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IN-DEPTH PERSPECTIVE

MEMORANDUM

Project No.: 020118-02

June 10, 2003

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cc: John Schwartz, Barrientos
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From: Lori Herman and Dave Heffner, Aspect Consulting
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Re: **Remedial Measures to Address Inhalation Exposure Concerns, Former Unocal Seattle Marketing Terminal Property**

This technical memorandum is presented pursuant to the Consent Decree between the Seattle Art Museum (SAM) and Museum Development Authority (MDA) and the Washington State Department of Ecology (Ecology) to conduct cleanup at the former Unocal Marketing Terminal property (Site) located on the 3100 block of Elliott Avenue in downtown Seattle. The Site is currently planned for redevelopment as a public park—the Olympic Sculpture Park (OSP)—with landscaped open space dedicated to exhibition of outdoor sculpture between Western Avenue and the Elliot Bay waterfront. Exhibit B to the Consent Decree is a Cleanup Action Plan (CAP) that describes, in general terms, remedial actions that will be performed in the course of property redevelopment to address issues related to residual petroleum-hydrocarbon contamination.

This technical memorandum focuses on the potential for residual petroleum-hydrocarbon contamination to cause inhalation exposures after the park is constructed. The CAP contains the following remedial action objectives (RAOs) addressing the inhalation exposure pathway:

- Verify that vapor emissions do not unacceptably impact ambient air quality; and
- Prevent potential indoor air impacts.

At the time the CAP was issued (October 1999), insufficient information was available to assess inhalation exposure potential. To provide data needed to address these RAOs, ambient air and soil vapor monitoring was conducted during the period June 2000 through November 2002. Monitoring was conducted in accordance with the Air Sampling/Monitoring and Contingency Plan (AS/M&CP), which is included in the Consent Decree as Exhibit F. This technical memorandum summarizes air monitoring results and proposes specific remedial measures and follow-up monitoring to satisfy the inhalation pathway RAOs. It is intended to fulfill the requirements of the following two items listed in the Consent Decree Exhibit E Schedule:

- Technical memorandum which summarizes the results of long-term air monitoring program and evaluates whether a contingency plan for ambient air is required; and

- Indoor air impact assessment report.

Summary of Air Monitoring Strategies and Results

Ambient Air Monitoring

Four ambient air monitoring rounds were conducted as follows:

- Short-term ambient air monitoring round - June 2000;
- Long-term ambient air monitoring Round 1 - October 2000;
- Long-term ambient air monitoring Round 2 - September 2001; and
- Long-term ambient air monitoring Round 3 - November 2002.

The sampling plan for the short-term monitoring round was provided in the AS/M&CP. Based on the results of that round (Hart Crowser 2000a), a sampling plan was then developed for long-term monitoring Round 1 (Hart Crowser 2000b). Results of the long-term monitoring rounds were reported in individual technical memoranda (Hart Crowser 2001a, 2001b, and 2003). The first two of those memoranda also include recommended modifications to the sampling plan for subsequent long-term monitoring rounds.

Ambient air monitoring was conducted within the Upper Yard, Lower Yard, and Off-Site Area—compliance areas of the CAP. In addition, samples were collected immediately upwind of the site and at nearby locations in downtown Seattle, to assess site background and local background concentrations respectively. (Many of the fuel compounds present in contaminated soil at the site are also emitted from motor vehicles, so ambient air background concentrations were an important consideration.) The short-term monitoring round included three sampling stations within each of the three compliance areas (for a total of nine on-site samples), as shown on Figure 1.

Six-liter evacuated SUMMA canisters were used to collect 8-hour composite air samples. The samples were analyzed for petroleum hydrocarbons and hydrocarbon fractions using EPA Method TO-14. Chemical analytical results for each monitoring round are provided in Tables 1 through 4, along with the corresponding Washington State Model Toxics Control Act (MTCA) Method B cleanup levels for ambient air established in the CAP. The AS/M&CP defines an exceedence of the ambient air RAO as any measured on-site concentration that exceeds both the MTCA Method B cleanup level and measured background concentrations. Table 5 summarizes measured exceedences of the ambient air RAO.

Long-term monitoring Round 1 included fewer sampling locations in the Lower Yard and Off-Site Areas because no exceedences of the ambient air RAO were measured in those areas during the short-term monitoring round. However, RAO exceedences were measured in the Upper Yard during both of those monitoring rounds (Table 5). The technical memorandum documenting long-term monitoring Round 1 results (Hart Crowser 2001a) concluded that remedial actions addressing soil gas emissions are required in the Upper Yard, and recommended that ambient air monitoring be discontinued in the Upper Yard until remedial actions are implemented. Thus, on-site ambient air sampling in long-term monitoring Rounds 2 and 3 was limited to the Lower Yard and Off-Site Area.

As summarized in Table 5, ambient air RAO exceedences were measured at two of the three Upper Yard sampling stations for three analyte groups: C_8-C_{10} aliphatic hydrocarbons; C_{10}-C_{12} aliphatic hydrocarbons; and C_{10}-C_{12} aromatic hydrocarbons. The short-term monitoring round produced exceedences for all three analyte groups at Station AA-1, and an exceedence for C_8-C_{10} aliphatic hydrocarbons at Station AA-2. A single exceedence was measured in long-term monitoring Round 1, for C_8-C_{10} aliphatic hydrocarbons at Station AA-2.

No exceedences of the ambient air RAO were measured in either the Lower Yard or the Off-Site Area during the four monitoring rounds. The highest exceedence in the Upper Yard occurred at Station AA-1, where 740 micrograms per cubic meter (ug/m^3) of C_8-C_{10} aliphatic hydrocarbons were measured during the short-term monitoring round. This concentration exceeds the corresponding MTCA Method B cleanup level by a factor of 5.4.

Soil Vapor Monitoring to Assess Indoor Air

Soil-to-indoor-air cleanup levels were not established in the CAP. Instead, the CAP states that the indoor air pathway will be addressed using engineering controls, if necessary. The AS/M&CP requires that soil vapor monitoring be conducted once the footprint of any proposed park building is determined, to evaluate whether engineering controls are needed. Soil vapor monitoring was conducted during geotechnical investigations for the OSP Pavilion building, proposed for construction in the southeast corner of the Upper Yard. (No other buildings are planned for the park.) The soil vapor monitoring plan (Hart Crowser 2002) was approved by Ecology, and monitoring was conducted in July 2002.

Three geotechnical borings (B-101 through B-103) were advanced in the vicinity of the proposed OSP Pavilion, at the locations shown on Figure 2. Soil samples were collected from these borings at depth intervals of 5 feet or less, and sample headspace was screened for organic vapors using a photo-ionization detector (PID). After placing the soil sample in a sample jar (partially filled), the jar was covered with aluminum foil and capped. After allowing the air space inside the jar to equilibrate for 10 to 20 minutes, the cap was removed and the tip of a PID probe was inserted through the aluminum foil cover. The PID reading was recorded during the first 10 seconds. In addition, hydrocarbon staining or odor, if observed, was noted on the boring log. Results of PID headspace screening are summarized in Table 6, and copies of the boring logs are provided in Attachment A.

No PID readings above background were detected in the two borings placed within the footprint of the proposed Pavilion (B-102 and B-103). However, soil samples taken from Boring B-101 (approximately 40 feet east of the Pavilion footprint within the Western Avenue right-of-way) exhibited PID headspace readings as high as 92 ppm.

Air Monitoring Conclusions

The ambient air monitoring results indicate that remedial action is required in the Upper Yard to address the ambient air RAO. No RAO exceedences were measured in either the Lower Yard or the Offsite Area during the four rounds of ambient air monitoring; therefore, no remedial actions addressing ambient air are required in these two compliance areas.

Soil vapor monitoring conducted during geotechnical investigations resulted in no detections of organic vapors within the footprint of the OSP Pavilion, the only building proposed for the park. However, organic vapors were detected in soil samples collected from beneath Western Avenue approximately 40 feet east of the proposed Pavilion. It is unlikely that these organic vapors are the result of historical Unocal operations at the site, for the following reasons:

- The boring location in which organic vapors were detected is upgradient of the site, and the highest PID reading is associated with a soil sample collected at an elevation higher than the ground surface of the former Unocal facility; and

- The Unocal office building occupied the southeast corner of the Upper Yard. Available records do not indicate that petroleum product was stored or handled at that location, and multiple environmental investigations performed in the Upper Yard have not indicated petroleum hydrocarbon impacts in the southeast corner.

Nonetheless, organic vapors beneath Western Avenue could potentially migrate onto the park property. The AS/M&CP states that, if soil headspace monitoring indicates the presence of organic vapors, a decision will be made to either add engineering controls or perform additional soil vapor monitoring to determine whether petroleum and BTEX vapor concentrations exceed MTCA Method A or B indoor air cleanup criteria. We propose that engineering controls be incorporated into the design of the OSP Pavilion to assure that potential vapor migration will not result in indoor air impacts.

Upper Yard Remedial Action to Address Ambient Air

Localized Zones of Potential Soil Vapor Emissions

The air quality exceedences measured in the Upper Yard likely resulted from soil vapor emissions emanating from localized zones of residual soil contamination. Unocal's 1997 remedial action removed most of the petroleum-contaminated soil encountered in the Upper Yard. Confirmation sampling within the Upper Yard verified that, on a statistical basis, total petroleum hydrocarbon (TPH) concentrations in remaining soil did not exceed the cleanup target of 200 mg/kg, except for a small area in the Yard's northwest corner (GeoEngineers 1997). At that location (shaded in tan on Figure 2), deep impacted soil could not be excavated without potentially compromising the stability of the shoring wall along Elliott Avenue. In addition, soil samples collected from behind shoring walls installed along the Upper Yard perimeter exceeded the TPH cleanup target at four locations. Cleanup target exceedence locations are depicted on Figure 2 along with PID headspace screening results and TPH concentrations measured in soil.

Based on the above information, we identified the following two zones (shown on Figure 2) as having the highest potential for significant soil vapor emissions to the Upper Yard:

Zone 1. This zone, located in the Upper Yard's northwest corner, contains the following potential emission sources:

1) Impacted soil that could not be excavated from the Upper Yard. (In-place volume estimated at 110 cubic yards.) No PID headspace measurements or chemical analyses of this soil were performed. The top of the residual impacted soil layer is approximately 17 feet below the Elliott Avenue street grade, and is currently covered with roughly a 10-foot thickness of loosely compacted soil.

2) Impacted soil behind (i.e., west of) the existing shoring wall, as indicated by the test results of three soil samples collected from directly behind the wall at depths of 14 to 20 feet beneath Elliott Avenue. PID headspace screening results up to 11,000 ppmv and TPH concentrations up to 6,870 mg/kg were measured in this soil.

3) The eastern end of the Unocal pipe tunnel that runs beneath Elliott Avenue, which is partially open to the Upper Yard (i.e., the existing soil cover only partially blocks the tunnel entrance). Petroleum-like odors have been noted in and around this tunnel.

Zone 2. This zone, located along the Yard's northern boundary, contains petroleum-impacted soil behind (i.e., north of) the existing shoring wall. A soil sample collected from directly behind the wall at a depth of 19.5 feet beneath the surface grade of Elliot Avenue (see Figure 2) contained 1,980 mg/kg TPH and exhibited a PID headspace measurement greater than 2,000 ppmv.

As shown on Figure 2, three confirmation surface soil samples located within the Upper Yard but outside the above zones had TPH concentrations in excess of the cleanup target. However, the highest TPH detection among these was only 369 mg/kg, and PID headspace measurements did not exceed 100 ppmv. Therefore, these three locations are judged to have a much lower potential for soil vapor emissions than the two zones described above. Similarly, perimeter soil in the vicinity of Boring B-101, which exhibited a maximum PID headspace measurement of 92 ppmv, is judged to have a low potential to impact Upper Yard ambient air.

