Seattle-Tacoma International Airport Third Runway Embankment Fill Water Quality and Transport Analysis

FINAL

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Section 1.0
Introduction

1.1 Background

The Port of Seattle has proposed construction of a third runway at Seattle-Tacoma International Airport (STIA). The third runway is to be built on fill and is to extend westward from the west side of the existing airport. Precipitation that infiltrates into the third runway fill will drain into the drainage basins of Miller and Walker Creeks. Concerns regarding adverse water-quality impacts resulted in proposed criteria for fill soil. These criteria are designed to prevent water-quality in the creeks from being adversely affected by metals and other compounds that may be in the fill material in quantities that could be transported to the creeks by infiltrating rain water. The criteria have been incorporated into the 401 Water Quality Certification for the third runway project.

The third runway fill extends along 8000 feet of the third runway project area (Figure 1). The main features of the fill design that relate to water quality are a drainage layer of relatively coarse material under the fill and a wedge of 'ultra clean' material sloping back from the embankment face into the fill (also referred to as the drainage layer cover). A typical section through the fill is shown in Figure 2.

1.2 Objective

A groundwater flow and transport model was developed to determine if fill placed within the Third Runway embankment will be protective of water quality in Miller and Walker Creeks. This model evaluated both:

- Soil already placed within the embankment in accordance with the 1998 and 1999 Ecology fill acceptance criteria; and
- Soil that will be placed within the embankment under the Ecology 401 Certification fill criteria.

Information used in developing this model includes published data, historic fill source sampling data, and more recent test data collected at several fill sources in compliance with the 401 Certification. The recent test data include results for total metals, petroleum hydrocarbons, and several other physical and chemical test parameters. Selected soil samples were analyzed using the Synthetic Precipitation Leaching Procedure (SPLP) in order to determine the fraction of chemicals that may be leached from soils in contact with water. The results of these soil analyses, in combination with historical test data, are used in a numerical model of the third runway embankment fill to predict the concentration of selected chemicals in water discharging from the embankment fill.

1.3 Approach

The approach implemented for the analysis of the potential transport of metals and other compounds from the embankment fill involves a number of steps to analyze the pathways by which compounds may leach from the fill material and be transported to Miller and Walker Creeks. The steps involved in this analysis are:

- presentation of the fill and water-quality criteria to provide a comparison between the results of the analysis and applicable water-quality criteria;
- analysis of data collected from soils and from leaching tests on those soils to develop parameters for the transport analysis; and
- simulation of leaching and groundwater transport within the embankment fill.

The groundwater flow and transport analysis was used for the following:

- prediction of the concentration of metals in water discharging from the embankment, assuming all fill was at the 401 Certification levels;
- prediction of the concentration of chemicals in water discharging from the embankment fill, assuming maximum concentrations from historic fill sources; and
- sensitivity analysis for the most mobile metal, assuming that all the fill was at 5 and 10 times the 401 Certification level.

Section 2.0
Embankment Fill Criteria

2.1 Soil Criteria

The applicable fill soil criteria incorporated in the 401 Water Quality Certification are presented in Table 1. The applicable numerical criteria vary from the drainage layer cover and the general embankment fill due to special criteria imposed by Ecology and the U.S. Fish and Wildlife Service on drainage layer cover material. The special criteria are presented in Attachment E of the 401 Water Quality Certification.

2.2 Water-Quality Criteria

The Washington State Surface Water Standards (WAC 173-201A) are the water-quality criteria used to determine whether groundwater discharge from the embankment to surface water are protective of aquatic resources for the constituents studied in this report. However, WAC 173-201A does not include antimony, barium, beryllium, silver (chronic), or thallium. Recommended thresholds for these metals were derived from the USEPA AQUIRE database (Attachment A). The selected water quality criteria for metals are shown in Table 1. Since WAC 173-201A does not include a standard for petroleum hydrocarbons, the Ecology CLARC II database was used to select water quality criteria for the petroleum hydrocarbons studied in this report. Water quality criteria for organic compounds studied in this report are shown in Table 8.

Section 3.0
Data Analysis

3.1 Soil Testing

Soil samples were collected at six of the major fill sources to the Third Runway embankment. These sources represent over 60 percent of the material placed to-date within the embankment and are expected to be significant sources in the future. These sources, which are generally representative of commercial fill sources within the Puget Sound area, include :

- Black River Quarry (Renton)
- Marine View Pit (Tacoma)
- Lincoln and Summit (Bellevue/Renton)
- Lakeland Pit (Sumner)
- CTI Pit No. 3 (Sumner)
- Stoneway/Kent Kangley Pit (Ravensdale)

Over 90 percent of the existing drainage layer that underlies the embankment is comprised of soil from the Stoneway/Kent Kangley Pit. Samples from the six fill sources were analyzed for the constituents listed in the 401 Certification fill criteria as well as a number of other physical and chemical properties. The sampling and analysis were used to provide data in support of parameter estimation for the numerical modeling analysis described later in this report.

