			GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES) <5%	SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
			SP	POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES) >12%	SM	SILTY SANDS, SAND-SILT MIXTURES
			SC	CLAYEY SANDS, SAND-CLAY MIXTURES
FINE GRAINED SOILS MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50	ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS			PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

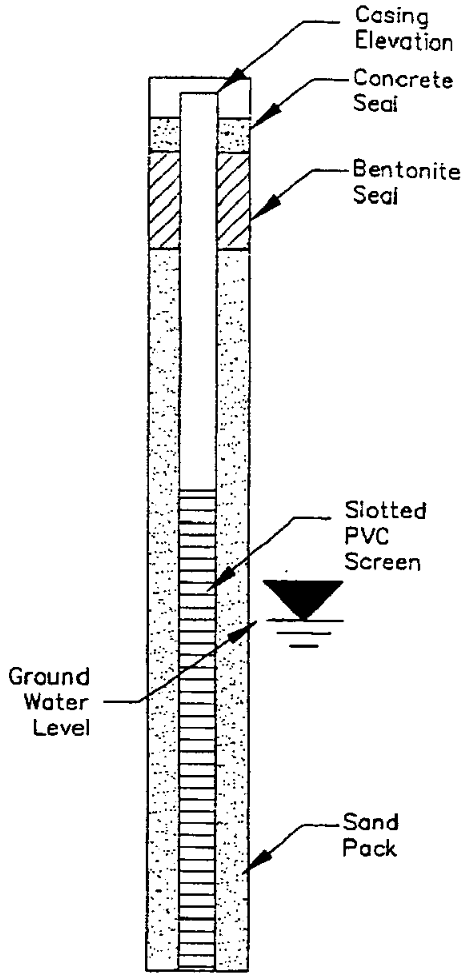
SOIL DESCRIPTIONS

Trace = 0-5%

Some = 5-12%

Gravelly
Sandy
Silty
Clayey } = 12-49%

KEY TO LOG OF WELLS



KEY TO LOG OF BORINGS

▯ SPT No recovery

☒ SPT Disturbed

▮ SPT Undisturbed

■ D&M Undisturbed

☒ D&M Disturbed

☐ D&M No recovery

● % Moisture

■ D&M 300# Hammer Blows/Ft.

▲ SPT 140# Hammer Blows/Ft.

▼ Static Water Level

JOB NO.: N/A
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: TEB
DWG FILE: USCS KEY TO WELLS

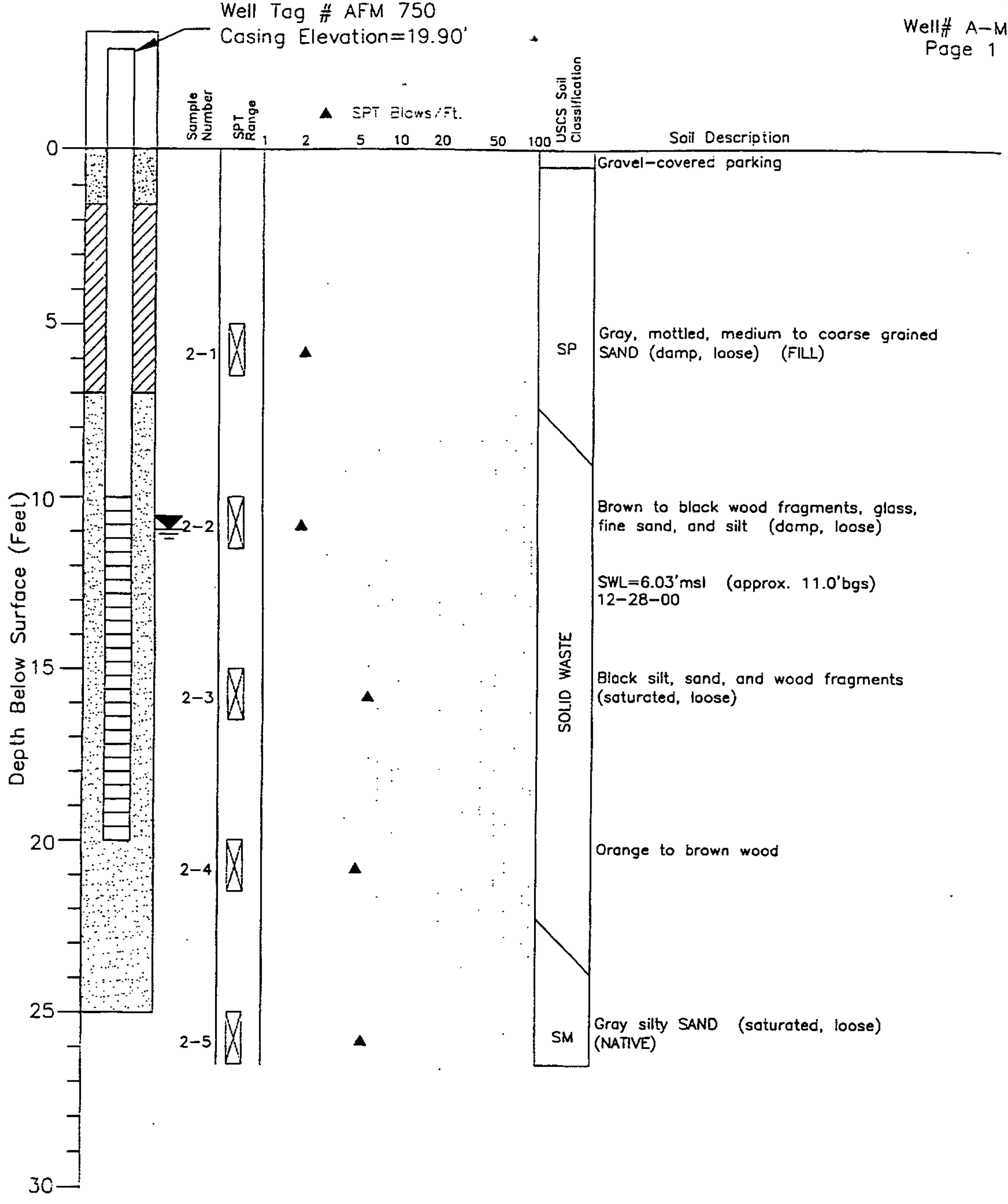
BEK ENGINEERING & ENVIRONMENTAL, INC.

CIVIL GEOTECHNICAL ENVIRONMENTAL
2138 Humboldt Street
Bellingham, WA 98225
Ph: (360) 676-9589
Ph: (800) 859-5597
Fax: (360) 676-4625

KEY TO WELL LOGS & UNIFIED SOILS CLASSIFICATION SYSTEM

DATE: N/A
SCALE: H: N/A V: N/A

Well# A-MW-4
Page 1 of 1



Gravel-covered parking

Gray, mottled, medium to coarse grained SAND (damp, loose) (FILL)

Brown to black wood fragments, glass, fine sand, and silt (damp, loose)

SWL=6.03'msl (approx. 11.0'bgs)
12-28-00

Black silt, sand, and wood fragments (saturated, loose)

Orange to brown wood

Gray silty SAND (saturated, loose) (NATIVE)

LOGGED BY: KRK	HAMMER SIZE: 140 lb. /30" drop AutoHammer
DRILLER: Gregory Drilling	DATE DRILLED: December 28, 2000
DRILLING METHOD: HSA	HOLE DIAMETER: 6.25-inch
SAMPLING METHOD: STP	HOLE DEPTH: 25'
CASING TYPE: PVC	WELL DIAMETER: 2"
ANNULAR PACK: 10/20 Sand	WELL DEPTH: 20'
SLOT SIZE: 10 slot	LOCATION: see drawing

See Site Plan for actual location

Soils classified visually using the Unified Soils Classification System

JOB NO.: 200195
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: JME
DWG FILE: WELL LOGS.DWG

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Bellingham, WA 98225
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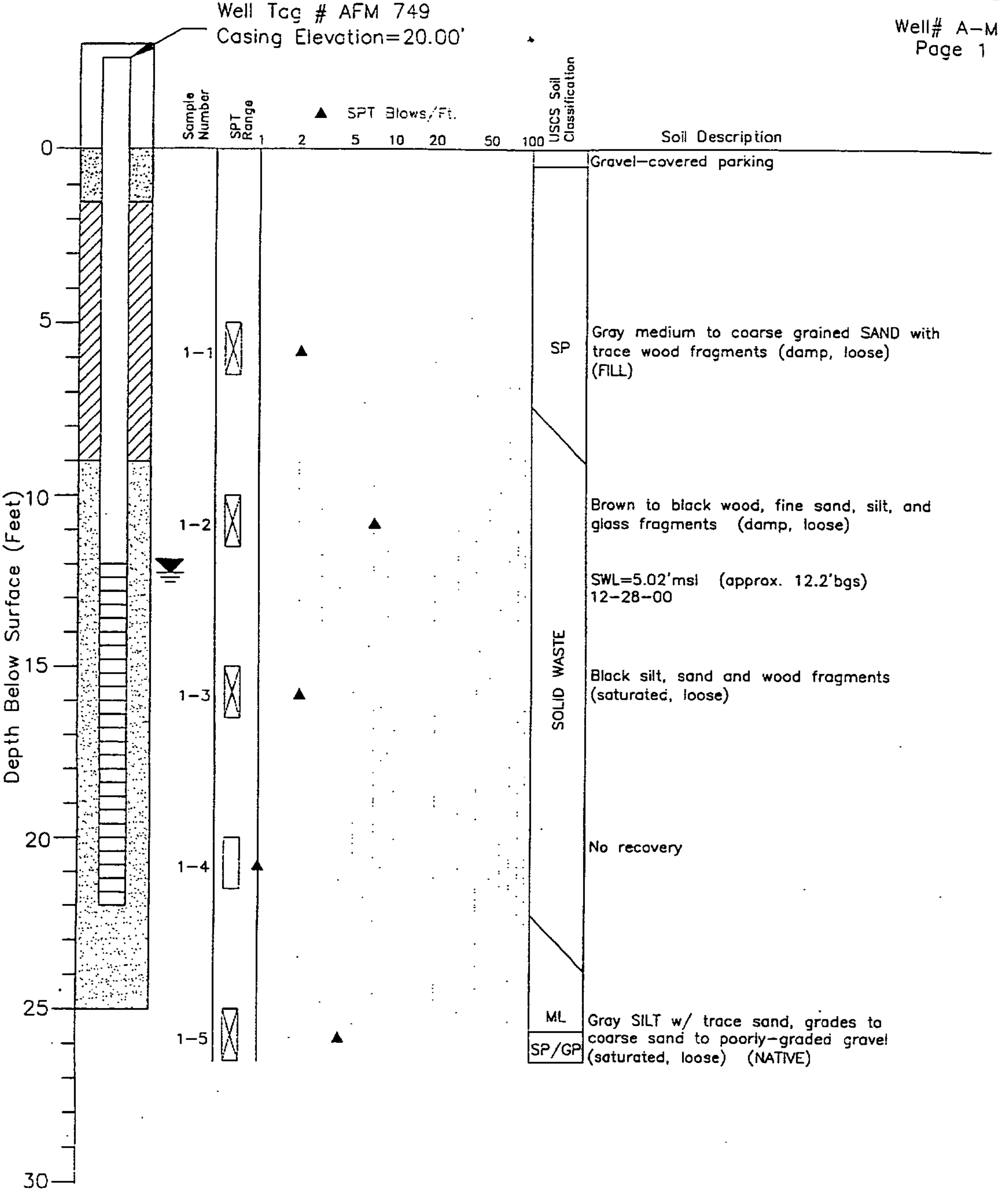
Ph: (800) 859-5597
Fax: (360) 676-4625

MONITORING WELL # A-MW-4
MARITIME HERITAGE PARK
BELLINGHAM, WASHINGTON

DATE: DECEMBER 28, 2000
SCALE: H: N/A V: N/A

Well# A-MW-5
Page 1 of 1



Gravel-covered parking

Gray medium to coarse grained SAND with trace wood fragments (damp, loose) (FILL)

Brown to black wood, fine sand, silt, and glass fragments (damp, loose)

SWL=5.02'msl (approx. 12.2'bgs)
12-28-00

Black silt, sand and wood fragments (saturated, loose)

No recovery

Gray SILT w/ trace sand, grades to coarse sand to poorly-graded gravel (saturated, loose) (NATIVE)

LOGGED BY: JME
DRILLER: Gregory Drilling
DRILLING METHOD: HSA
SAMPLING METHOD: STP
CASING TYPE: PVC
ANNULAR PACK: 10/20 Sand
SLOT SIZE: 10 slot

HAMMER SIZE: 140 lb. /30" drop AutoHammer
DATE DRILLED: December 28, 2000
HOLE DIAMETER: 6.25-inch
HOLE DEPTH: 25'
WELL DIAMETER: 2"
WELL DEPTH: 22'
LOCATION: see drawing