Proposed Remedial Action and Required Emission Reductions

It is proposed that a layer of well-compacted clean fill be added to the Upper Yard to reduce soil vapor emissions and achieve the ambient air RAO. The fill layer, which will be incorporated into the architectural design for the proposed park, will reduce the rate at which petroleum hydrocarbon vapors are emitted to ambient air from the potential source areas discussed above. The emission reductions that must be achieved by the fill layer to meet the MTCA cleanup levels is calculated as follows:

$$\text{Required emission reduction (percent)} = 100 \times [1 - (C_{MTCA} / C_{max})],$$

where

C_{max} = highest measured ambient air concentration for the given analyte group

C_{MTCA} = respective MTCA Method B cleanup level.

Using the exceedences measured during the ambient air monitoring program and respective cleanup levels summarized in Table 5, the following emission reductions are calculated:

Analyte Group	Required Emission Reduction
C_8-C_{10} Aliphatics	82%
C_{10}-C_{12} Aliphatics	35%
C_8-C_{10} Aromatics	20%

In terms of hydrocarbon vapor emission rates, the required emission reductions can be expressed as

$$\text{Required emission reduction (percent)} = 100 \times [1 - (E_f / E_e)],$$

where E_e and E_f are the existing and final (post-remedial action) emission rates, respectively.

Methodology for Evaluating Emission Reductions

The magnitude of emission rate reduction achieved by placing a fill layer over a vapor source is dependent on both the fill layer thickness and its physical properties. To calculate emission reductions under various scenarios, we used Fick's Law of molecular diffusion in accordance with EPA guidance on soil vapor emissions from contaminated sites (EPA 2000). For this application, Fick's Law can be expressed as:

$$E = A\,(C_s - C_a)\,\mathcal{D}^{eff}/L,$$

where

E = hydrocarbon vapor emission rate

A = cross-sectional area through which the vapors pass

C_s = vapor concentration at the source

C_a = vapor concentration at the fill layer surface (ambient air interface)

$\mathcal{D}^{eff}$ = effective diffusion coefficient across the fill layer

L = fill layer thickness

The analysis was conducted for the two localized areas having the highest potential for significant soil vapor emissions to the Upper Yard (Zone 1 and Zone 2). We evaluated fill layer requirements at each zone under the assumption that emissions were coming exclusively from the zone under consideration. In addition, we made the following zone-specific assumptions:

Zone 1. Since the impacted soil within the Upper Yard (shaded area inside Zone 1 on Figure 2) is already covered with roughly 10 feet of loosely compacted "clean" soil, it is the least receptive of the three potential sources in Zone 1 to emission reduction via placement of additional clean fill. Therefore, in evaluating fill layer requirements at Zone 1, we conservatively assumed that emissions come exclusively from that buried soil layer.

Zone 2. The potential emission source in this zone is impacted soil behind the shoring wall, which has been exposed to air since the 1997 remedial action. It is likely that ongoing volatilization of hydrocarbons from this soil into the Upper Yard has resulted in the formation of a thin layer of relatively clean soil at the soil:air interface. To conservatively evaluate the emission reduction potential of clean fill material placed against the shoring wall, we assumed that a 6-inch-thick layer of relatively clean soil currently exists between the impacted soil and the wall.

Thus, at both locations our conceptual model assumes that the emission source currently has a layer of clean soil separating it from the ambient air, and additional soil cover must be added to achieve the required emission reductions. Fick's Law can be applied to both the existing and the future (post-remedial action) cases, where the future case includes two soil layers through which the hydrocarbon vapors must diffuse to reach the ambient air.

We assumed that the cross-sectional area through which the vapors pass would not change as a result of placing a fill layer, and that the vapor concentration is much greater at the source than at the fill layer-ambient air interface. Therefore, applying Fick's Law to the emission rate ratio yields the following relationship:

$$E_f / E_e = \mathcal{D}_{T,f}^{eff} L_e / (\mathcal{D}_e^{eff} L_T),$$

where

L_e = existing fill layer thickness

L_T = total final fill layer thickness (sum of existing and new layer thicknesses)

$\mathcal{D}_e^{eff}$ = effective diffusion coefficient across the existing fill layer

$\mathcal{D}_{T,f}^{eff}$ = total overall effective diffusion coefficient across the two final fill layers
$= L_T / (L_e / \mathcal{D}_e^{eff} + L_n / \mathcal{D}_n^{eff}),$

where

L_n = new fill layer thickness

$\mathcal{D}_n^{eff}$ = effective diffusion coefficient across the new fill layer.

The conceptual model assumes the soil void spaces are filled with both air and liquid-phase water. Hydrocarbon molecules are assumed to migrate through the void spaces by both vapor-phase and aqueous-phase diffusion. On this basis, layer-specific effective diffusion coefficients were estimated using the following equation:

$$\mathcal{D}_i^{eff} = \mathcal{D}_a(\Theta_{a,i}^{3.33}/n_i^2) + (\mathcal{D}_w/H'_{TS})(\Theta_{w,i}^{3.33}/n_i^2),$$

where

$\mathcal{D}_i^{eff}$ = effective diffusion coefficient across fill layer i

$\mathcal{D}_a$ = diffusivity in air

$\mathcal{D}_w$ = diffusivity in water

$\Theta_{a,i}$ = air-filled porosity of fill layer i

$\Theta_{w,i}$ = water-filled porosity of fill layer i

n_i = total porosity of fill layer i = $\Theta_{a,i} + \Theta_{w,i}$

H'_{TS} = Henry's Law constant at the system temperature.

In simple terms, the rate of molecular diffusion is governed mainly by the bulk soil porosity and the soil's water content. In general, reduction of the molecular diffusion rate is enhanced by minimizing the void volume (e.g., by selecting a soil with a high fines content and by compacting the soil) and by maximizing the soil's water content.

Since some of the required inputs to the above equations are properties available only for pure compounds, we selected one compound to represent each analyte group as follows:

Analyte Group	Representative Compound
C_8-C_{10} Aliphatics	1,1,3-trimethylcyclohexane
C_{10}-C_{12} Aliphatics	2,3,7-trimethyloctane
C_8-C_{10} Aromatics	butylbenzene

Compound selection was based on our review of chemical speciation data for separate-phase product recovered from extraction wells located near the northwest corner of the Upper Yard (GeoEngineers 1997).

The ultimate goal of this evaluation was to determine appropriate limits for import fill material, such that the required emission reduction efficiencies are achieved in the constructed park. The emission calculation methodology described above yields fill layer requirements in terms of bulk soil porosity, water content, and layer thickness. While fill layer thickness and minimum water content are parameters that are appropriate to specify in a construction bid package, maximum bulk soil porosity is not. Therefore, as an additional step in the evaluation process, we determine a minimum soil fines content (i.e., weight percent passing a No. 200 sieve) and a minimum soil compaction, parameters that can be specified in a construction bid package, to serve as surrogates for maximum bulk soil porosity.

The evaluation process involved iteratively specifying fill soil properties and determining, based on those properties, the minimum thicknesses of additional fill layers at Zones 1 and 2 to achieve the required emission reduction efficiencies. Sample calculation spreadsheets are provided in Attachment B. Since there is more than one independent variable in this evaluation, there is a range of potential solutions. For example, for a given fill layer thickness, tradeoffs can be made between the soil fines content and its compaction to achieve the same emission reduction efficiency. However, in order to avoid undue complexity in the requirements of the construction bid package, we determined a single set of soil property limits that meet the emission reduction criteria while providing the contractor flexibility in selecting among fill soils that may be available at the time of park construction.

Proposed Fill Soil Thicknesses and Limits

Based on our evaluation results, the following fill soil thicknesses and limits are proposed:

- Minimum fill layer thicknesses of 29 feet at Zone 1 and 7 feet at Zone 2;
- Fill soil having a minimum fines content of 5 percent by weight, and a water content (at the time of placement) of no less than 1 percent greater than the optimum water content for soil compaction (per ASTM D1557); and
- Soil compaction to at least 90 percent of the Modified Proctor Density (ASTM D1557).

Figure 3, prepared in collaboration with Hart Crowser, illustrates the ability of potential fill soils to meet the 82 percent emission reduction requirement for C_8-C_{10} aliphatics at 90 percent compaction and fill thicknesses of 29 feet at Zone 1 and 7 feet at Zone 2. (The requirement to reduce C_8-C_{10} aliphatics emissions by 82 percent was the most restrictive emission reduction criterion in all cases evaluated.) The curve on the figure represents fill soil properties (water content and dry density at 90 percent compaction) that just meet the emission reduction requirement. Each individual data point represents a local fill soil plotted at 1 percent greater than its optimum water content for soil compaction. All local fill soils for which Hart Crowser was able to obtain dry density and optimum water content data are shown on Figure 3. The fines content of the soil, if available, is displayed next to the data point.

All Figure 3 data points (except one) fall to the right of the curve and, therefore, satisfy the emission reduction requirement. By restricting the fines content of the fill soil to at least 5 percent by weight, we eliminate that data point from consideration. (As discussed below, establishing a minimum fines content is also necessary to ensure that adequate soil moisture will be retained after placement.) This demonstrates that the fill layer thicknesses and limits proposed above have a high probability of meeting the emission reduction requirements at the time of fill placement.

The proposed remedial action is considered sufficiently protective as the analysis built in conservativeness as follows:

- Zone 1 was evaluated under the assumption that emissions came exclusively from the potential source that would be least receptive to emission reduction via placement of additional clean fill material (i.e., the impacted soil currently covered with clean fill). If either of the other two potential sources in Zone 1 (the Unocal pipe tunnel or impacted soil behind the shoring wall) is a significant contributor to ambient air exceedences, then the proposed remedial action should result in even higher emission reductions.
- A reduced permeability layer over Zone 1 will be installed at street grade, and will extend from Elliott Avenue approximately 57 feet into the Upper Yard. It will consist of a minimum 12-inch thickness of controlled density fill (CDF) or other granular material or combination of granular materials having a maximum vertical permeability no greater than 10^{-5} cm/sec. The layer's purpose is to reduce infiltration potential in the northwest corner of the Upper Yard, but it will also serve as a barrier to upward diffusion of vapors. Vapors will be forced to migrate around the layer. Therefore, although it has not been considered explicitly in the current evaluation, the reduced permeability layer will increase the travel distance of hydrocarbon vapors migrating from Zone 1 to the park surface, resulting in higher-than-calculated emission reductions.

Potential for Fill Layer Desiccation over Time

As previously noted, the rate of vapor diffusion through soil is sensitive to soil water content. The proposed limitation on fill soil water content assures that the fill layer will meet the emission reduction requirement at the time of placement. It remains to be demonstrated that the water content of the in-place fill soil is not likely to decrease over time to less than the optimum water content for soil compaction.

Water could potentially leave the in-place fill layer either by draining from it as a liquid, by evaporating from it as a vapor, or through plant transpiration. (The latter two of these mechanisms are collectively referred to as "evapotranspiration.") The field capacity of a soil is defined as the water content at which internal drainage becomes negligible. Field capacity increases with soil fines content. For the fill soils on Figure 3 with fines contents greater than 5 percent, the plotted water contents (1 percent above optimum for compaction) are all below their field capacities. Soils below the effect of the root zone will increase in moisture, attaining moisture contents near field capacity as a result of infiltration from late fall and winter rains. Therefore, drainage of liquid water from the fill soils below the root zone is not a concern, and the increase in moisture content is expected to improve the overall effectiveness of the fill material in mitigating vapor diffusion.

Within the root zone, evapotranspiration can cause near-surface soils to dry out over periods of low rainfall. However, the potential for significant soil dessication exists only during the summer months, and even then only the top 1 to 2 feet of soil may be impacted. Rains during the wet season are always more than sufficient to rehydrate the near-surface soils, such that there is no cumulative drying effect from one year to the next. In addition, it should be noted that the finished park areas above Zones 1 and 2 will be largely vegetated, and vegetated areas will have irrigation systems operating during the summer months. Therefore, evapotranspiration has the potential to impact only a small fraction of fill layer soils (i.e., soils within 1 to 2 feet of the ground surface that are outside irrigation zones), and those soils would have the potential for diminished water content only during a few months of the year (i.e., the dry season). Overall, the effect of soil dessication via evapotranspiration in the upper 1 to 2 feet will be offset by the increase in soil moisture beneath the root zone, and will not significantly impact the fill layer's ability to achieve the required reduction in soil vapor emissions.

Post-Construction Confirmation Monitoring

One round of ambient air monitoring is proposed within and around the Upper Yard to confirm the effectiveness of the remedial action. The sampling and analysis methods will be identical to those used previously for the long-term ambient air monitoring rounds. Key elements of the confirmation ambient air monitoring round are proposed as follows:

- Confirmation monitoring will be conducted at least 6 months after installation of the compacted soil cover, to allow time for soil vapor profiles above the zones of potential emissions to equilibrate.

- Confirmation monitoring will be conducted on a relatively calm day following an extended period of dry weather. This will provide the reasonable worst-case conditions for soil vapor emissions.

- 8-hour ambient air samples will be collected within the Upper Yard at sampling locations AA-1, AA-2, and AA-3 (see Figure 1). A site background sample will be collected at either B-2N or B-2S (depending on wind direction at the start of the sampling period), and a local background sample will be collected at B-SAM.

- The sampling and analysis methods will be identical to those used in the previous ambient air monitoring rounds. Chemical analysis will be by EPA Method TO-14, with GC analysis of individual fuel compounds and fuel hydrocarbon groups.

- Measured on-site concentrations will be compared to the MTCA Method B cleanup levels and measured background concentrations.

Engineering Control to Address Pavilion Indoor Air

The CAP specifies that construction of an open-air garage beneath the Pavilion is an appropriate engineering control to mitigate the potential for soil vapors to impact indoor air. SAM has incorporated such an open-air garage into the Pavilion design; with remedial elements such as vapor barriers and drainage material around the foundation, in addition to the ventilation system of the open-air design. The garage will be open on three sides, and the Pavilion will be constructed on an above-ground pier with no soil connection to Western Avenue. This design ensures there will be no significant pathway for soil vapors from the unidentified source under Western Avenue to migrate into the Pavilion. Since there will be no significant vapor pathway, confirmation sampling of indoor air is not warranted.

References

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GeoEngineers 1997. Final Cleanup Report, Remedial Excavation Monitoring, Upper Yard, Former Unocal Seattle Marketing Terminal, Seattle, Washington. Volume I of III. December 16, 1997.

GeoEngineers 1998. Remedy Selection Report. Elliott Avenue, Former Seattle Marketing Terminal. Prepared for Unocal AMG. January 1997.

Hart Crowser 2000a. Technical Memorandum Re: Ambient Air Monitoring Results, Olympic Sculpture Park/Unocal Seattle Marketing Terminal Property, Seattle, Washington. August 11, 2000.

Hart Crowser 2000b. Technical Memorandum Re: Long-Term Air Monitoring Plan – Initial Sampling Event, Olympic Sculpture Park/Unocal Seattle Marketing Terminal Property, Seattle, Washington. September 27, 2000.

Hart Crowser 2001a. Technical Memorandum Re: Long-Term Ambient Air Monitoring – First Round Results, Soil-Vapor Extraction System Design, Olympic Sculpture Park/Unocal Seattle Marketing Terminal Property, Seattle, Washington. August 15, 2001.

Hart Crowser 2001b. Technical Memorandum Re: Long-Term Ambient Air Monitoring – Second Round Results, Olympic Sculpture Park/Unocal Seattle Marketing Terminal Property, Seattle, Washington. November 14, 2001.

Hart Crowser 2002a. Letter Re: Geotechnical Boring and Soil Vapor Monitoring Plan, Proposed Olympic Sculpture Park. July 16, 2002.

Hart Crowser 2002b. Memorandum Re: Subsurface Conditions, Settlement Estimates for Bridges and Elliott Tunnel Infilling, Olympic Sculpture Park. September 27, 2002.

Hart Crowser 2003. Technical Memorandum Re: Long-Term Ambient Air Monitoring – Third Round Results, Olympic Sculpture Park/Unocal Seattle Marketing Terminal Property, Seattle, Washington. January 29, 2003.

SAM 2000. Letter from C. Rogers (Seattle Art Museum) to Nnamdi Madakor (Ecology) regarding Olympic Sculpture Park Ambient Air Monitoring. June 26, 2000.

Attachments:

Table 1 – Short-Term Ambient Air Monitoring Round Results (June 2000)
Table 2 – Long-Term Ambient Air Monitoring Round 1 Results (October 2000)
Table 3 – Long-Term Ambient Air Monitoring Round 2 Results (September 2001)
Table 4 – Long-Term Ambient Air Monitoring Round 3 Results (November 2002)
Table 5 – Summary of Measured Exceedences of the Ambient Air RAO
Table 6 – Soil Vapor Monitoring Results

Figure 1 – Ambient Air Monitoring Location Plan
Figure 2 – Geotechnical Borings and Residual Soil Contamination – Upper Yard
Figure 3 – Ability of Fill Soils to Meet Emission Reduction Requirement

Attachment A	Boring Logs, Hart Crowser Investigation, August 2002
Attachment B	Sample Calculation Spreadsheets, Vapor Emission Reductions Provided by New Soil Fill

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Table 1 - Short-Term Ambient Air Monitoring Round Results (June 2000)

	Concentration in ug/m^3												
	MTCA Method B	Upper Yard			Lower Yard			Off-Site Area			Site Background		
Analytes	Cleanup Level	AA-1	AA-2	AA-3	AA-4	AA-5	AA-6	AA-7	AA-8	AA-9	B-2N	B-3N	B-4N
Individual Constituents													
Benzene	0.259	3.0 U	3.1 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	2.8 U	3.0 U	2.9 U	3.0 U	3.0 U
Toluene	183	**20**	3.6 U	**12**	3.6 U	3.5 U	**3.9**	**5**	**6.7**	3.6 U	**6.3**	3.6 U	3.6 U
Ethyl Benzene	457	**6.9**	4.2 U	4.0 U	4.1 U	4.0 U	4.0 U	4.1 U	3.9 U	4.1 U	3.9 U	4.1 U	4.1 U
m,p-Xylene	320	**15**	4.2 U	4.0 U	4.1 U	4.0 U	**9.5**	4.1 U	**3.9**	4.1 U	4.0 U	4.1 U	4.1 U
o-Xylene	320	**6.4**	4.2 U	4.0 U	4.1 U	4.0 U	4.0 U	4.1 U	3.9 U	4.1 U	4.0 U	4.1 U	4.1 U
1,3,5-Trimethylbenzene	420	4.6 U	4.8 U	4.6 U	4.7 U	4.6 U	4.6 U	4.7 U	4.4 U	4.7 U	4.5 U	4.7 U	4.7 U
1,2,4-Trimethylbenzene	420	**9.3**	4.8 U	4.6 U	4.7 U	4.6 U	**5.6**	4.7 U	4.4 U	4.7 U	4.5 U	4.7 U	4.7 U
Propylene	--	6.4 U	6.7 U	6.4 U	6.5 U	6.4 U	6.4 U	6.5 U	6.1 U	6.5 U	6.3 U	6.5 U	6.5 U
1,3-Butadiene	0.00417	8.2 U	8.6 U	8.2 U	8.4 U	8.2 U	8.2 U	8.4 U	7.9 U	8.4 U	8.0 U	8.4 U	8.4 U
Hexane	91.4	13 U	14 U	13 U	13 U	13 U	13 U	13 U	12 U	13 U	13 U	13 U	13 U
Cyclohexane	3,400	13 U	13 U	13 U	13 U	13 U	13 U	13 U	12 U	13 U	12 U	13 U	13 U
4-Ethyltoluene	--	18 U	19 U	18 U	19 U	18 U	18 U	19 U	17 U	19 U	18 U	19 U	19 U
Heptane	5,500	15 U	16 U	15 U	16 U	15 U	15 U	16 U	14 U	16 U	15 U	16 U	16 U
Naphthalene	170	96 U	100 U	96 U	100 U	96 U	96 U	100 U	96 U	100 U	96 U	100 U	100 U
Aliphatic Hydrocarbons													
C_3 to C_5	--	**230**	**40**	**81**	34 U	34 U	34 U	**53**	**33**	**53**	**38**	**40**	34 U
C_5 to C_6	9,120	**150**	57 U	55 U	56 U	55 U	55 U	56 U	52 U	56 U	54 U	56 U	56 U
C_6 to C_8	9,120	**260**	68 U	66 U	67 U	66 U	66 U	67 U	63 U	67 U	64 U	67 U	67 U
C_8 to C_{10}	136	**$\boxed{740}$**	**$\boxed{260}$**	**85 J**	89 U	87 U	87 U	89 U	83 U	89 U	85 U	89 U	89 U
C_{10} to C_{12}	136	**$\boxed{210}$**	110 U	110 U	110 U	110 U	110 U	110 U	100 U	110 U	100 U	110 U	110 U
> C_{12}	--	130 U	140 U	130 U	130 U	130 U	130 U	130 U	120 U	130 U	130 U	130 U	130 U
Aromatic Hydrocarbons													
C_6 to C_8	--	59 U	62 U	59 U	61 U	59 U	59 U	61 U	57 U	61 U	58 U	61 U	61 U
C_8 to C_{10}	80	**$\boxed{100}$**	84 U	81 U	82 U	81 U	81 U	82 U	77 U	82 U	79 U	82 U	82 U
C_{10} to C_{11}	80	97 U	100 U	97 U	100 U	97 U	97 U	100 U	93 U	100 U	95 U	100 U	100 U

Bold indicates analyte detection.

J Estimated value.

U Not detected at indicated detection limit.

☐ Concentration exceeds ambient air remedial action objective (i.e., both the MTCA Method B cleanup level and background concentrations are exceeded).

V:\020118 SAM Olympic Sculpture Park\[SAM Air Tech MemoTables 1 thru 6.xls]T1 - June 2000

Table 2 - Long-Term Ambient Air Monitoring Round 1 Results (October 2000)