See Site Plan for actual location

Soils classified visually using the Unified Soils Classification System

JOB NO.: 200195
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: JME
DWG FILE: WELL LOGS.DWG

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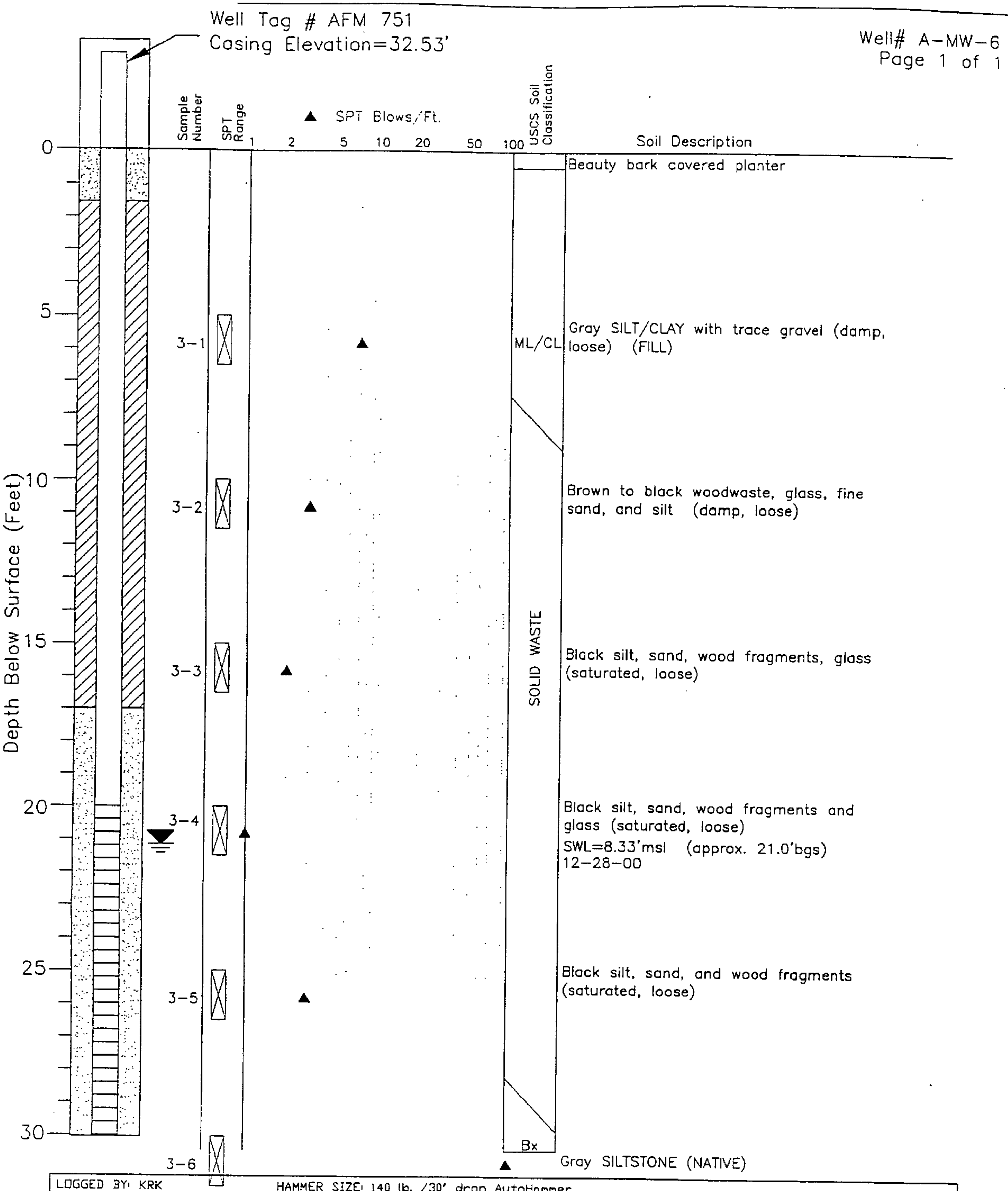
Ph: (800) 859-5597
Fax: (360) 676-4625

MONITORING WELL # A-MW-5
MARITIME HERITAGE PARK
BELLINGHAM, WASHINGTON

DATE: DECEMBER 28, 2000
SCALE: H: N/A V: N/A

Well# A-MW-6
Page 1 of 1



LOGGED BY: KRK
DRILLER: Gregory Drilling
DRILLING METHOD: HSA
SAMPLING METHOD: STP
CASING TYPE: PVC
ANNULAR PACK: 10/20 Sand
SLOT SIZE: 10 slot

HAMMER SIZE: 140 lb. /30" drop AutoHammer
DATE DRILLED: December 28, 2000
HOLE DIAMETER: 6.25-inch
HOLE DEPTH: 30'
WELL DIAMETER: 2"
WELL DEPTH: 30'
LOCATION: see drawing

See Site Plan for actual location

Soils classified visually using the Unified Soils Classification System

JOB NO.: 200195
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: JME
DWG FILE: WELL LOGS.DWG

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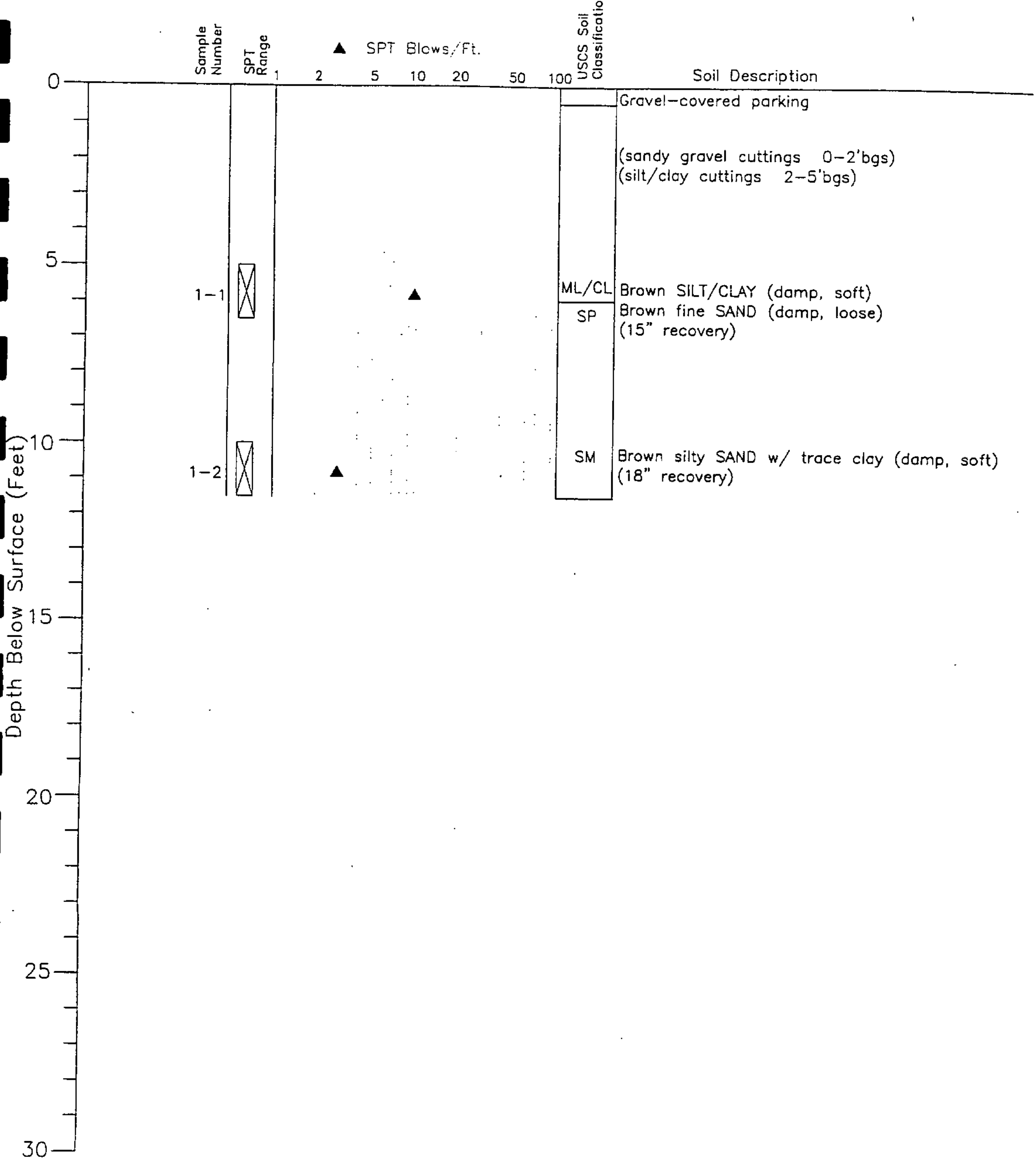
Ph: (800) 859-5597
Fax: (360) 676-4625

MONITORING WELL # A-MW-6
MARITIME HERITAGE PARK
BELLINGHAM, WASHINGTON

DATE: DECEMBER 28, 2000
SCALE: H: N/A V: N/A

Boring# B-1
Page 1 of 1



Gravel-covered parking

(sandy gravel cuttings 0-2'bgs)
(silt/clay cuttings 2-5'bgs)

Brown SILT/CLAY (damp, soft)

Brown fine SAND (damp, loose)
(15" recovery)

Brown silty SAND w/ trace clay (damp, soft)
(18" recovery)

LOGGED BY: JME
DRILLER: Gregory Drilling
DRILLING METHOD: HSA
SAMPLING METHOD: STP
CASING TYPE: n/a
ANNULAR PACK: n/a
SLOT SIZE: n/a

HAMMER SIZE: 140 lb. /30" drop AutoHammer
DATE DRILLED: December 29, 2000
HOLE DIAMETER: 6.25-inch
HOLE DEPTH: 10.0'
WELL DIAMETER: n/a
WELL DEPTH: n/a
LOCATION: see drawing

See Site Plan for actual location

Soils classified visually using the Unified Soils Classification System

JOB NO.: 200195
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: JME
DWG FILE: WELL LOGS.DWG

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ENVIRONMENTAL

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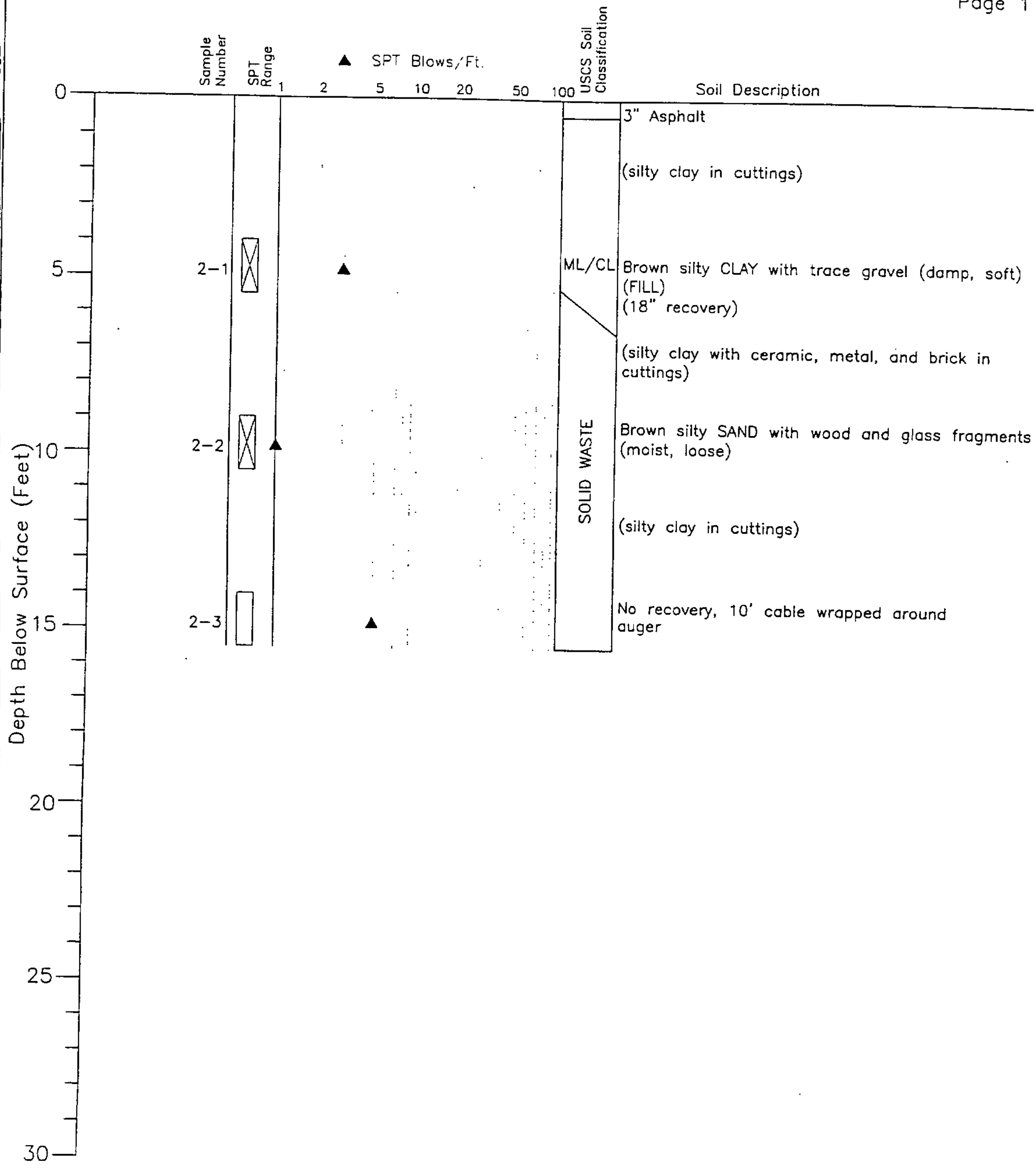
Bellingham, WA 98225
Ph: (360) 676-9589
Ph: (800) 859-5597
Fax: (360) 676-4625