	Concentration in ug/m^3												
	MTCA Method B	Upper Yard			Lower Yard	Off-Site Area		Site Background			Local Background		
Analytes	Cleanup Level	AA-1	AA-2	AA-3	AA-5	AA-7	AA-8	B-2N	B-2S	B-3S	B-SC	B-WLC	B-SAM
Individual Constituents													
Benzene	0.259	2.7 U	2.7 U	2.7 U	2.7 U	3.4	2.7 U	2.6 U	4.4	3.8	3.8	2.8 U	3.2
Toluene	183	**4.7**	**3.7**	**5.0**	**3.9**	10	**5.5**	**4.7**	9.3	**9.1**	**7.0**	**6.7**	**6.8**
Ethyl Benzene	457	3.6 U	3.7 U	3.7 U	3.6 U	3.9 U	3.7 U	3.6 U	3.7 U	3.6 U	3.8 U	3.9 U	3.9 U
m,p-Xylene	320	3.6 U	3.7 U	3.7 U	3.6 U	**6.1**	3.7 U	3.6 U	**5.4**	**5.3**	**4.0**	3.9 U	**4.4**
o-Xylene	320	3.6 U	3.7 U	3.7 U	3.6 U	3.9 U	3.7 U	3.6 U	3.7 U	3.6 U	3.8 U	3.9 U	4.0 U
1,3,5-Trimethylbenzene	420	4.1 U	4.2 U	4.2 U	4.1 U	4.4 U	4.2 U	4.0 U	4.2 U	4.1 U	4.3 U	4.4 U	4.5 U
1,2,4-Trimethylbenzene	420	4.1 U	4.2 U	4.2 U	4.1 U	4.4 U	4.2 U	4.0 U	4.2 U	4.1 U	4.3 U	4.4 U	4.5 U
Propylene	--	5.7 U	5.9 U	5.9 U	5.7 U	6.1 U	5.9 U	5.6 U	5.9 U	5.7 U	6.0 U	6.1 U	6.3 U
1,3-Butadiene	0.00417	7.4 U	7.6 U	7.6 U	7.4 U	7.9 U	7.6 U	7.2 U	7.6 U	7.4 U	7.7 U	7.9 U	8.0 U
Hexane	91.4	12 U	12 U	12 U	12 U	12 U	12 U	12 U	12 U	12 U	12 U	12 U	13 U
Cyclohexane	3,400	11 U	12 U	12 U	11 U	12 U	12 U	11 U	12 U	11 U	12 U	12 U	12 U
4-Ethyltoluene	--	16 U	17 U	17 U	16 U	17 U	17 U	16 U	17 U	16 U	17 U	17 U	18 U
Heptane	5,500	14 U	14 U	14 U	14 U	14 U	14 U	13 U	14 U	14 U	14 U	14 U	15 U
Naphthalene	170	87 U	90 U	90 U	87 U	93 U	90 U	86 U	90 U	87 U	91 U	93 U	95 U
Aliphatic Hydrocarbons													
C_3 to C_5	--	**93**	**110**	**99**	**59**	**95**	**110**	**110**	31 U	**100**	**99**	**70**	**92**
C_5 to C_6	9,120	49 U	50 U	50 U	49 U	52 U	50 U	48 U	50 U	49 U	51 U	52 U	54 U
C_6 to C_8	9,120	59 U	**64**	60 U	59 U	63 U	60 U	58 U	60 U	59 U	61 U	63 U	64 U
C_8 to C_{10}	136	78 U	80 U	80 U	78 U	83 U	80 U	76 U	80 U	78 U	81 U	83 U	85 U
C_{10} to C_{12}	136	**150**	99 U	99 U	97 U	100 U	99 U	95 U	99 U	97 U	100 U	100 U	100 U
> C_{12}	--	120 U	120 U	120 U	120 U	120 U	120 U	110 U	120 U	120 U	120 U	120 U	130 U
Aromatic Hydrocarbons													
C_6 to C_8	--	53 U	54 U	54 U	53 U	57 U	54 U	52 U	54 U	53 U	56 U	57 U	58 U
C_8 to C_{10}	80	72 U	74 U	74 U	72 U	77 U	74 U	71 U	74 U	72 U	75 U	77 U	79 U
C_{10} to C_{11}	80	87 U	90 U	90 U	87 U	93 U	90 U	86 U	90 U	87 U	91 U	93 U	95 U
Carbon Monoxide in %[1]		0.0016 U	0.0017 U	0.0017 U	0.0016 U	0.0018 U	0.0017 U	0.0016 U	0.0017 U	0.0016 U	0.0017 U	0.0018 U	0.0018 U

Bold indicates analyte detection.

U Not detected at indicated detection limit.

▭ Concentration exceeds MTCA Method B cleanup level.

☐ Concentration exceeds ambient air remedial action objective (i.e., both the MTCA Method B cleanup level and background concentrations are exceeded).

Notes:

1) In this round only, samples were analyzed for carbon monoxide using modified ASTM Method D-1945. Results were intended to help evaluate potential impacts from background motor vehicle emissions. However, since carbon monoxide was not detected in any sample, this analytical method was abandoned.

Table 3 - Long-Term Ambient Air Monitoring Round 2 Results (September 2001)

	Concentration in ug/m^3							
	MTCA Method B Cleanup Level	Lower Yard		Off-Site Area	Site Background	Local Background		
Analytes		AA-4	AA-6	AA-7	B-3S	B-SC	B-WLC	B-SAM
Individual Constituents								
Benzene	0.321	2.9 U	2.8 U	3.0 U	**3.5**	2.8 U	3.0 U	2.9 U
Toluene	183	3.4 U	**5.2**	**4.1**	**8.0**	3.3 U	**5.1**	**6.4**
Ethyl Benzene	4,570	3.9 U	3.9 U	4.0 U	3.9 U	3.8 U	4.0 U	3.9 U
m,p-Xylene	320	4.0 U	3.9 U	4.0 U	**5.5**	3.8 U	4.0 U	4.0 U
o-Xylene	320	4.0 U	3.9 U	4.0 U	4.0 U	3.8 U	4.0 U	4.0 U
1,3,5-Trimethylbenzene	2.72	4.5 U	4.4 U	4.6 U	4.5 U	4.3 U	4.6 U	4.5 U
1,2,4-Trimethylbenzene	2.72	4.5 U	4.4 U	4.6 U	4.5 U	4.3 U	4.6 U	4.5 U
Propylene	--	6.3 U	6.1 U	6.4 U	6.3 U	6.0 U	6.4 U	6.3 U
1,3-Butadiene	0.00893	8.0 U	7.9 U	8.2 U	8.0 U	7.7 U	8.2 U	8.0 U
Hexane	91.4	13 U	12 U	13 U	13 U	12 U	13 U	13 U
Cyclohexane	9,120	12 U	12 U	13 U	12 U	12 U	13 U	12 U
4-Ethyltoluene	--	18 U	17 U	18 U	18 U	17 U	18 U	18 U
Heptane	5,500	15 U	14 U	15 U	15 U	14 U	15 U	15 U
Naphthalene	1.37	95 U	93 U	97 U	95 U	91 U	97 U	95 U
Aliphatic Hydrocarbons								
C_3 to C_5	--	33 U	32 U	34 U	33 U	31 U	34 U	33 U
C_5 to C_6	9,120	54 U	52 U	55 U	54 U	51 U	55 U	54 U
C_6 to C_8	9,120	64 U	63 U	66 U	64 U	61 U	66 U	64 U
C_8 to C_{10}	136	85 U	83 U	87 U	85 U	81 U	87 U	85 U
C_{10} to C_{12}	136	100 U	100 U	110 U	100 U	100 U	110 U	100 U
> C_{12}	--	130 U	120 U	130 U	130 U	120 U	130 U	130 U
Aromatic Hydrocarbons								
C_6 to C_8	--	58 U	57 U	59 U	58 U	56 U	59 U	58 U
C_8 to C_{10}	80	79 U	77 U	81 U	79 U	75 U	81 U	79 U
C_{10} to C_{11}	80	95 U	93 U	97 U	95 U	91 U	97 U	95 U

Bold indicates analyte detection.

U Not detected at indicated detection limit.

⬚ Concentration exceeds MTCA Method B cleanup level.

Table 4 - Long-Term Ambient Air Monitoring Round 3 Results (November 2002)

	Concentration in µg/m³						
	MTCA Method B	Lower Yard		Off-Site Area	Site Background	Local Background	
Analytes	Cleanup Level	AA-4	AA-6	AA-7	B-3S	B-SC	B-SAM
Individual Constituents							
Benzene	0.321	2.6 U	2.7 U	2.7 U	2.6 U	2.6 U	2.6 U
Toluene	183	3.0 U	**7.7**	3.1 U	3.1 U	**4.0**	3.1 U
Ethyl Benzene	4570	3.5 U	3.6 U	3.6 U	3.6 U	3.5 U	3.6 U
m,p-Xylene	320	3.5 U	**3.7**	3.6 U	**3.6**	3.5 U	3.6 U
o-Xylene	320	3.5 U	3.6 U	3.6 U	3.6 U	3.5 U	3.6 U
1,3,5-Trimethylbenzene	2.72	3.9 U	4.1 U	4.1 U	4 U	3.9 U	4 U
1,2,4-Trimethylbenzene	2.72	3.9 U	4.1 U	4.1 U	4 U	3.9 U	4 U
Propylene	--	5.5 U	5.7 U	5.7 U	5.6 U	5.5 U	5.6 U
1,3-Butadiene	0.00893	7.1 U	7.4 U	7.4 U	7.2 U	7.1 U	7.2 U
Hexane	91.4	11 U	12 U	12 U	12 U	11 U	12 U
Cyclohexane	9,120	11 U	11 U	11 U	11 U	11 U	11 U
4-Ethyltoluene	--	16 U	16 U	16 U	16 U	16 U	16 U
Heptane	5,500	13 U	14 U	14 U	13 U	13 U	13 U
Naphthalene	1.37	84 U	87 U	87 U	86 U	84 U	86 U
Aliphatic Hydrocarbons							
C_3 to C_5	--	29 U	30 U	**160**	**33**	**44**	**36**
C_5 to C_6	9,120	47 U	49 U	**270**	48 U	47 U	48 U
C_6 to C_8	9,120	57 U	59 U	59 U	58 U	57 U	58 U
C_8 to C_{10}	136	75 U	78 U	78 U	76 U	75 U	76 U
C_{10} to C_{12}	136	93 U	97 U	97 U	95 U	93 U	95 U
$> C_{12}$	--	110 U	120 U	120 U	110 U	110 U	110 U
Aromatic Hydrocarbons							
C_6 to C_8	--	51 U	53 U	53 U	52 U	51 U	52 U
C_8 to C_{10}	80	70 U	72 U	72 U	71 U	70 U	71 U
C_{10} to C_{11}	80	84 U	87 U	87 U	86 U	84 U	86 U

Bold indicates analyte detection.

U Not detected at indicated detection limit.

Table 5 - Summary of Measured Exceedences of the Ambient Air RAO

Analytes	Concentration in ug/m³										
	MTCA Method B Cleanup Level	Upper Yard			Lower Yard			Off-Site Area			Background (Range of Measured Values)
		AA-1	AA-2	AA-3	AA-4	AA-5	AA-6	AA-7	AA-8	AA-9	
Short-Term Monitoring Round (June 2000)											
Aliphatic Hydrocarbons											
C_8 to C_{10}	136	**740**	**260**	**85 J**	89 U	87 U	87 U	89 U	83 U	89 U	85(U) - 89(U)
C_{10} to C_{12}	136	**210**	110 U	110 U	110 U	110 U	110 U	110 U	100 U	110 U	100(U) - 110(U)
Aromatic Hydrocarbons											
C_8 to C_{10}	80	**100**	84 U	81 U	82 U	81 U	81 U	82 U	77 U	82 U	79(U) - 82(U)
Long-Term Monitoring Round 1 (October 2000)											
Aliphatic Hydrocarbons											
C_{10} to C_{12}	136	**150**	99 U	99 U		97 U		100 U	99 U		95(U) - 100(U)
Long-Term Monitoring Round 2 (September 2001)											
There were no RAO exceedences measured at any Lower Yard or Off-Site Area monitoring location. (No Upper Yard locations were monitored.)											
Long-Term Monitoring Round 3 (November 2002)											
There were no RAO exceedences measured at any Lower Yard or Off-Site Area monitoring location. (No Upper Yard locations were monitored.)											

Bold indicates analyte detection.

J Estimated value.

RAO Remedial action objective.

U Not detected at indicated detection limit.

☐ Concentration exceeds ambient air RAO (i.e., both the MTCA Method B cleanup level and background concentrations are exceeded).

Table 6 - Soil Vapor Monitoring Results

Boring ID								
B-101			B-102			B-103		
Soil Sample ID	Top of Sample Depth Interval in Feet BGS	PID Reading in ppm	Soil Sample ID	Top of Sample Depth Interval in Feet BGS	PID Reading in ppm	Soil Sample ID	Top of Sample Depth Interval in Feet BGS	PID Reading in ppm
S-1	2.5	<1	S-1	3	<1	S-1	3.5	<1
S-2	5	15.2	S-2	5.5	<1	S-2	6	<1
S-3	7.5	87	S-3	8	<1	S-3	8.5	<1
S-4	10	92	S-4	10.5	<1	S-4	11	<1
S-5	12.5	78.7	S-5	13	<1	S-5	13.5	<1
S-6	15	5	S-6	15.5	<1	S-6	16	<1
S-7	17.5	18.7	S-7	18	<1	S-7	18.5	<1
S-8	20	66.5	S-8	23	<1	S-8	23.5	<1
S-9	25	3	S-9	28	<1	S-9	28.5	<1
S-10	30	<1	S-10	33	nsr	S-10	33.5	<1
S-11	35	2.3	S-11	38	<1			
S-12	40	<1						
S-13	45	<1						
S-14	50	<1						

BGS	Below ground surface.
nsr	No sample recovery.
PID	Photo-ionization detector.
ppm	Parts per million.

Notes:

1) Boring locations are shown on Figure 2; boring logs are provided in Attachment A.

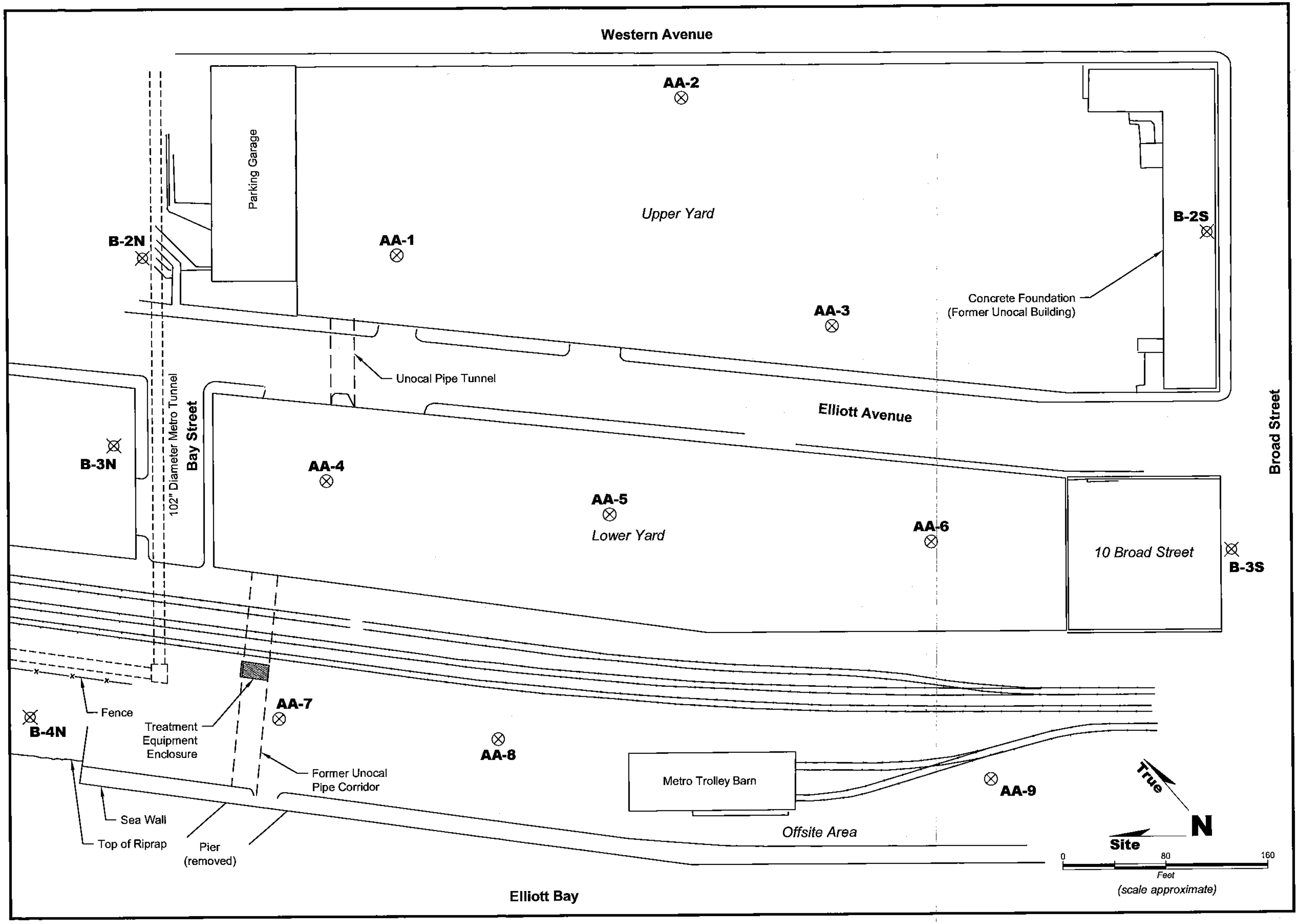
2) No indication of petroleum hydrocarbon staining or odor is noted on any of the boring logs.

Legend

⊗ On-Site Ambient Air Sample

⊠ Site Background Ambient Air Sample

Note: Site background sampling locations were selected based on the wind direction at the start of the 8-hour sampling period (i.e., upwind locations were selected)



Note: The locations of all features shown are approximate.
Reference: *Unocal/Seattle Marketing Terminal*, undated.

Jones & Stokes

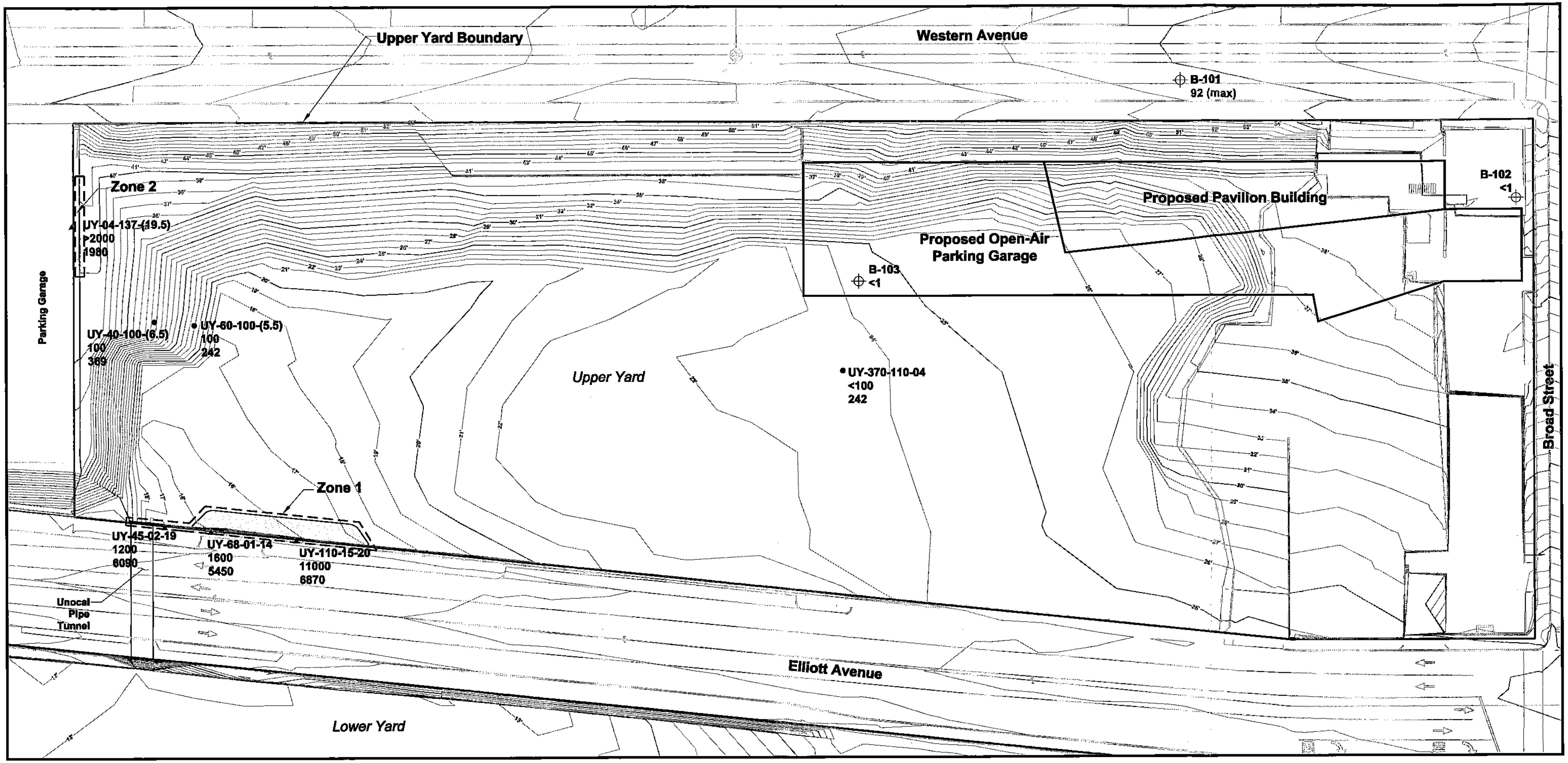
Aspect consulting
IN-DEPTH PERSPECTIVE
179 Madrone Lane North
Bainbridge Island, WA 98110
Tel: (206) 780-9370
Fax: (206) 780-9438

Ambient Air Monitoring Location Plan

Seattle Art Museum / Olympic Sculpture Park
Seattle, Washington

DATE: May 2003	PROJECT NO. 020118
DESIGNED BY: DAH	
DRAWN BY: SDM	FIGURE NO. 1
REVISED BY:	

Q:\Seattle Art Museum\020118 OSP Cleanup Mgt\2003-05 J&S Air Quality\020118-js-03.dwg



Elevations are based on SEANET Datum

Legend

—25'—	Existing Elevation Contour (in Feet)
⊃	Estimated Extent of Soils Remaining in NW corner of Upper Yard with TPH Concentrations > 200 mg/kg
[- - -]	Zone of Potentially Significant Soil Vapor Emissions
●	Post-Excavation Surface Soil Sample
▲	Property Line Soil Sample (collected from behind shoring wall)
UY-45-02-19	Soil Sample ID, 1997 Remedial Action - last number is approximate depth in feet below Elliot Avenue grade.
1200	Soil Vapor Concentration by PID Headspace Screening (in ppmv)
6090	Total TPH in Soil (in mg/kg)
⌖	Geotechnical Boring

Jones & Stokes

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Seattle, WA 98104
(206)-328-7443

Geotechnical Borings and Residual Soil Contamination - Upper Yard

Seattle Art Museum / Olympic Sculpture Park
Seattle, Washington

DATE: May 2003	PROJECT NO. 020118
DESIGNED BY: DAH	
DRAWN BY: SDM	FIGURE NO. 2
REVISED BY:	

Q:\Seattle Art Museum\020118 OSP Cleanup Mgt\2003-05 J&S Air Quality\020118-js-02.dwg