EXPLORATORY BORING # A-BI
MARITIME HERITAGE PARK
BELLINGHAM, WASHINGTON

DATE: DECEMBER 29, 2000
SCALE: H: N/A V: N/A

Boring# B-2
Page 1 of 1



3" Asphalt

(silty clay in cuttings)

Brown silty CLAY with trace gravel (damp, soft) (FILL)
(18" recovery)

(silty clay with ceramic, metal, and brick in cuttings)

Brown silty SAND with wood and glass fragments (moist, loose)

(silty clay in cuttings)

No recovery, 10' cable wrapped around auger

LOGGED BY: JME
DRILLER: Gregory Drilling
DRILLING METHOD: HSA
SAMPLING METHOD: STP
CASING TYPE: n/a
ANNULAR PACK: n/a
SLOT SIZE: n/a

HAMMER SIZE: 140 lb. /30' drop AutoHammer
DATE DRILLED: December 29, 2000
HOLE DIAMETER: 6.25-inch
HOLE DEPTH: 14.0'
WELL DIAMETER: n/a
WELL DEPTH: n/a
LOCATION: see drawing

See Site Plan for actual location

Soils classified visually using the Unified Soils Classification System

JOB NO.: 200195
DESIGNED BY/DRAWN BY: KRK
CHECKED BY: JME
DWG FILE: WELL LOGS.DWG

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2138 Humboldt Street
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Ph: (800) 859-5597
Fax: (360) 676-4625

EXPLORATORY BORING # A-B2
MARITIME HERITAGE PARK
BELLINGHAM, WASHINGTON

DATE: DECEMBER 29, 2000
SCALE: H: N/A V: N/A

APPENDIX B

RESULTS OF SUPPLEMENTARY PRE-REMEDIAL DESIGN MONITORING AND ANALYSIS

APPENDIX C

DESIGN LEVEL GROUNDWATER FLOW AND OXYGEN INTRUSION MODELING

Prepared By:
Aspect Consulting, Inc.

C-1 BACKGROUND

The groundwater flow system at the Holly Street Landfill Site consists of a shallow unconfined aquifer within the refuse and underlying Recent Alluvial sediment as discussed in Section 4.5 of the RI/FS report (Anchor et al, 2001). Groundwater flow within this unconfined aquifer is generally directed from the upland areas toward Whatcom Creek. Fine-grained silts and clays present beneath the aquifer function as confining layers, restricting downward groundwater flow into deeper units.

Leachate within the refuse is generated from infiltration of incident precipitation and from lateral inflow of groundwater into the landfill area. Tidal influence creates a sinusoidal groundwater flow path as the groundwater approaches the point of discharge into Whatcom Creek, and oscillates in response to tidally propagated waves. These oscillations are most pronounced within approximately 20 feet of the shoreline.

Monitoring performed during the RI/FS (Anchor and Aspect 2001) indicated that copper and zinc concentrations exceed MTCA surface water cleanup levels in shoreline seeps along portions of the northwest lobe of the Holly Street Landfill. The geochemical data suggest that water within the Whatcom Creek estuary, high in dissolved oxygen, migrates into the shallow groundwater zone during high tides, creating oxidizing conditions within the saturated refuse. As discussed in the RI/FS, oxidizing conditions are expected to mobilize copper and zinc present within the refuse.

The cleanup alternative selected by Ecology in the CAP includes removal of a portion of the refuse currently exposed to oxygenated water infiltrating from Whatcom Creek and placement of a permeable shoreline cap. The intent of this action is to reduce concentrations of copper and zinc discharging to Whatcom Creek by displacing the zone of mixing outward from the refuse. Such displacement would separate the reduced geochemical environment within the refuse from oxidizing surface water, which in turn would reduce the release of dissolved copper and zinc.

C.2 PREVIOUS ANALYSIS

Section 8.1 of the RI/FS describes preliminary numerical modeling analysis of the potential effectiveness of the action in reducing copper and zinc discharges to Whatcom Creek. For that analysis, a two-dimensional groundwater flow model was constructed using the U.S.G.S. MODFLOW model (MacDonald and Harbaugh 1988). The model used a simplified geometry to represent the shoreline cap configuration. The analysis evaluated the influence of tidal fluctuations on advective transport of a non-sorbing tracer to assess the effectiveness of the cap design in reducing intrusion of oxygenated water from Whatcom Creek into the refuse. The preliminary results indicated that a non-sorbing constituent (e.g., dissolved oxygen) would be attenuated within a 5-foot thick soil cap with permeability on the order of 10^{-2} centimeters per second (cm/sec).

The performance of the cap in the preliminary model used in the RI/FS was sensitive to the permeability of the cap, with values greater than 10^{-2} cm/sec being less effective at reducing oxygenated water intrusion. However, the preliminary model did not consider diffusion and dispersion process that also influence transport of a non-sorbing constituent. Data collected during the March/April 2002 tidal monitoring study at the Site indicated that tidal mixing and dispersion could be a significant factor in enhancing the mobility of dissolved constituents and dissolved oxygen (see Appendix B.2). Consequently, additional refined numerical modeling analysis was completed to support the shoreline cap design for the Design-Level Report.

C.3 DESIGN-LEVEL MODELING ANALYSIS

For the Design-Level modeling analysis, a numerical transport analysis was performed to evaluate the influence of tidal fluctuations, molecular diffusion, and hydrodynamic dispersion on inland migration of a non-sorbing tracer to finalize the design criteria for the shoreline cap.

The scope of the Design-Level modeling analysis included:

- Revising the RI/FS model grid to better represent hydrostratigraphic units and physical characteristics of the site
- Calibrating the revised groundwater flow model to data from an additional tidal monitoring study conducted at the site in March/April 2002
- Running a numerical transport model to assess migration of a non-sorbing constituent, nominally dissolved oxygen, into the landfill through a 5-foot engineered cap considering both advection and dispersion.

C.3.1 Groundwater Flow Modeling

A numerical groundwater flow model was developed to provide groundwater velocity values for input into a numerical groundwater transport model. Sections below describe model development and calibration.

C.3.1.1 Model Development

For this analysis the MODFLOW model grid developed for the RI/FS was modified to reflect the sloping contact between the Recent Alluvium and the underlying Bellingham Drift. Previously the modeled hydrostratigraphic units were represented as a sequence of horizontal layers (RI/FS Report; Figure 8-1). The finite-difference grid and the model layering used to represent hydrostratigraphic units encountered at the site are illustrated on Figure C-1. The grid is comprised of one row, 64 columns, and seven layers. The model grid consists of two principal hydrostratigraphic units, refuse and alluvium. Based on a review of the boring logs, the alluvium was further divided into an upper more permeable sandy unit and a lower less permeable silty unit. The fine-grained glacial marine deposits of the Bellingham Drift underlying the Recent Alluvium had negligible contribution to groundwater flow discharging to Whatcom Creek and were not represented in the model.

Precipitation recharge and groundwater flow into the model grid from the north (upgradient) was represented by specifying a constant groundwater elevation (head) of 11 feet in model cells along the right edge of the model grid (see Figure C-1a). Tidally fluctuating groundwater discharge to and recharge from Whatcom Creek was represented using time-varying specified head cells on the left side of the model grid. One column of cells contacting the creek and one layer of cells underlying the creek (Figure C-1a) were assigned head values based on tidal stage recorded by the National Oceanographic and Atmospheric Administration (NOAA) tide gauge located at Cherry Point, Washington. For the calibration effort, a regular sinosoidally varying portion of the tide stage recorded on hourly intervals between April 16 and 17, 2002, was replicated to specify the head of cells adjacent to Whatcom Creek for a 14-day simulation. Because the lowest tide observed during the monitoring study (0 ft MLLW) fell below the base of the refuse horizon at +7 ft MLLW, it was not practical to specify constant head cells in the model layers representing the refuse horizon. Therefore columns of cells with very high hydraulic conductivity (K) were specified in the region of the model occupied by Whatcom Creek to facilitate surface water contact with the refuse horizon at high tides.

Within the model grid, the uppermost active layer is treated as an unconfined layer while lower layers can be treated as confined/unconfined. This is accomplished through the “LAYCON” variable in MODFLOW. The storage parameter in the lower layers and in cells adjacent to Whatcom Creek were automatically adjusted in the model to use a storage coefficient (Ss) when the cells were fully saturated or a specific yield value (Sy) when the water table dropped below the top of cells. For these simulations, portions of the refuse and Alluvium adjacent to Whatcom Creek became unsaturated during low tides and rewetted during high tides. The REWET option was specified to simulate this behavior in model cells adjacent to Whatcom Creek.

C.3.1.2 Calibration

The groundwater flow model was calibrated using a combination of manual and automated parameter estimation techniques. Initially, hydraulic conductivity (K) and storage parameters from the calibrated RI groundwater model were used. The hydraulic parameters were then manually adjusted in an iterative process until good agreement was obtained between modeled and observed groundwater elevation at wells MW-2 and MW-3. Final calibration was performed using an automated parameter estimation program, PEST (Watermark Computing, 1994). Final calibrated hydraulic parameters are listed in Table C-1. Good agreement between modeled and observed groundwater elevations in wells MW-2 and MW-3 was obtained with the calibrated model (Figure C-2).

Table C-1
Calibrated Model Hydraulic Parameter Summary

Hydrostratigraphic Unit	K, cm/sec	Ss, 1/ft	Sy	n
Refuse	.04	5e-5	.122	.25
Upper Alluvium	.003	5e-5	.033	.2
Lower Alluvium	.0003	1.5e-5	.045	.2
High K Boundary Cells	100	0.001	.01	.9

The most significant change in model parameters compared to the preliminary modeling effort described in the RI/FS is the representation of the Recent Alluvium with an upper and lower unit. Previously, the Recent Alluvium was represented as a single hydrostratigraphic unit with a uniform hydraulic conductivity of 0.00031 cm/sec. For the Design Level analysis, the hydraulic conductivity of the lower alluvium was unchanged from the value used in the RI/FS. The hydraulic conductivity of the upper alluvium in the Design Level was an order of magnitude higher at 0.003 cm/sec. This change better reflects the loose sandy materials encountered below the refuse horizon in boring MW-3.

C.3.2 Contaminant Transport Modeling

Numerical transport modeling was performed to assess the influence of cap hydraulic conductivity and thickness on attenuation of dissolved oxygen intrusion in surface water from Whatcom Creek. Sections below describe model development, simulations to assess cap performance, and results.

C.3.2.1 Model Development

To represent the shoreline cap in the numerical model, the hydraulic conductivity of model grid cells near Whatcom Creek were modified as illustrated in Figure C-3. The modifications consisted of changing the hydraulic conductivity of cells in the uppermost two model layers within 30 feet of Whatcom Creek. To represent the shoreline cap, the hydraulic conductivity of three cells in the uppermost layer between 25 and 30 feet from

Whatcom Creek and all cells in the second (5 foot thick) layer were set to an initial value of 0.02 cm/sec. Cells in the uppermost layer to a distance of 25 feet from Whatcom Creek were set to the high K value of 100 cm/sec to simulate surface water flow over the engineered cap during high tides.

The numerical transport model was developed using MT3D (Zheng, 1990). For this, porosity values of 0.25 and 0.2 were assigned to the refuse and Alluvium units, respectively, based on data presented in the RI report. A uniform dispersion coefficient of 1 foot and aqueous diffusion coefficient of 2 x 10^{-5} ft^2/day were used in all model layers. Because oxygen is not expected to adsorb to soil materials, transport was simulated without retardation. Cap performance was evaluated by specifying a constant concentration boundary at a unit value in cells representing Whatcom Creek (Figure C-3).