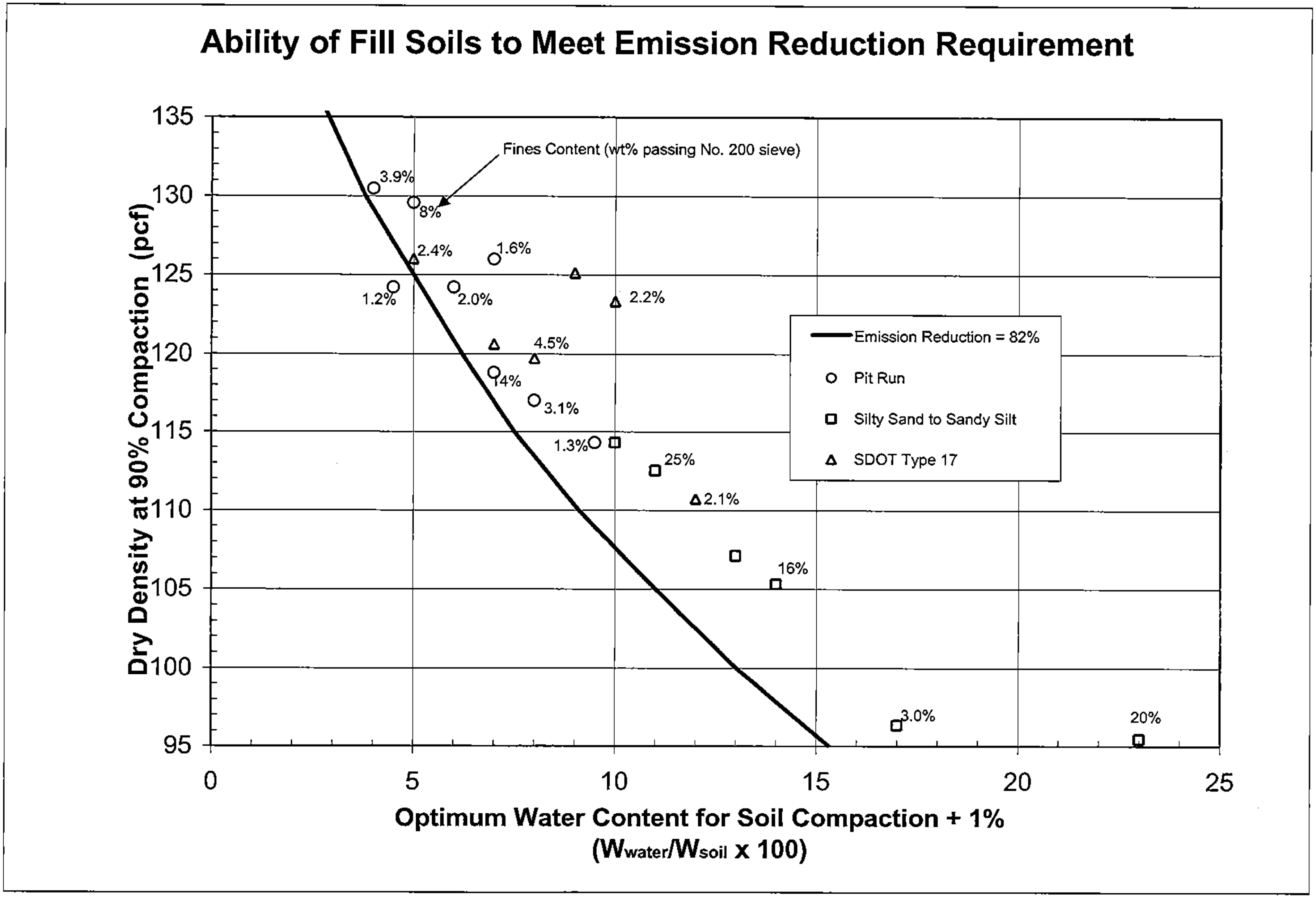


Figure 3

Note: The 82% emission reduction calculation is based on placing additional fill soils in Zones 1 and 2 at thicknesses of 29 feet and 7 feet, respectively.

ATTACHMENT A

Boring Logs
Hart Crowser Investigation
August 2002

Key to Exploration Logs

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

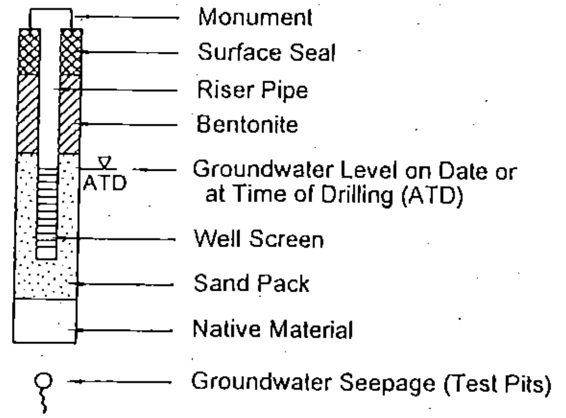
Minor Constituents	Estimated Percentage
Not identified in description	0 - 5
Slightly (clayey, silty, etc.)	5 - 12
Clayey, silty, sandy, gravelly	12 - 30
Very (clayey, silty, etc.)	30 - 50

Legends

Sampling Test Symbols

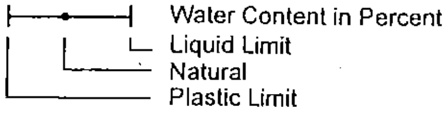
Boring Samples		Test Pit Samples	
☒	Split Spoon	☒	Grab (Jar)
⧅	Shelby Tube	⧄	Bag
▥	Cuttings	⧅	Shelby Tube
◫	Core Run		
*	No Sample Recovery		
P	Tube Pushed, Not Driven		

Groundwater Observation Wells



Test Symbols

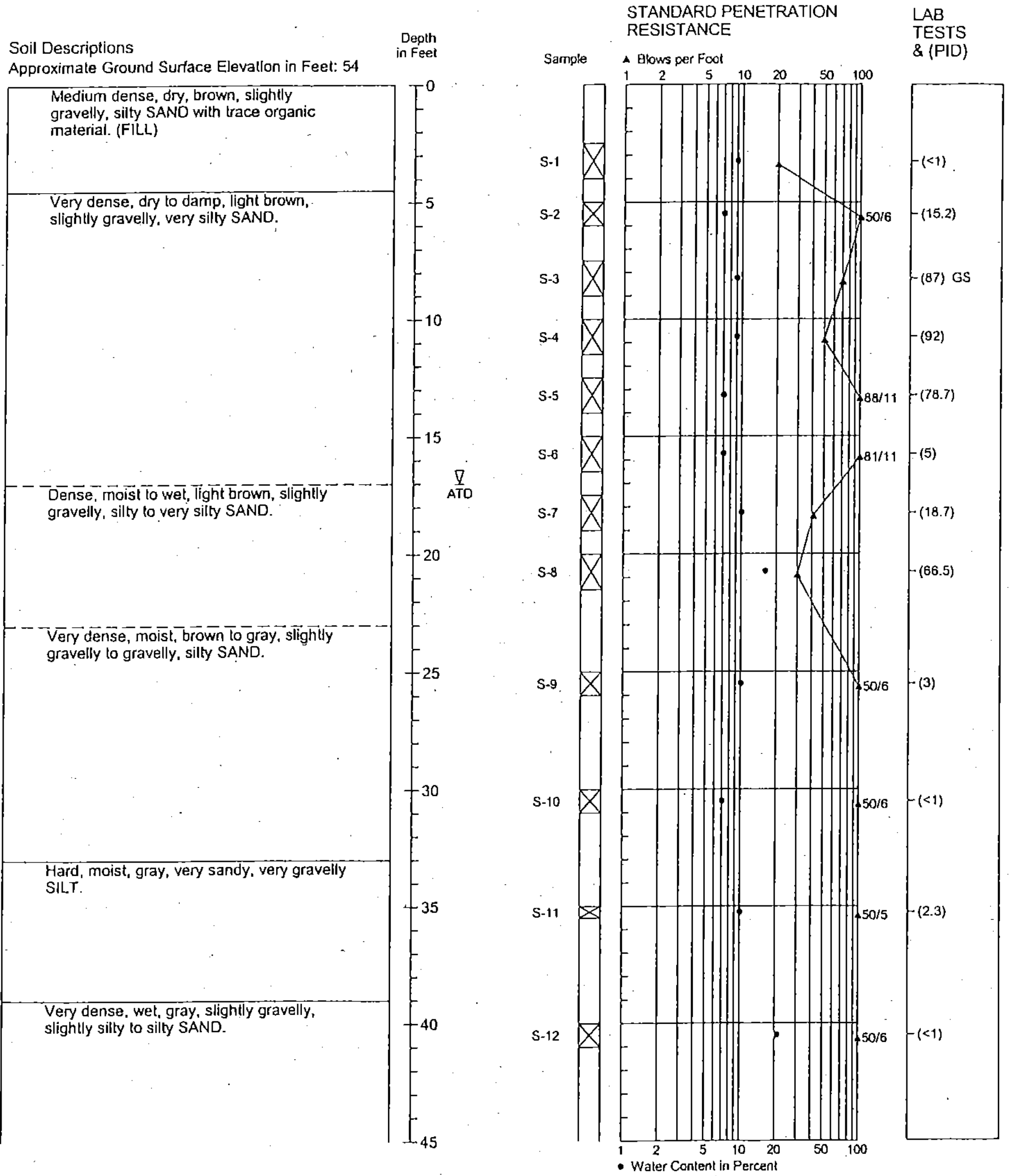
GS	Grain Size Classification
CN	Consolidation
UU	Unconsolidated Undrained Triaxial
CU	Consolidated Undrained Triaxial
CD	Consolidated Drained Triaxial
QU	Unconfined Compression
DS	Direct Shear
K	Permeability
PP	Pocket Penetrometer Approximate Compressive Strength in TSF
TV	Torvane Approximate Shear Strength 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

Boring Log B-101

Soil Descriptions
Approximate Ground Surface Elevation in Feet: 54



Medium dense, dry, brown, slightly gravelly, silty SAND with trace organic material. (FILL)

Very dense, dry to damp, light brown, slightly gravelly, very silty SAND.

Dense, moist to wet, light brown, slightly gravelly, silty to very silty SAND.

Very dense, moist, brown to gray, slightly gravelly to gravelly, silty SAND.

Hard, moist, gray, very sandy, very gravelly SILT.

Very dense, wet, gray, slightly gravelly, slightly silty to silty SAND.

S-1		(<1)
S-2	50/6	(15.2)
S-3		(87) GS
S-4		(92)
S-5	88/11	(78.7)
S-6	81/11	(5)
S-7		(18.7)
S-8		(66.5)
S-9	50/6	(3)
S-10	50/6	(<1)
S-11	50/5	(2.3)
S-12	50/6	(<1)

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. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

HARTCROWSER

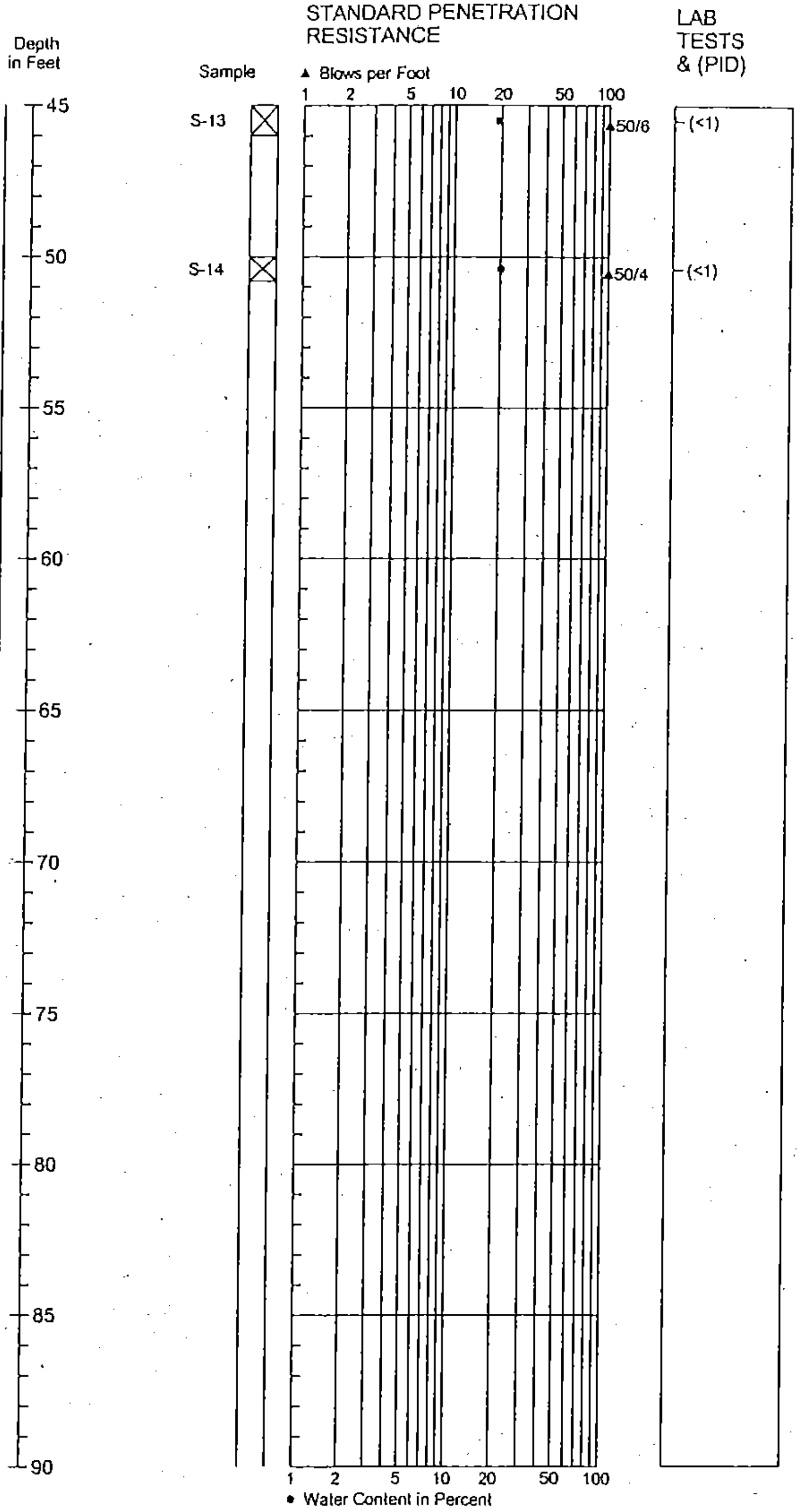
7018-03 08/02
Figure A-2 1/2

Boring Log B-101

Soil Descriptions
Approximate Ground Surface Elevation in Feet: 54

Very dense, wet, gray, slightly gravelly, slightly silty to silty SAND.