C.3.2.2 Cap Performance Simulations

Two cap design scenarios were evaluated: a cap with a uniform hydraulic conductivity of 0.02 cm/sec (the same as specified for the RI/FS) and a cap with a uniform hydraulic conductivity of 0.005 cm/sec. Multi-year transport simulations were performed with both configurations until a steady-state concentration profile was developed. The steady-state concentration profile for the 0.02 cm/sec cap and the 0.005 cm/sec cap were similar. The concentration profile for the 0.02 cm/sec cap simulation is presented on Figure C-4.

C.3.3 Results

As shown in Figure C-5, the modeling analyses indicate that a 3-foot-thick shoreline cap constructed at a permeability of approximately 0.02 cm/sec would attenuate migration of a non-sorbing constituent to less than 5 percent of the concentration of that constituent in Whatcom Creek while the cap with a lower hydraulic conductivity of 0.005 cm/sec attenuates the influx from Whatcom Creek by more than 99 percent. Groundwater migrating towards Whatcom Creek through the refuse horizon will also experience a substantial biological and chemical oxygen demand as a result of contact with materials placed in the landfill. This oxygen demand would further reduce the dissolved oxygen concentration in groundwater contacting the refuse. Currently, Whatcom Creek is a relatively significant source of oxygenated water within the zone influenced by tidal fluctuations. The modeling results are significant in that they indicate that a 3- to 5-foot thick layer of soil with a hydraulic conductivity of 0.02 cm/sec or less will greatly reduce the oxygen flux inland from Whatcom Creek. With this source of oxygen cut off, the oxygen concentration in groundwater within the refuse will decrease substantially following placement of the cap. Consequently, concentrations of zinc and copper in groundwater within the refuse will also decrease because both metals are less soluble at lower dissolved oxygen concentrations. As a result of the reduction in oxygen influx to the refuse, and mixing and dispersion within the cap as a result of tidal fluctuations, the copper and zinc concentrations in groundwater discharging to Whatcom Creek will be substantially reduced following placement of the shoreline cap.

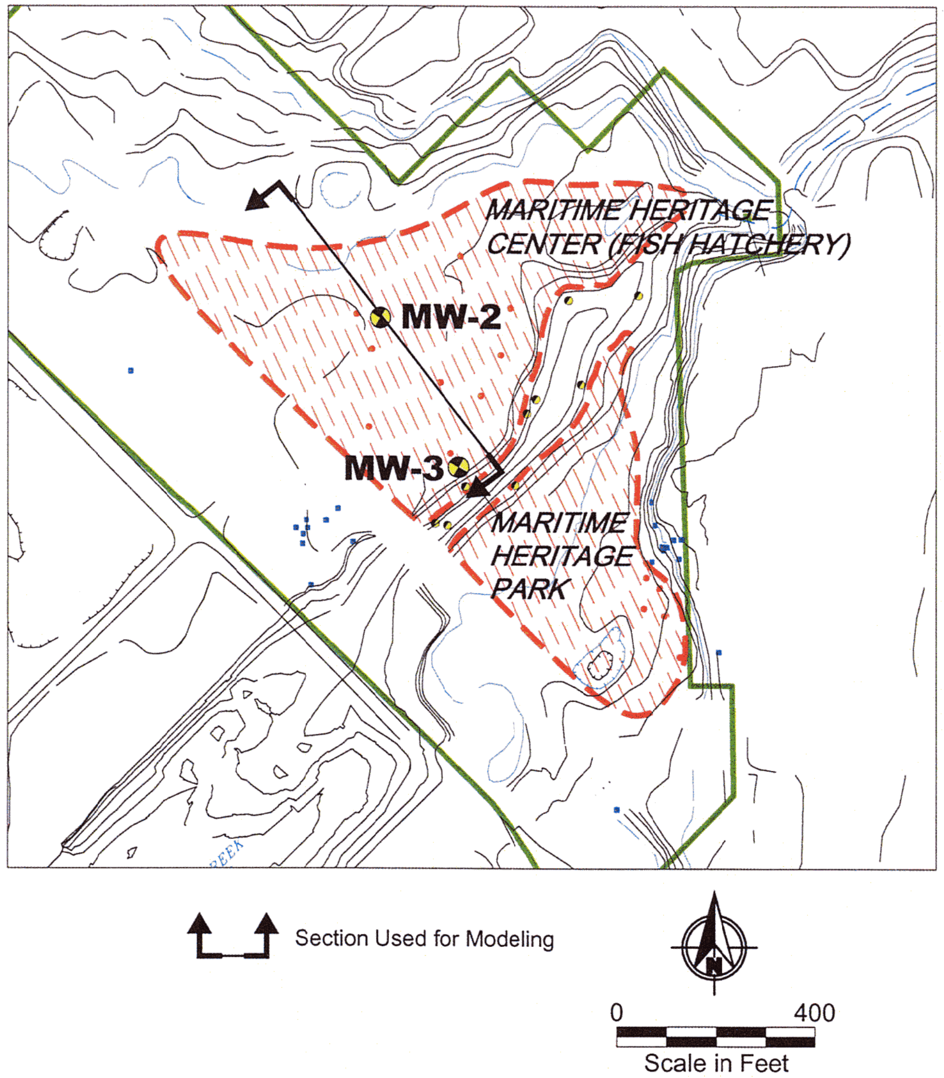
C.4 REFERENCES

Anchor Environmental, LLC, Aspect Consulting, LLC, and Heartland, 2001, Remedial Investigation/Feasibility Study Holly Street Landfill Redevelopment Project, Draft Final, November 2001, Prepared for City of Bellingham

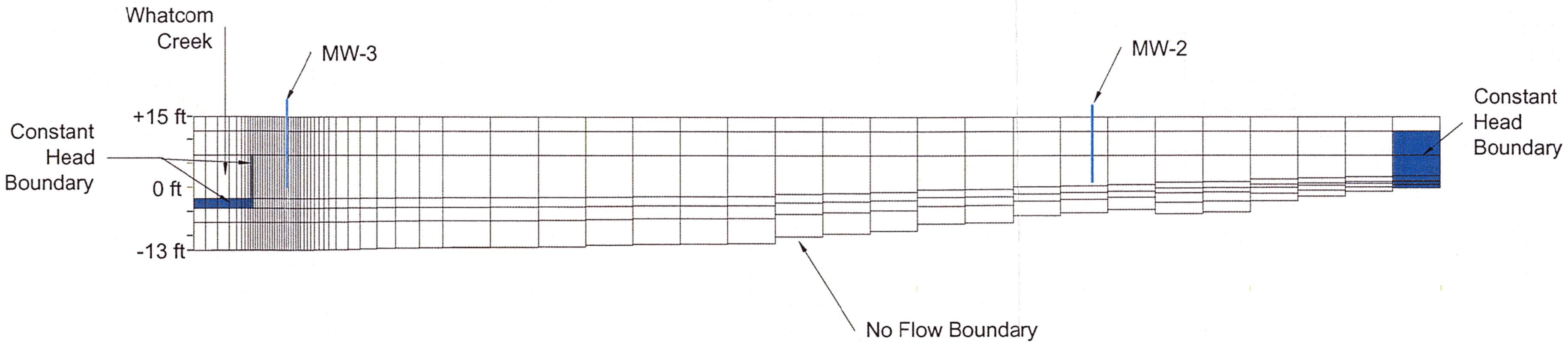
McDonald, M.G. and A.W. Harbaugh, 1988, *A Modular Three-Dimensional Finite-Difference Groundwater Flow Model*, U.S. Geological Survey Open File Report 83-875.

Zheng, C., 1990, MT3D: A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems, Report to the U.S. Environmental Protection Agency, Ada, OK, 170 pp.

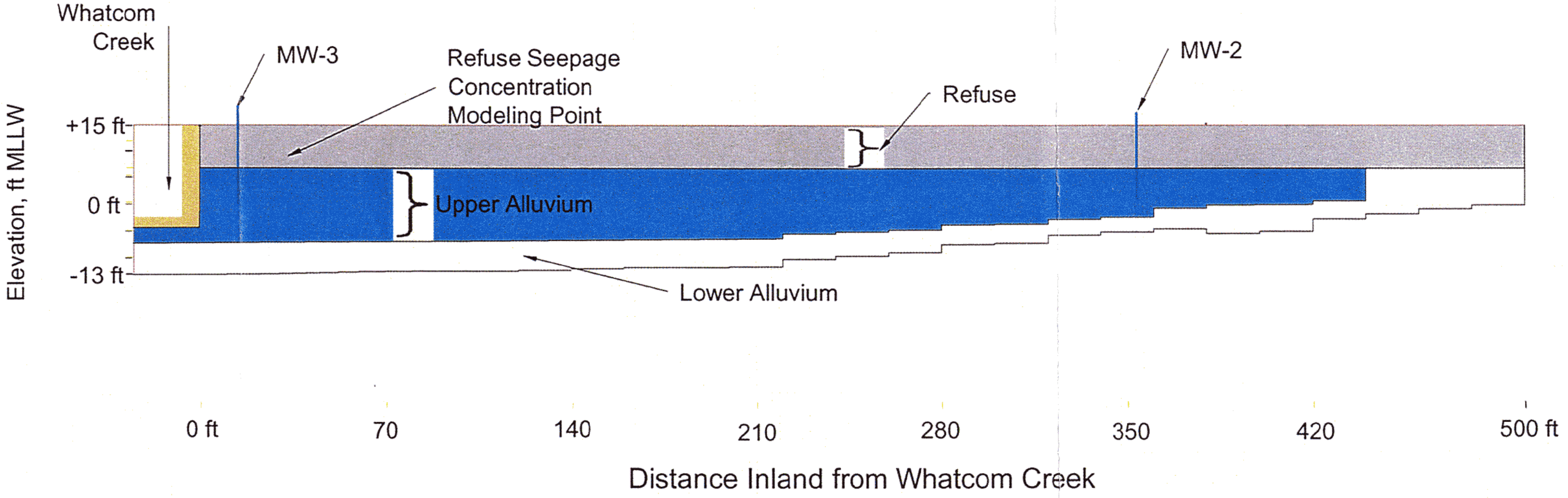
Well Location Map



C-1a - Calibration Model Grid with Boundary Conditions



C-1b - Hydrogeologic Unit Representation



Hydraulic Conductivity, cm/s

- 🟦 0.003
- 🟨 100
- ▨ 0.04
- ☐ 0.0003

Aspectconsulting
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179 Madrone Lane North
Bainbridge Island, WA 98110
Tel: (206) 780-9370
Fax: (206) 780-9438

Model Layout for Calibration

Holly Street Landfill
Bellingham, Washington

DATE: 10/03/02	PROJECT NO. 990139
DESIGNED BY: DWM	
DRAWN BY: MS	FIGURE NO. C-1
REVISED BY:	