Bottom of Boring at 56.5 Feet.
Completed 08/12/02.



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. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

Boring Log B-102

Soil Descriptions
Approximate Ground Surface Elevation in Feet: 52

Very loose, moist, light to dark brown, slightly gravelly, silty SAND with trace organic material. (FILL)

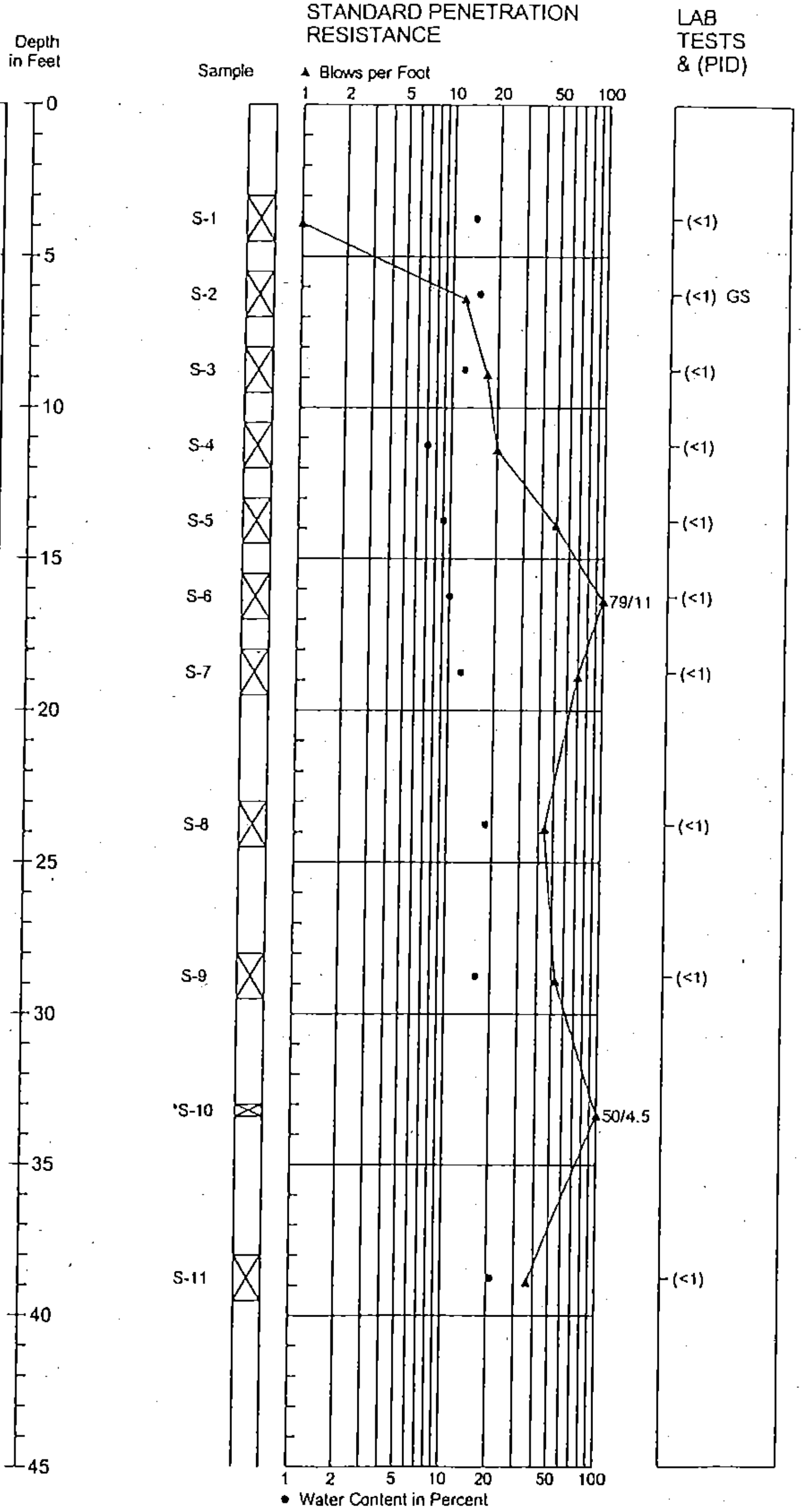
Medium dense, moist, light brown, gravelly, silty SAND. (FILL?)

Dense to very dense, moist, light brown, silty, clayey SAND.

Very dense, moist, gray-brown, slightly gravelly, slightly clayey, silty SAND.

Hard, damp, gray, slightly gravelly, sandy, clayey SILT. (TILL)

Bottom of Boring at 39.5 Feet.
Completed 08/06/02.



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. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

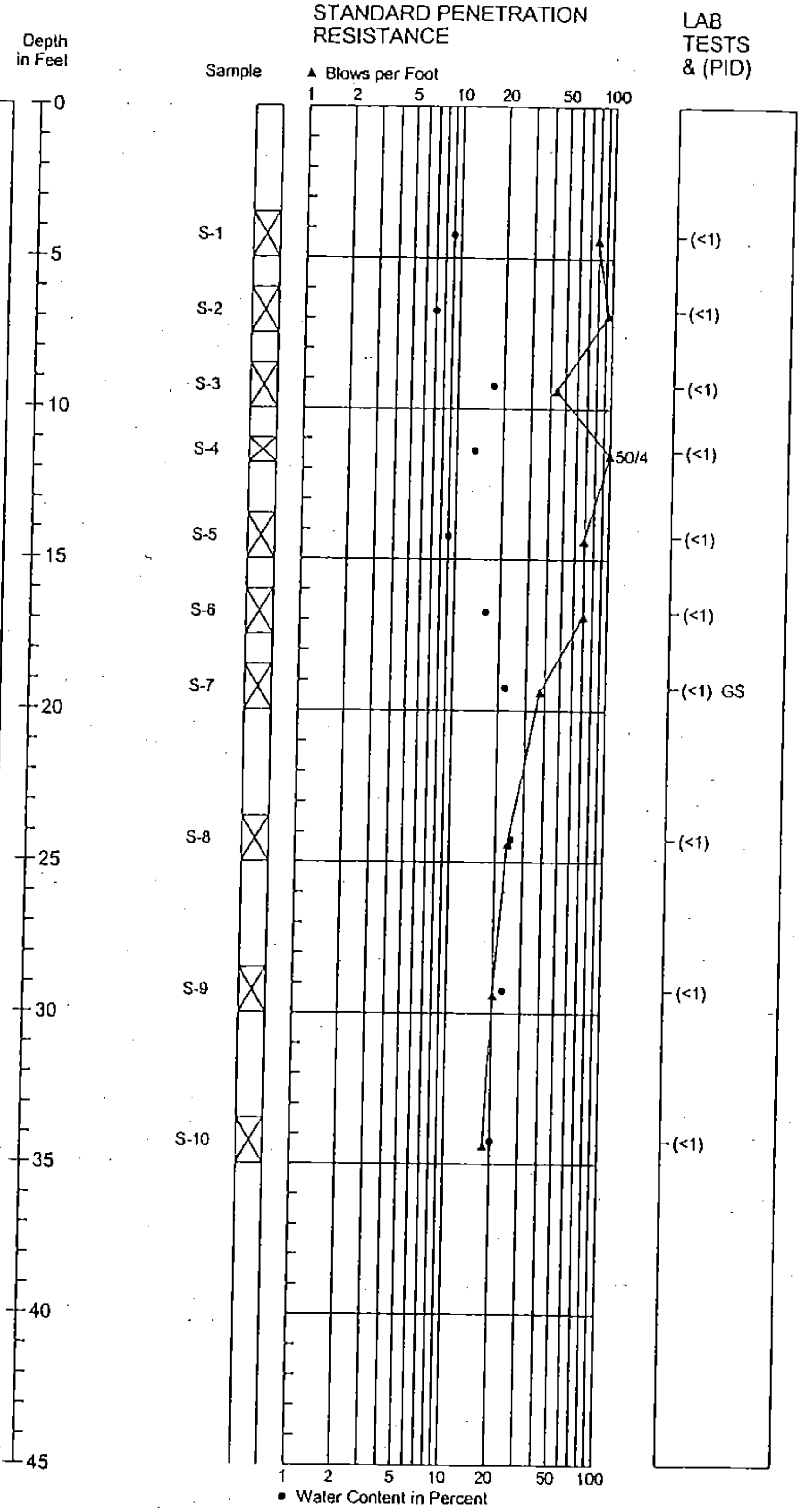
Boring Log B-103

Soil Descriptions
Approximate Ground Surface Elevation in Feet: 24

Dense to very dense, damp to wet, brown to gray, slightly gravelly to very gravelly, silty to very silty SAND. (TILL)

Very stiff to hard, damp to moist, gray, sandy SILT. (TILL)

Bottom of Boring at 35.0 Feet.
Completed 08/06/02.



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. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

HARTCROWSER

7018-03 08/02

Figure A-4

ATTACHMENT B

Sample Calculation Spreadsheets

Vapor Emission Reductions Provided by New Soil Fill

VAPOR EMISSION REDUCTIONS PROVIDED BY NEW SOIL FILL IN ZONE 1
OLYMPIC SCULPTURE PARK UPPER YARD

Basis of Geotechnical Properties (Garry Horvitz, Hart Crowser, 1/9/03)

Existing low-quality fill at UW4 backfill based on data from geotechnical boring B-108. Measured soil moisture in September, 2002 =5%-8%. Estimated bulk wet soil density = 120 pcf wet weight basis.
Future low-quality fill: dry bulk density = 110 pcf; soil mositure 10%.
Future select fill: dry bulk density = 125 pcf, soil moisture range from 5%-15%.

Geotechnical Properties of Existing Fill and New Fill

			Existing	Future		
Upper Layer Soil Properties	Thickness of layer	ft	0	29		
	Dry Bulk Soil Density	lbs/cf dry weight basis	125	105	Geot Water content, w	
	Wet Bulk Soil Density	lbs/cf wet weight basis	137.2	115.3	Existing	Future
	Wet Soil Moisture Content,	fraction (g water/g bulk soil)	0.0979	0.0979	0.11	0.11
Lower Layer Soil Properties	Thickness of layer	ft	10	10		
	Dry Bulk Soil Density	lbs/cf dry weight basis	113	113		
	Wet Bulk Soil Density	lbs/cf	119.9	119.9		
	Wet Soil Moisture Content,	fraction (g water/g bulk soil)	0.060775	0.060775	0.065	0.065

					Emission Reduction Provided by New Fill
Summary Flux Rates	C8-C10 Aliphatic	g/cm2-sec	1.81E-08	3.15E-09	82.6%
	C10-C12 Aliphatic	g/cm2-sec	1.98E-09	3.44E-10	82.6%
	C8-C10 Aromatic	g/cm2-sec	3.23E-09	5.60E-10	82.6%

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ZONE 1 EVALUATION
CHEMICAL PROPERTIES OF SUBSURFACE HYDROCARBONS

C8-C10 Aliphatic Chem Properties	Surrogate compound	1,1,3-trimethylcyclohexane		
	Formula and Molec. Wt.	C9H18	126	126
	Pure Vapor Pressure	atm	3.0E-03	3.0E-03
	Henrys Coefficient	cm3/cm3	55	55
	Air Diffusivity	cm2/sec	0.06	0.06
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06
C10-C12 Aliphatic Chem Properties	Surrogate compound	2,3,7-trimethyloctane		
	Formula and Molec. Wt.	C11H14	146	146
	Pure Vapor Pressure	atm	5.8E-04	5.8E-04
	Henrys Coefficient	cm3/cm3	60.3	60.3
	Air Diffusivity	cm2/sec	0.09	0.09
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06
C8-C10 Aromatic Chem Properties	Surrogate compound	butylbenzene		
	Formula and Molec. Wt.	C10H14	134	134
	Pure Vapor Pressure	atm	1.3E-03	1.3E-03
	Henrys Coefficient	cm3/cm3	0.39	0.39
	Air Diffusivity	cm2/sec	0.06	0.06
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06

Upper Layer Porosity	Wet bulk density	g/cc	2.20	1.85
	Dry bulk density	g/cc	1.98	1.67
	Total Porosity	fraction	0.27	0.38
	Water Porosity	fraction	0.22	0.18
	Air Porosity	fraction	0.05	0.20
	Diffusion length	cm	0	883.92
Lower Layer Porosity	Wet bulk density	g/cc	1.92	1.92
	Dry bulk density	g/cc	1.80	1.80
	Total Porosity	fraction	0.33	0.33
	Water Porosity	fraction	0.12	0.12
	Air Porosity	fraction	0.22	0.22
	Diffusion length	cm	304.8	304.8

Upper Layer, C8-C10 Aliphatics	Eff. Vapor Diffusivity	cm2/sec	0.0000	0.0020
	Eff. Water Diffusivity	cm2/sec	1.2E-08	3.3E-09
	Total Eff. Diffusivity	cm2/sec	0.0000	0.0020
Upper Layer, C10-C12 Aliphatics	Eff. Vapor Diffusivity	cm2/sec	0.0001	0.0030
	Eff. Water Diffusivity	cm2/sec	1.1E-08	3.0E-09
	Total Eff. Diffusivity	cm2/sec	0.0001	0.0030
Upper Layer, C8-C10 Aromatics	Eff. Vapor Diffusivity	cm2/sec	0.0000	0.0020
	Eff. Water Diffusivity	cm2/sec	1.8E-06	4.7E-07
	Total Eff. Diffusivity	cm2/sec	0.0000	0.0020
Lower Layer, C8-C10 Aliphatic	Eff. Vapor Diffusivity	cm2/sec	0.0033	0.0033
	Eff. Water Diffusivity	cm2/sec	1.04E-09	1.04E-09
	Total Eff. Diffusivity	cm2/sec	0.0033	0.0033
	Eff. Vapor Diffusivity	cm2/sec	0.0049	0.0049

VAPOR EMISSION REDUCTIONS PROVIDED BY NEW SOIL FILL IN ZONE 1
OLYMPIC SCULPTURE PARK UPPER YARD

Lower Layer, C10-C12 Aliphatic	Eff. Water Diffusivity	cm2/sec	9.44E-10	9.44E-10
	Total Eff. Diffusivity	cm2/sec	0.0049	0.0049
Lower Layer, C8-C10 Aromatic	Eff. Vapor Diffusivity	cm2/sec	0.0033	0.0033
	Eff. Water Diffusivity	cm2/sec	1.46E-07	1.46E-07
	Total Eff. Diffusivity	cm2/sec	0.0033	0.0033

2-Layer Effective Diffusivities	C8-C10 Aliphatic	cm2/sec	0.0033	0.0022
	C10-C12 Aliphatic	cm2/sec	0.0049	0.0033
	C8-C10 Aromatic	cm2/sec	0.0033	0.0022

C8-C10 Aliphatic Flux Rate	At-Depth Vapor Conc.	g/m3	1.7E-03	1.7E-03
	Effective Diffusivity	cm2/sec	0.0033	0.0022
	Soil Column Depth	cm	304.8	1188.72
	Vapor Flux Rate	g/cm2-sec	1.8E-08	3.1E-09
C10-C12 Aliphatic Flux Rate	At-Depth Vapor Conc.	g/m3	1.2E-04	1.2E-04
	Effective Diffusivity	cm2/sec	0.0049	0.0033
	Soil Column Depth	cm	304.8	1188.72
	Vapor Flux Rate	g/cm2-sec	2.0E-09	3.4E-10
C8-C10 Aromatic Flux Rate	At-Depth Vapor Conc.	g/m3	3.0E-04	3.0E-04
	Effective Diffusivity	cm2/sec	0.0033	0.0022
	Soil Column Depth	cm	304.8	1188.72
	Vapor Flux Rate	g/cm2-sec	3.2E-09	5.6E-10

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VAPOR EMISSION REDUCTIONS PROVIDED BY NEW SOIL FILL IN ZONE 2
OLYMPIC SCULPTURE PARK UPPER YARD

Basis of Geotechnical Properties (Garry Horvitz, Hart Crowser, 1/9/03)

Existing low-quality fill at UW4 backfill based on data from geotechnical boring B-108. Measured soil moisture in September, 2002 =5%-8%. Estimated bulk wet soil density = 120 pcf wet weight basis.
Future low-quality fill: dry bulk density = 110 pcf; soil mositure 10%.
Future select fill: dry bulk density = 125 pcf; soil moisture range from 5%-15%.

Geotechnical Properties of Existing Fill and New Fill

			Existing	Future		
Upper Layer Soil Properties	Thickness of layer	ft	0	6.4		
	Dry Bulk Soil Density	lbs/cf dry weight basis	105	105	Geot Water content, w	
	Wet Bulk Soil Density	lbs/cf wet weight basis	115.3	115.3	Existing	Future
	Wet Soil Moisture Content	fraction (g water/g bulk soil)	0.0979	0.0979	0.11	0.11
Lower Layer Soil Properties	Thickness of layer	ft	0.5	0.5		
	Dry Bulk Soil Density	lbs/cf dry weight basis	120	120		
	Wet Bulk Soil Density	lbs/cf	129.6	129.6		
	Wet Soil Moisture Content	fraction (g water/g bulk soil)	0.08	0.08	0.065	0.065

					Emission Reduction Provided by New Fill
Summary Flux Rates	C8-C10 Aliphatic	g/cm2-sec	7.91E-08	1.42E-08	82.1%
	C10-C12 Aliphatic	g/cm2-sec	8.64E-09	1.55E-09	82.1%
	C8-C10 Aromatic	g/cm2-sec	1.41E-08	2.52E-09	82.1%

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ZONE 2 EVALUATION
CHEMICAL PROPERTIES OF SUBSURFACE HYDROCARBONS

C8-C10 Aliphatic Chem Properties	Surrogate compound	1,1,3-trimethylcyclohexane		
	Formula and Molec. Wt.	C9H18	126	126
	Pure Vapor Pressure	atm	3.0E-03	3.0E-03
	Henrys Coefficient	cm3/cm3	55	55
	Air Diffusivity	cm2/sec	0.06	0.06
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06
C10-C12 Aliphatic Chem Properties	Surrogate compound	2,3,7-trimethyloctane		
	Formula and Molec. Wt.	C11H14	146	146
	Pure Vapor Pressure	atm	5.8E-04	5.8E-04
	Henrys Coefficient	cm3/cm3	60.3	60.3
	Air Diffusivity	cm2/sec	0.09	0.09
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06
C8-C10 Aromatic Chem Properties	Surrogate compound	butylbenzene		
	Formula and Molec. Wt.	C10H14	134	134
	Pure Vapor Pressure	atm	1.3E-03	1.3E-03
	Henrys Coefficient	cm3/cm3	0.39	0.39
	Air Diffusivity	cm2/sec	0.06	0.06
	Water Diffusivity	cm2/sec	8.0E-06	8.0E-06

Upper Layer Porosity	Wet bulk density	g/cc	1.85	1.85
	Dry bulk density	g/cc	1.67	1.67
	Total Porosity	fraction	0.38	0.38
	Water Porosity	fraction	0.18	0.18
	Air Porosity	fraction	0.20	0.20
	Diffusion length	cm	0	195.072
Lower Layer Porosity	Wet bulk density	g/cc	2.08	2.08
	Dry bulk density	g/cc	1.91	1.91
	Total Porosity	fraction	0.29	0.29
	Water Porosity	fraction	0.17	0.17
	Air Porosity	fraction	0.13	0.13
	Diffusion length	cm	15.24	15.24

Upper Layer, C8-C10 Aliphatics	Eff. Vapor Diffusivity	cm2/sec	0.0020	0.0020
	Eff. Water Diffusivity	cm2/sec	3.3E-09	3.3E-09
	Total Eff. Diffusivity	cm2/sec	0.0020	0.0020
Upper Layer, C10-C12 Aliphatics	Eff. Vapor Diffusivity	cm2/sec	0.0030	0.0030
	Eff. Water Diffusivity	cm2/sec	3.0E-09	3.0E-09
	Total Eff. Diffusivity	cm2/sec	0.0030	0.0030
Upper Layer, C8-C10 Aromatics	Eff. Vapor Diffusivity	cm2/sec	0.0020	0.0020
	Eff. Water Diffusivity	cm2/sec	4.7E-07	4.7E-07
	Total Eff. Diffusivity	cm2/sec	0.0020	0.0020
Lower Layer, C8-C10 Aliphatic	Eff. Vapor Diffusivity	cm2/sec	0.0007	0.0007
	Eff. Water Diffusivity	cm2/sec	4.32E-09	4.32E-09
	Total Eff. Diffusivity	cm2/sec	0.0007	0.0007
	Eff. Vapor Diffusivity	cm2/sec	0.0011	0.0011

VAPOR EMISSION REDUCTIONS PROVIDED BY NEW SOIL FILL IN ZONE 2
OLYMPIC SCULPTURE PARK UPPER YARD

Lower Layer, C10-C12 Aliphatic	Eff. Water Diffusivity	cm2/sec	3.94E-09	3.94E-09
	Total Eff. Diffusivity	cm2/sec	0.0011	0.0011
Lower Layer, C8-C10 Aromatic	Eff. Vapor Diffusivity	cm2/sec	0.0007	0.0007
	Eff. Water Diffusivity	cm2/sec	6.09E-07	6.09E-07
	Total Eff. Diffusivity	cm2/sec	0.0007	0.0007

2-Layer Effective Diffusivities	C8-C10 Aliphatic	cm2/sec	0.0007	0.0018
	C10-C12 Aliphatic	cm2/sec	0.0011	0.0026
	C8-C10 Aromatic	cm2/sec	0.0007	0.0018

C8-C10 Aliphatic Flux Rate	At-Depth Vapor Conc.	g/m3	1.7E-03	1.7E-03
	Effective Diffusivity	cm2/sec	0.0007	0.0018
	Soil Column Depth	cm	15.24	210.312
	Vapor Flux Rate	g/cm2-sec	7.9E-08	1.4E-08
C10-C12 Aliphatic Flux Rate	At-Depth Vapor Conc.	g/m3	1.2E-04	1.2E-04
	Effective Diffusivity	cm2/sec	0.0011	0.0026
	Soil Column Depth	cm	15.24	210.312
	Vapor Flux Rate	g/cm2-sec	8.6E-09	1.5E-09
C8-C10 Aromatic Flux Rate	At-Depth Vapor Conc.	g/m3	3.0E-04	3.0E-04
	Effective Diffusivity	cm2/sec	0.0007	0.0018
	Soil Column Depth	cm	15.24	210.312
	Vapor Flux Rate	g/cm2-sec	1.4E-08	2.5E-09

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