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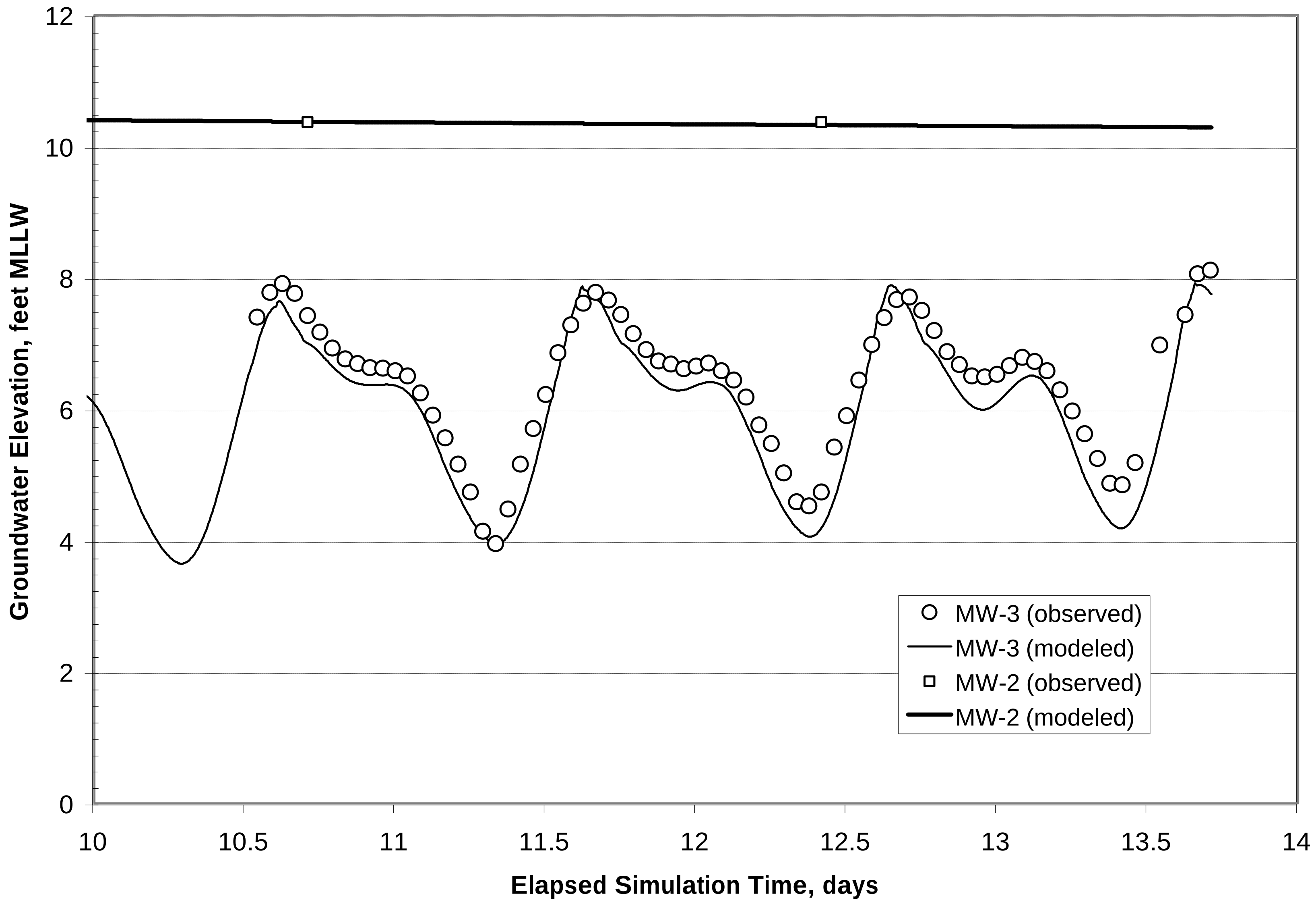
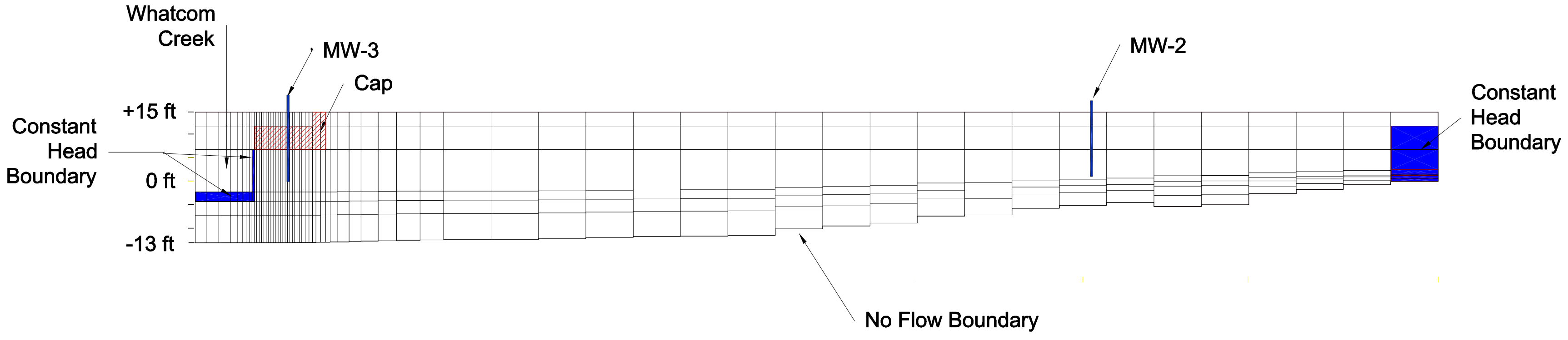


Aspect consulting
IN-DEPTH PERSPECTIVE

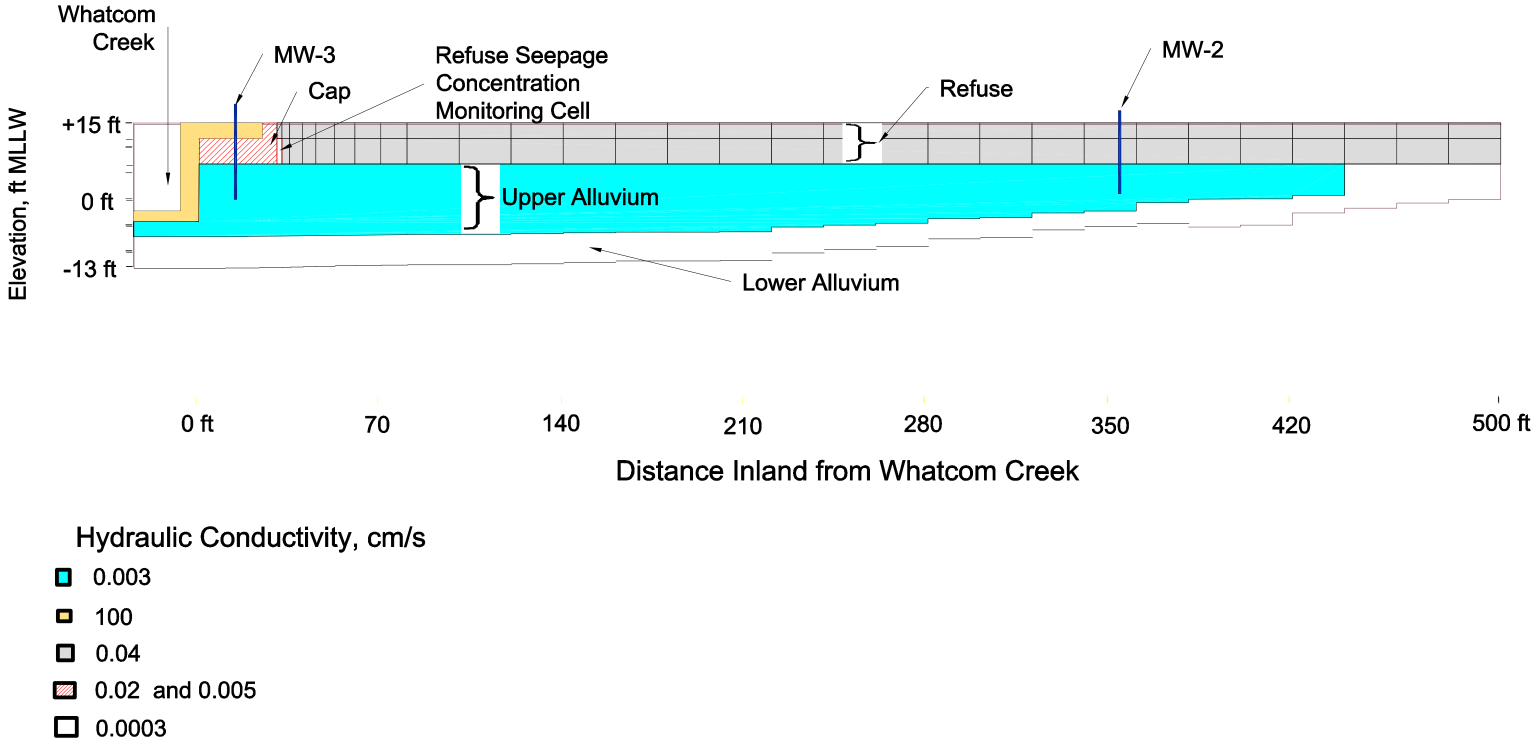
\CALIBRATION.XLS\\FlowCal

Figure C-2 - Flow Model Calibration Results
990139-8

C-3a - Cap Performance Model Grid with Boundary Conditions



C-3b - Hydrogeologic Unit Representation



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Model Layout for Cap Evaluation

Holly Street Landfill
Bellingham, Washington

DATE: 10/03/02
DESIGNED BY: DWM
DRAWN BY: DWM
REVISED BY: MS
SCALE: As Shown
PROJECT NO. 990139
FIGURE NO. C-3

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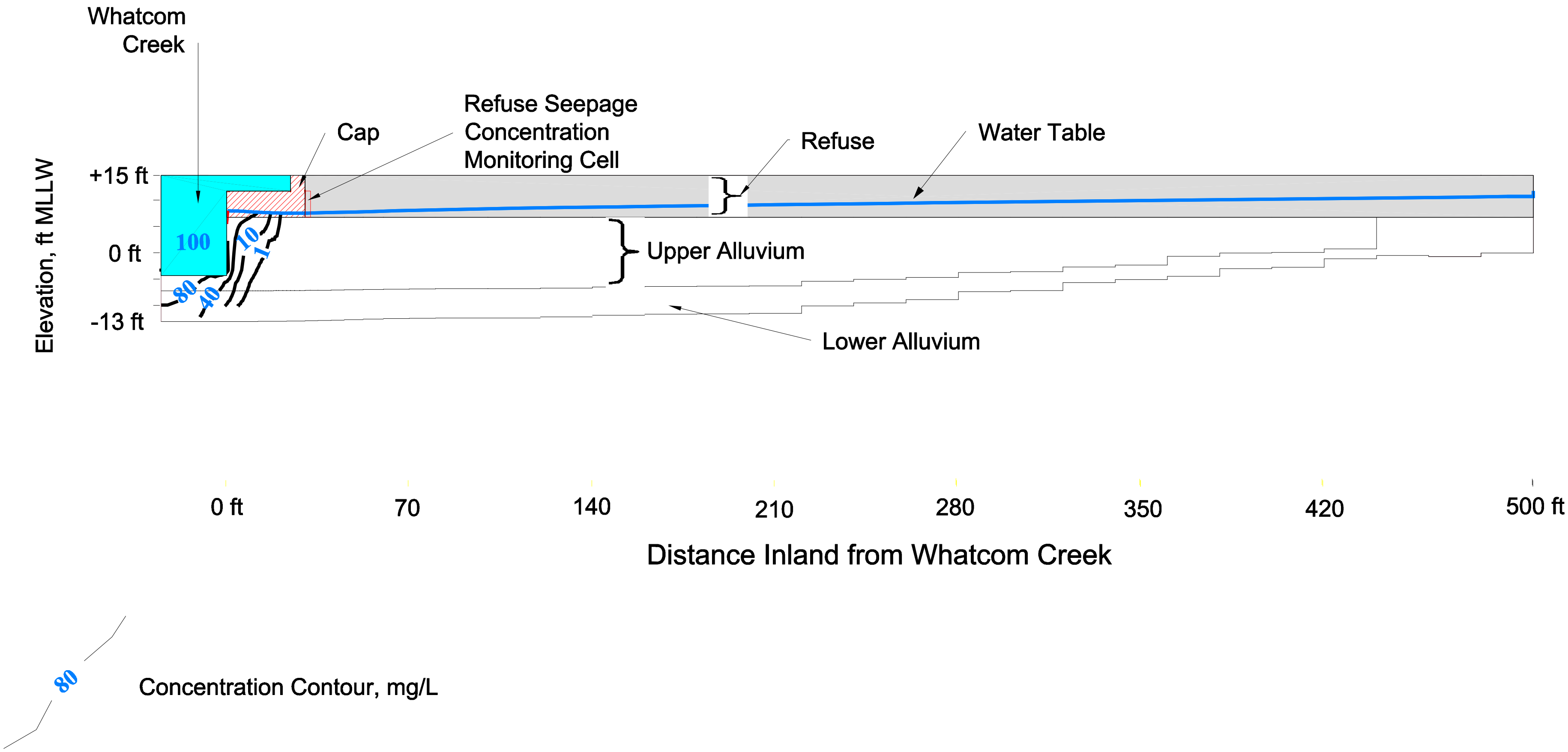

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Steady-State Concentration
Profile for 0.02 cm/s Cap

Holly Street Landfill
Bellingham, Washington

DATE: 10/03/02	SCALE: As Shown
DESIGNED BY: DWM	PROJECT NO. 990139
DRAWN BY: DWM	FIGURE NO. C-4
REVISED BY: MS	

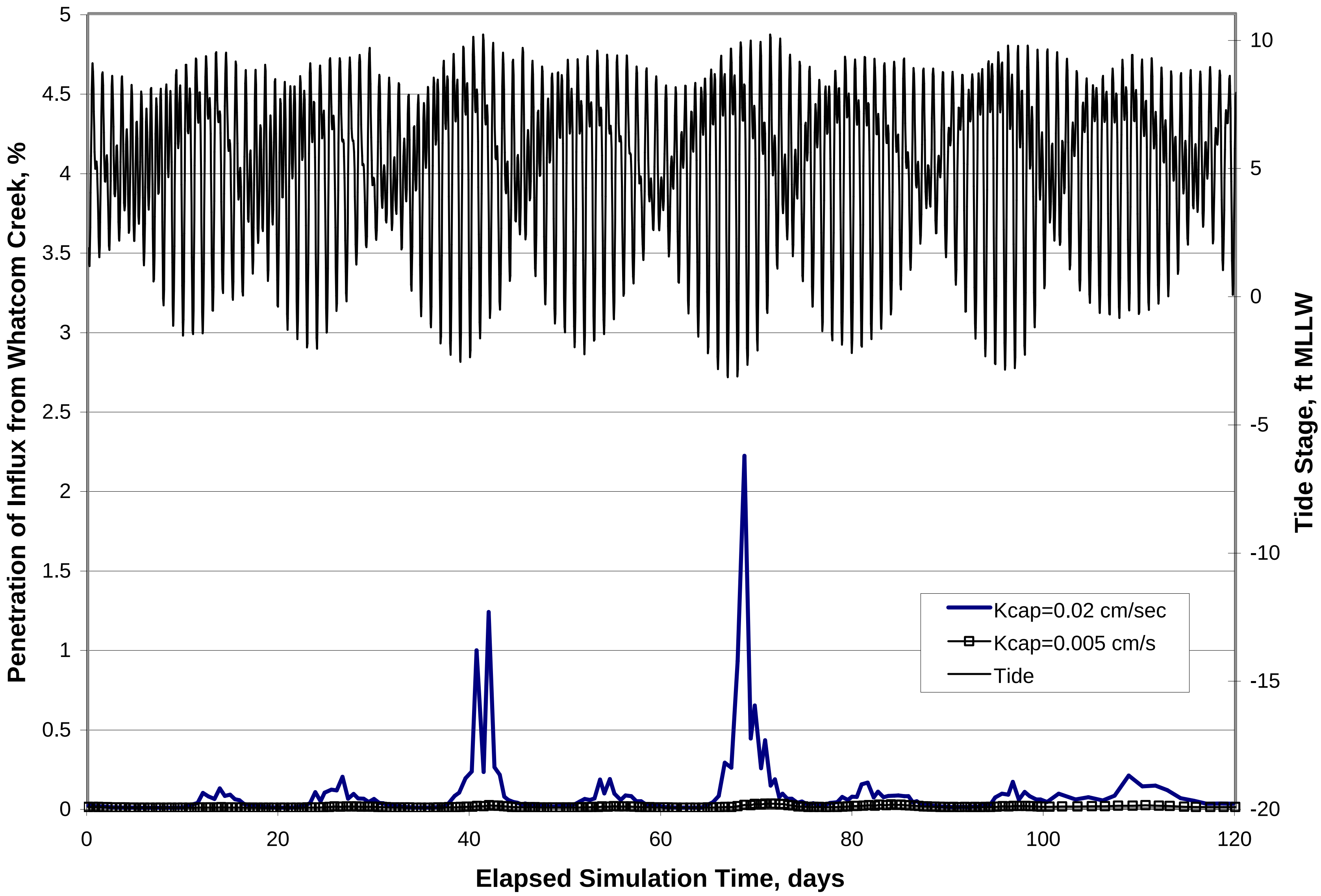

Figure C-5 - Alternative 3 Cap Performance
(Predicted at Face of Refuse)

\June2002ModelingResults.xls\\refuse

APPENDIX D
STATIC AND SEISMIC SLOPE STABILITY

This section describes procedures used to analyze the stability of the existing and proposed slopes under both the static and seismic conditions.

1 METHODS OF ANALYSIS

Stability was checked using the limit equilibrium procedure implemented in the following software packages

- XSTABL (v5.204), by Interactive Software Designs 1999
- SLIDE (v5.0) by RocScience, 2003

All analyses were conducted assuming Spencer's method for satisfying both force and moment equilibrium of the critical slip surface. Seismic (pseudostatic) analyses were performed by modeling the earthquake as a sustained horizontal force acting on the failure mass.

To perform pseudostatic analyses, a design-level earthquake was selected based on a recurrence interval of 475 years, which is the equivalent of a 10 percent probability that this event will occur in a 50-year time period. The USGS Earthquake Mapping Hazard Project has determined that an earthquake of this frequency would have a peak ground acceleration (PGA) of 0.23 g at the Holly Street Landfill site (USGS 2002). The PGA represents the peak acceleration that is anticipated for an earthquake of a given magnitude. For pseudostatic slope stability analyses, it is appropriate to use 50 percent of the PGA as an input horizontal force to model the average shaking that the soil mass will "feel" during an earthquake (Kramer 1996). Thus, seismic stability analyses employed a horizontal force of 0.115 g to the critical slip surface when computing factor of safety.

2 STABILITY OF SOUTH BANK AND ROCK BUTTRESS

Stability was checked for cross sections AA and BB, shown on sheets C-1 and C-3 of the plans. Section AA is slightly steeper than 2H:1V, and will be regraded with a thin fill sand and gravel buttress at the toe. Section BB is oversteepened and currently supported by a wooden bulkhead. The sand and gravel buttress will be up to about 10 feet thick in this area to provide the final grade of 2H:1V.

Assumed Soil and Sediment Properties

Sediment and soil strength, as modeled using a friction angle (ϕ), was selected using a combination of engineering judgment and experience, as well as by examining the blow count data and soil descriptions provided in the RI/FS for the Holly Street Landfill (Anchor, et. al., 2001). Copies of the boring logs and site plan are provided in Appendix A. Refuse engineering and strength parameters were compared to published research on this type of "soil" (Gabr and Valero, 1995). Table D-1 provides the assumed engineering and strength properties that were used in the slope stability model.

Table D-1
Soil and Sediment Properties for Stability Analyses

Soil Unit	Soil Description	Unit Weight (pcf]	Cohesion (c) (psf]	Friction Angle (ϕ) (degrees]
Fill	Sand (SP)	120	0	30
Refuse	Sandy Silt with debris (ML)	90	0	28
Alluvium	Silt with sand (ML)	90	0	26
Buttress Fill	Sand and Gravel	125	0	34

Conclusions of Analysis

Existing slope factors of safety (FOS) indicate marginal stability, with FOS ranging from 1.0 to 1.2 for the static condition. In areas, pseudostatic factors of safety are less than 1.0, which indicates that some sloughing may occur during a design-level earthquake. It is typically more cost-effective to plan on regrading slopes following an earthquake than it would be to take all steps necessary to design a slope that would resist the larger seismic events.

As mentioned previously, the sand and gravel fill will act as a berm, or "buttress" that will help stabilize the slope in the oversteepened areas where bulkheads are deteriorating. Because the depth of the existing bulkhead piles is not well-known, and due to the likely variability of shear strength in the solid waste, quantifying the exact FOS for the pile-reinforced slope is not feasible. However, in combination with the support provided by the existing piles, it is expected that the buttress will increase the existing factor of safety at least 40 to 50 percent for both the static and pseudostatic cases.

3 STABILITY OF EXCAVATION ADJACENT TO EXISTING RE-STORE BUILDING

Slope stability was evaluated to determine if regrading of the bank adjacent to the Re-store building would potentially affect the integrity of this structure. The Re-store building is located at the top of the bank within approximately five to 10 feet of the planned excavation. Few structural details were readily available regarding the design of the foundation of the building (i.e. pile supported or shallow footings), although it is known that the building has one basement level.

To conservatively model the surcharge load from the Re-Store building, it was assumed that the structure was founded on shallow footings with a maximum load of 2,000 psf at an elevation 10 feet below the existing grade. A pile-supported foundation would transfer loads even deeper than the assumed 10 feet below existing grade, which would result in minimal influence between the Re-Store Building and the adjacent regraded slope.

The minimum static factor of safety for circular slip surfaces passing beneath the Re-Store building was 3.22. The seismic factor of safety for the same critical slip surface was 2.10. Figure D-3 shows the location of the critical slip surface relative to the Re-Store Building. These factors of safety indicate that regrading of slopes adjacent to the Re-Store Building will not likely affect the stability of this structure's foundation.

4 STABILITY OF CONSTRUCTION SURCHARGE LOADS

It is specified that construction surcharge loads be maintained a minimum of 5 feet back from the top of the bank. Slope stability was evaluated for a surcharge representing a soil stockpile with a maximum load of 1,500 psf, which represents a stockpile approximately 12 feet high adjacent to the bank.

The minimum static factor of safety was determined to be 1.35 for a stockpile located 5 feet from the top of the bank, as shown in Figure D-4. The seismic factor of safety was not evaluated because the stockpile represents a temporary condition that will only occur for a short duration during construction. The factor of safety for this condition is adequate for short-term loading conditions, particularly considering the low likelihood that stockpiles of this height would be required during construction.

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Kramer, S.L., "Geotechnical Earthquake Engineering," Prentice-Hall, Inc., 1996.

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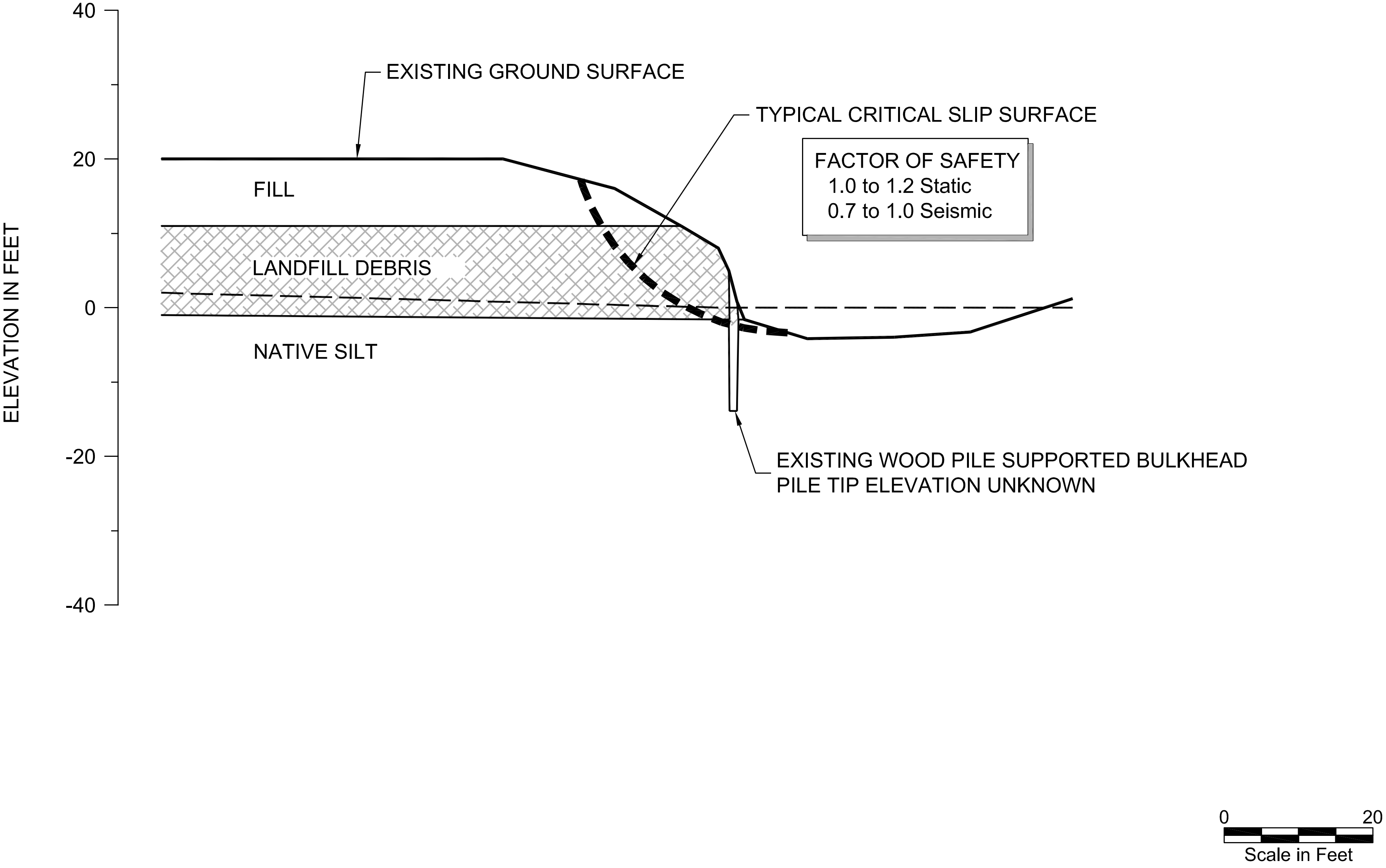
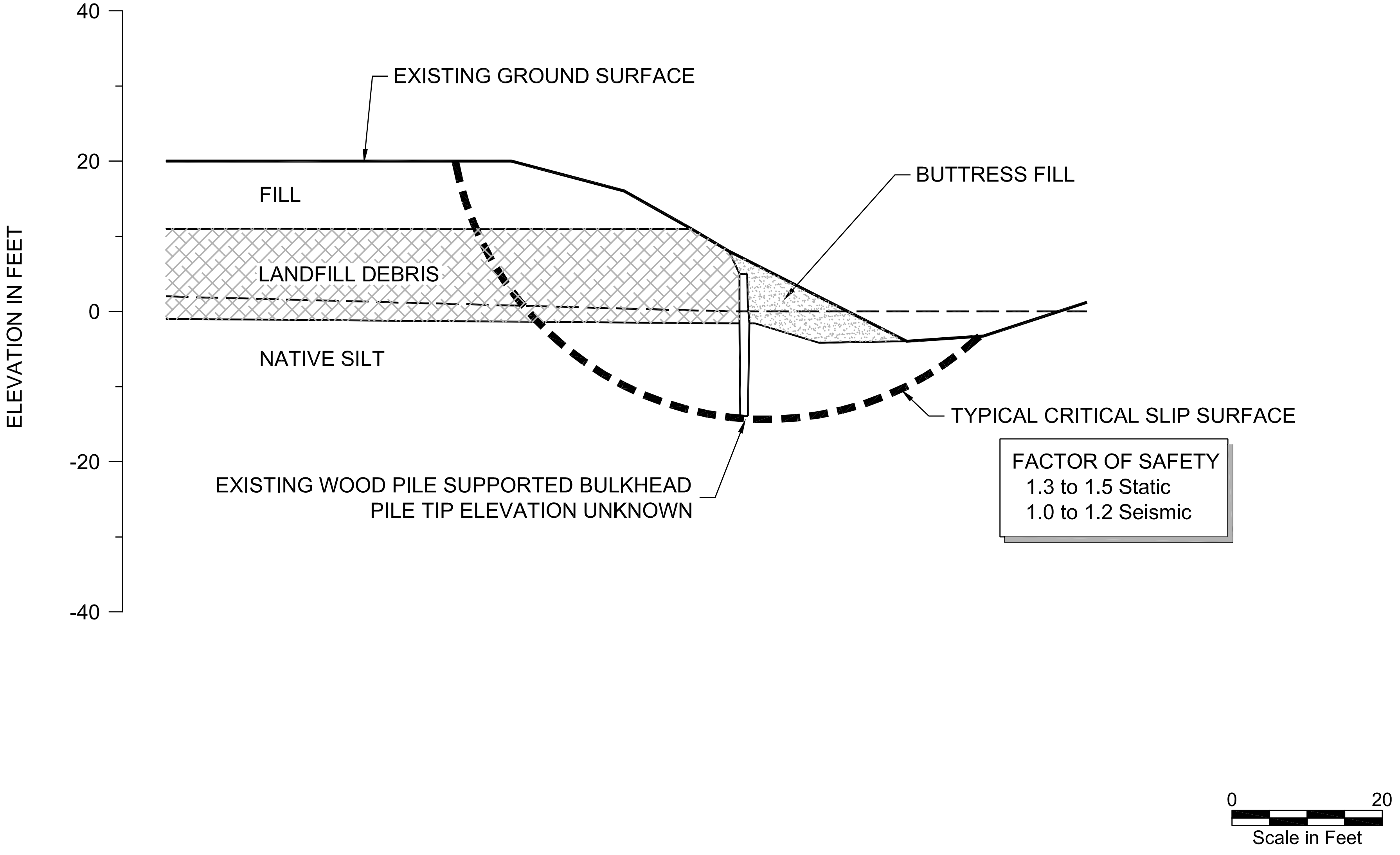


ANCHOR ENVIRONMENTAL, L.L.C.

Figure D-1
Slope Stability Section B-B
Existing Conditions



FACTOR OF SAFETY
1.3 to 1.5 Static
1.0 to 1.2 Seismic

Plotted: Nov 17, 2003 11:45am cdavidson K:\Jobs\990062-Holly Street\99006204\HOL-99006204-28.dwg D-2

Figure D-2
Slope Stability Section B-B
Proposed Buttress Fill

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ENVIRONMENTAL, L.L.C.

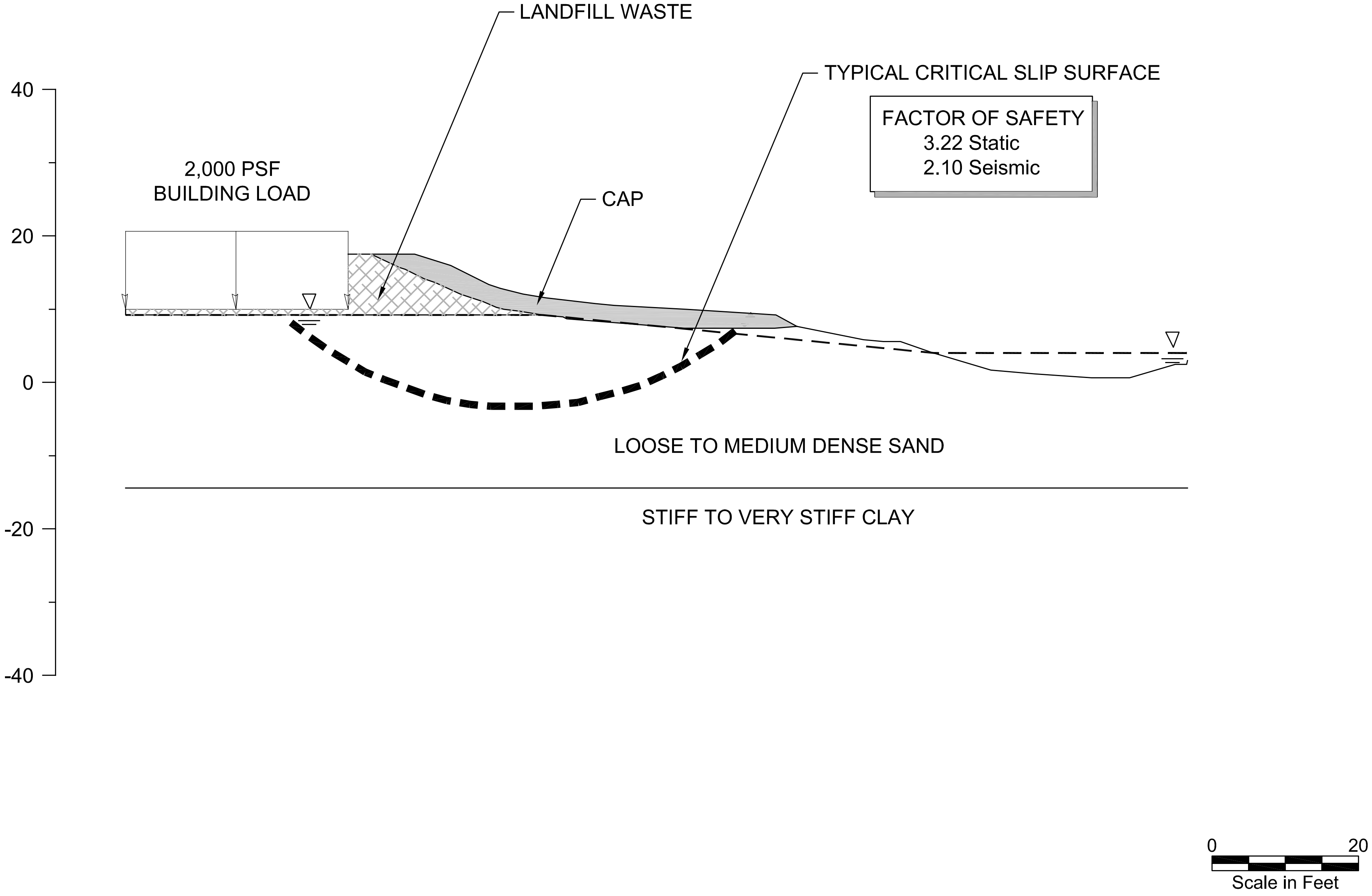

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Figure D-3
Slope Stability
Existing Re-Store Building

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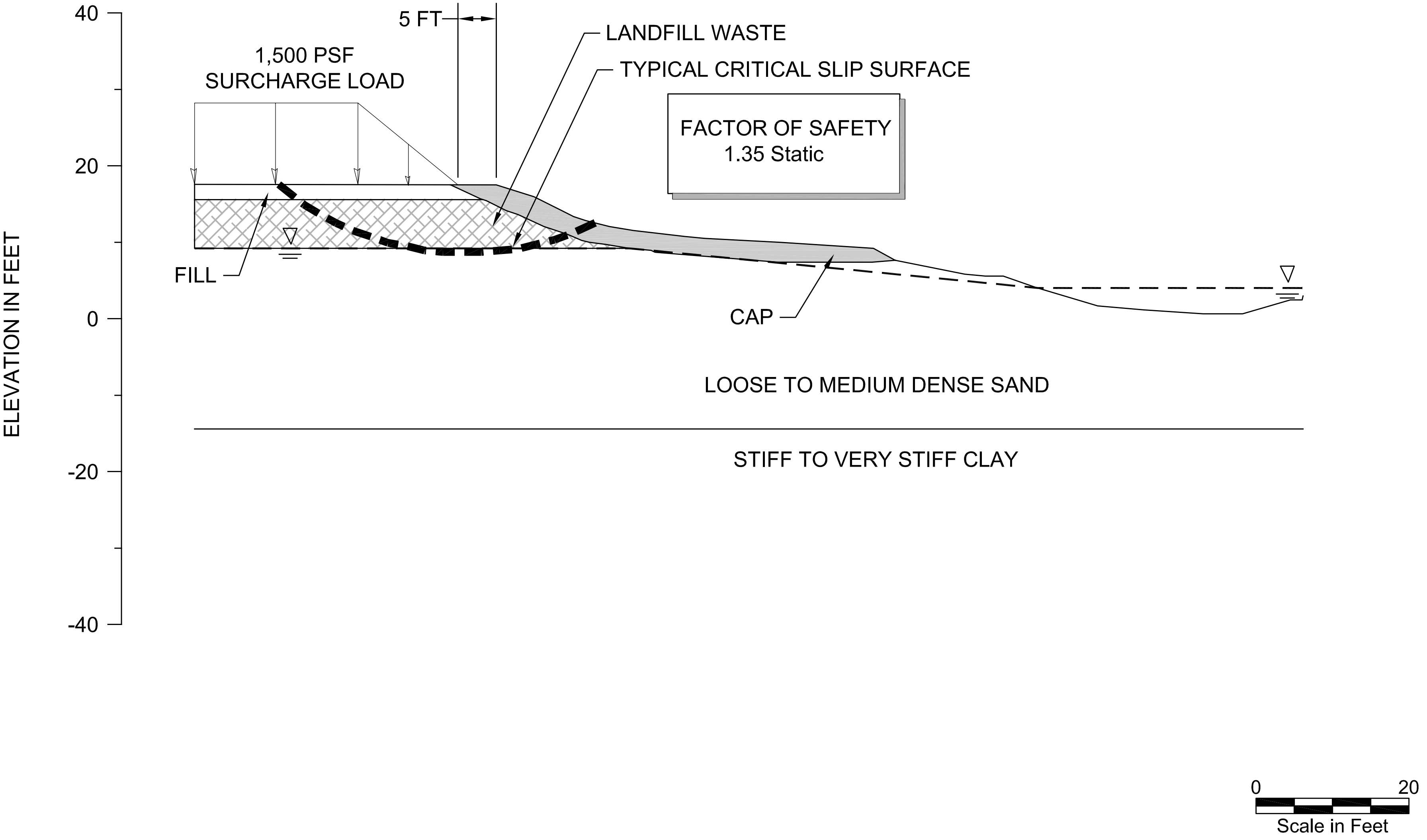

ANCHOR ENVIRONMENTAL, L.L.C.

Figure D-4
Slope Stability
Construction Surcharge

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APPENDIX E
ARMORING SIZE CALCULATIONS FOR EROSION PROTECTION

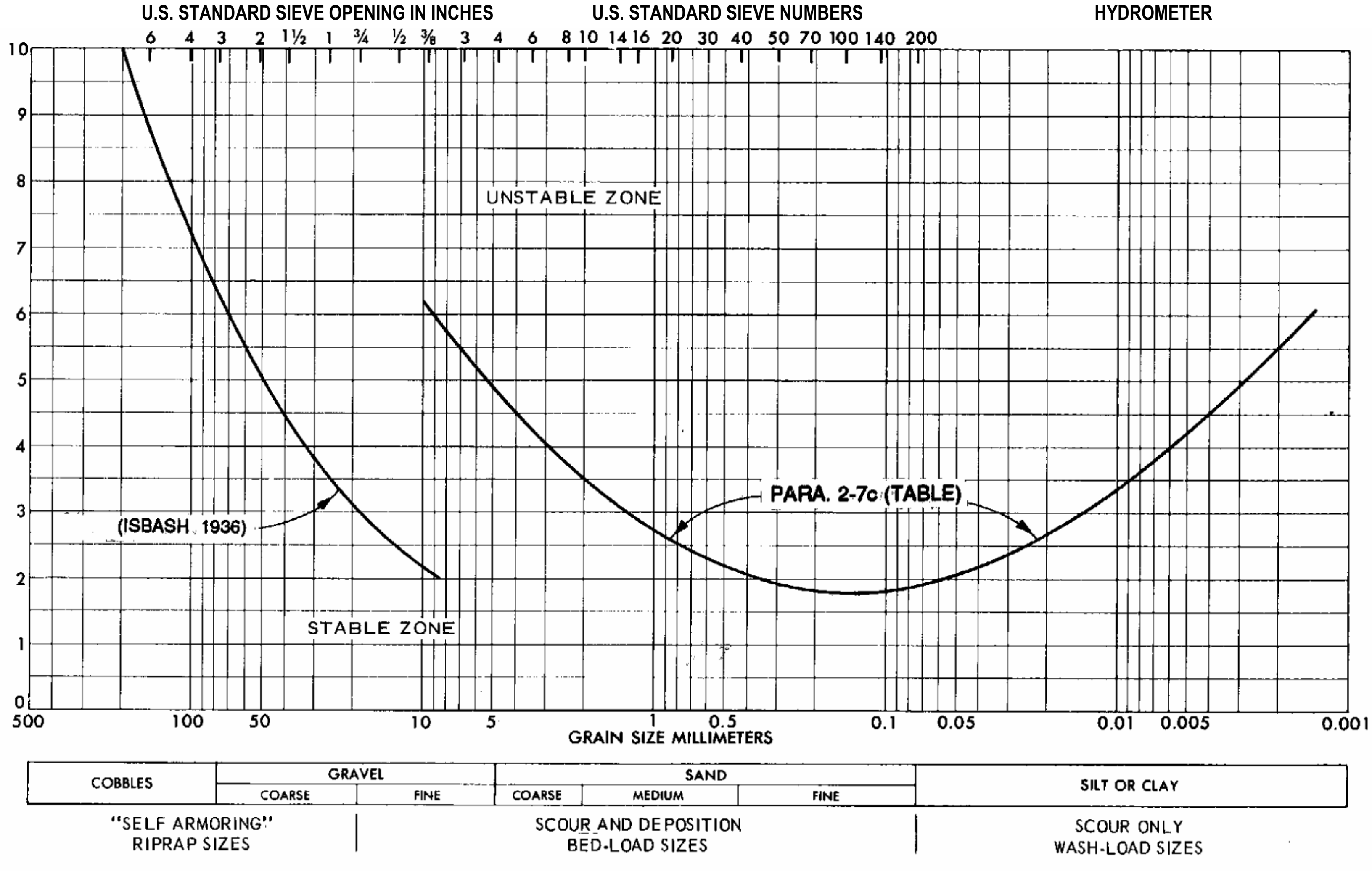

Figure E1
Noncohesive sediment gradation and permissible velocity.

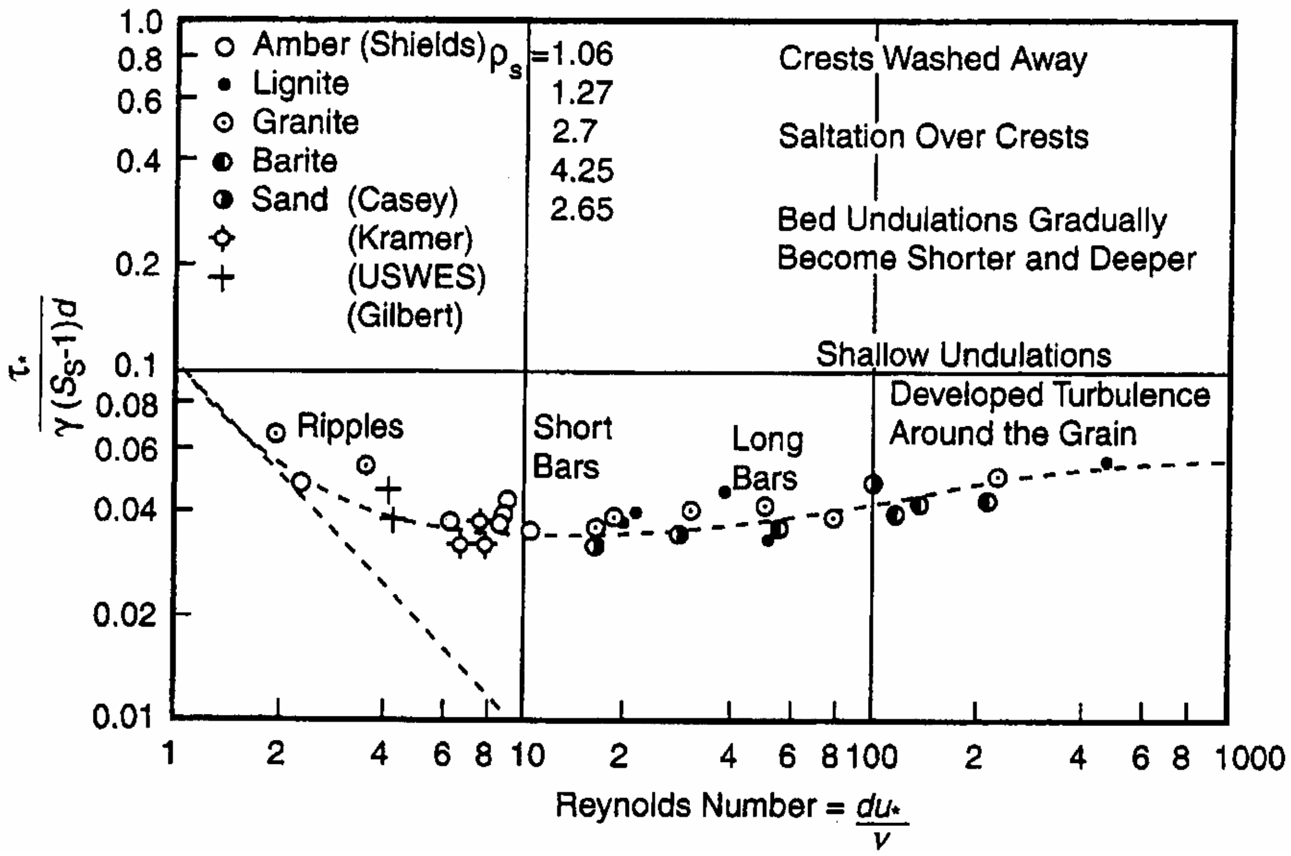

Figure E2
Critical water velocities for quartz sediment as function of mean grain.

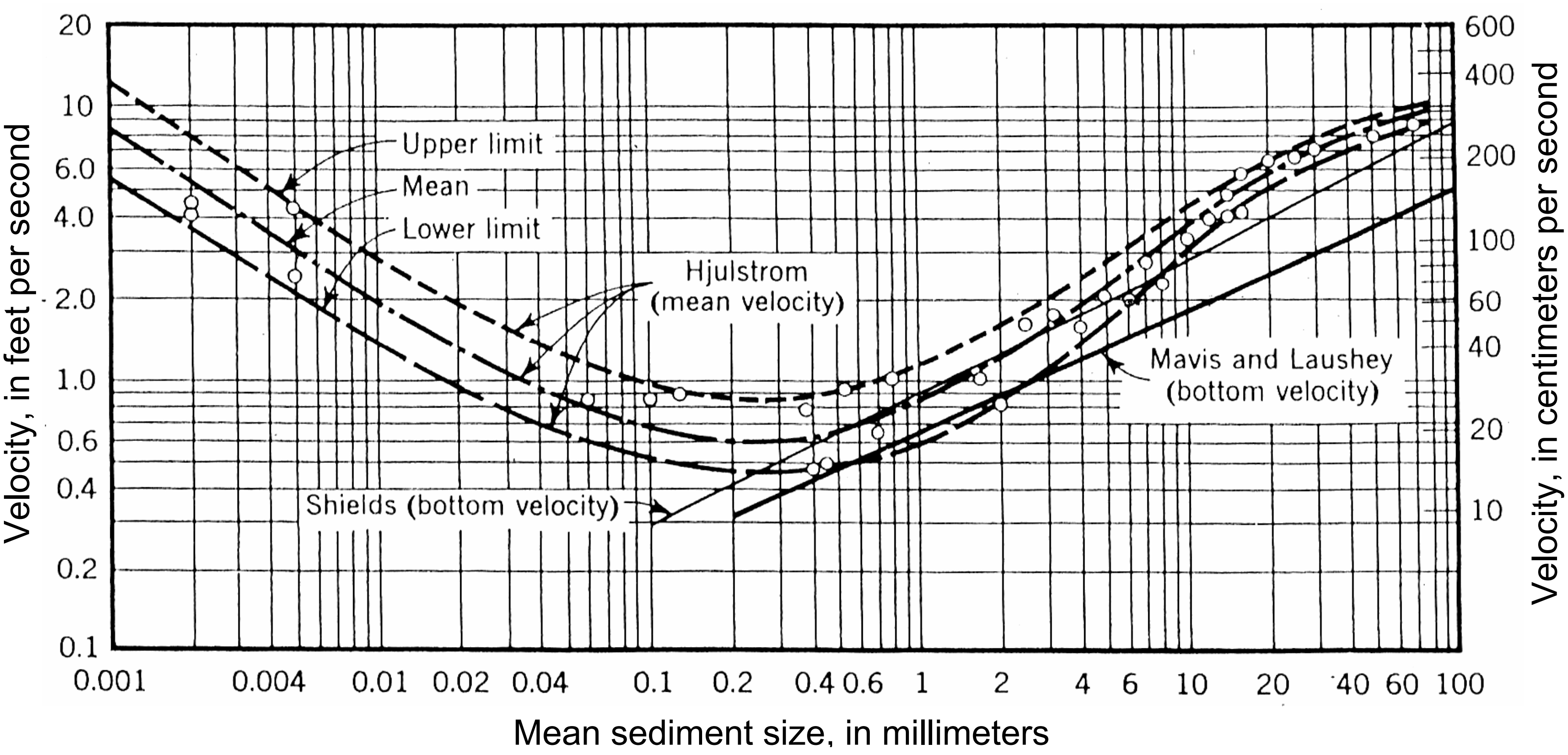

Figure E3
Shields diagram for initiation of cap material movement.

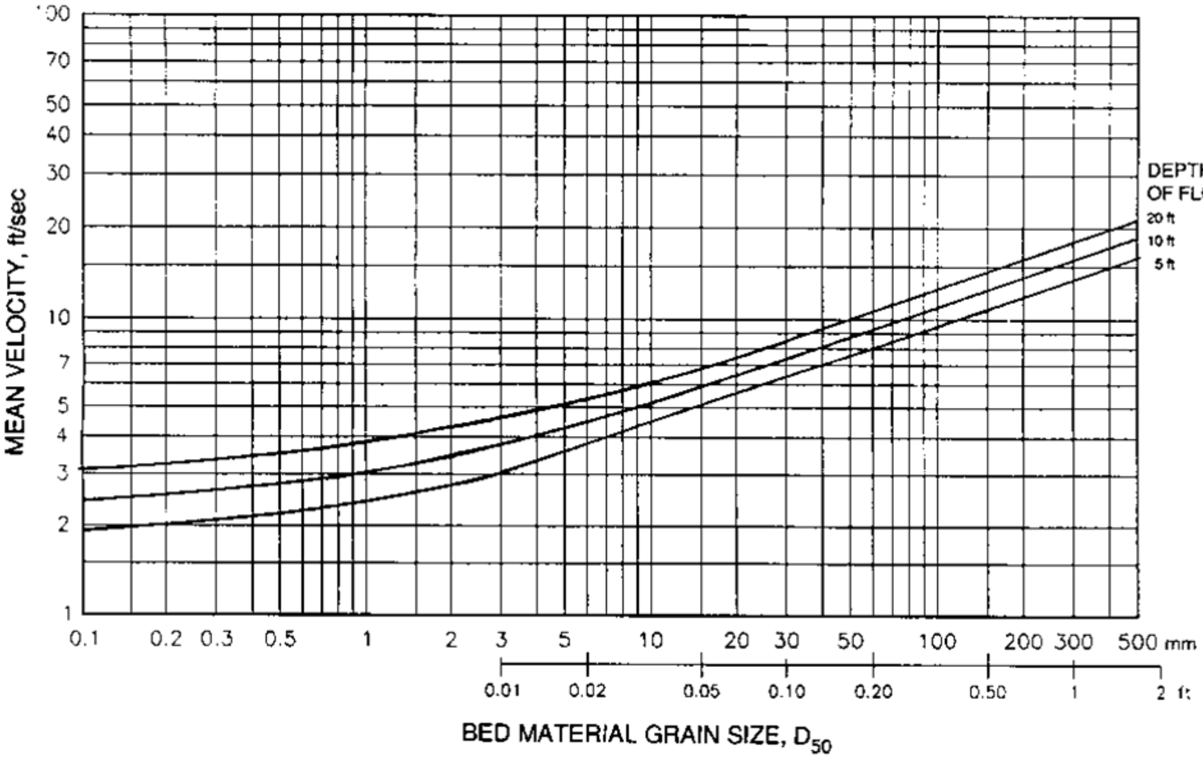

Figure E4
Example of allowable velocity depth data for granular materials.