In addition to data collected from the six fill sources, historical fill source data were used from the following sources:

- WSDOT First Avenue
- USCOE Hamm Creek
- Black River Quarry

These data were used to evaluate migration of specific constituents from these fill sources.

3.1.1 Chemical Analysis of Soils

Soil chemical analyses were conducted to determine the concentration of metals and petroleum hydrocarbons in the different fill source areas. The results of these analyses are presented in Attachment B.

3.1.2 Adsorption Capacity

Selected soil samples were analyzed for iron and aluminum oxide content, clay mineralogy, and total organic carbon content. These analyses are used to estimate the sorption capacity of soils and consequently the ability of soils to attenuate the transport of metals and organics in groundwater. Samples were selected to include the range of sources under consideration for the embankment fill. From each of the source areas, one or more samples for which bulk metals data were determined were chosen for the adsorption analyses. When multiple samples from the same source area showed a significant range in total metals concentrations, preference was given to samples that had the higher metals concentrations, which have the highest potential to leach to groundwater. The analytical results are presented in Attachment B.

The soils show a substantial cation exchange capacity due to the presence of montmorillonite. In addition, iron oxides are present in important quantities as well. Organic carbon is also present at concentrations that could be important in limiting the transport of organic constituent as well. Overall, these results indicate that the soils possess a significant capacity to adsorb metals and organic compounds and that adsorption is likely to be a dominant process in attenuating transport of dissolved compounds through the fill

3.2 Synthetic Precipitation Leaching Procedure

Selected soil samples were also analyzed in a leaching test using the Synthetic Precipitation Leaching Procedure (SPLP). The SPLP test is designed to mimic the leaching of metals from soil to groundwater in contact with the soil. As in the attenuation capacity analyses, samples were selected to include the range of sources under consideration for the embankment fill. When multiple samples from the same source area showed a significant range in concentrations of total metals, preference was given to samples that had the higher metals concentrations, which have the highest potential to leach to groundwater. The results from this analysis are used to develop soil-water partitioning coefficients (K_d) for use in the numerical modeling. Results from the SPLP testing are presented in Attachment C.

Section 4.0
Numerical Modeling Analysis

The movement of water in the embankment occurs generally at partially saturated conditions as rainwater infiltrates from the ground surface to the groundwater table under the fill. Water under unsaturated conditions moves slowly downward. As it flows through the soil, it picks up some compounds adsorbed to the surfaces of soil particles. These compounds become dissolved in the infiltrating water, but move even more slowly than the water as the compounds may adsorb back onto soil particles.

Simulating the process of infiltration and transport of compounds in the infiltrating water can be performed using a number of computer codes. In this study, the U.S. Geological Survey (USGS) code VS2DT was selected (Lappala *et al.*, 1987; Healy, 1990; Hsieh *et al.*, 2000). The VS2DT code is a well-established, public-domain code supported by the USGS. The VS2DT code uses state-of-the-science methods for the simulation of flow and transport of dissolved compounds in variably saturated soils and is designed for the type of analysis conducted here.

The VS2DT code is applied to a specific problem by configuring the model to the physical setting and by choosing model parameters to represent the soil- and water-quality properties within the physical setting. The configuration of the model and the selection of model parameters are described in the following sections.

4.1 Model Configuration

The VS2DT code supports simulation of flow and transport within a vertical cross-section. Flow and transport are modeled in both the vertical and horizontal direction within the cross-section. The model cross-section is based on the cross-sections shown in Figure 2. The fill material is divided into four types of fill: an 'ultra clean' wedge (drainage layer cover), general embankment fill material above the wedge, a free drainage layer on the face of the embankment, and the drainage layer under the fill. The model section is shown in Figure 3.

The drainage layer is set at the bottom of the model. The assumption is made that all recharge eventually discharges through the drainage layer. In actuality, most of the water infiltrating through the fill leaks through the drainage layer and into the underlying groundwater (Pacific Groundwater Group, 2001). Therefore, the assumption made here is conservative as it results in a faster travel time for the transport of metals, does not account for any loss of flow to groundwater, and does not include dilution by groundwater within the drainage layer or dilution between the embankment and the creeks.

4.2 Model Parameters

Model parameters fall into two broad categories: parameters related to groundwater flow, and parameters related to the transport of dissolved substances in groundwater.

4.2.1 Flow Parameters

The primary flow parameter in groundwater modeling is the saturated hydraulic conductivity. Hydraulic conductivity is a measure of the resistance to groundwater flow by the soil matrix. Finer-grain material is more resistant to flow than is coarse material and, therefore, has a lower hydraulic conductivity. In the present model, the drainage layer and the material along the outer face of the fill are relatively coarse, and the general embankment fill material is relatively fine. Because the general embankment fill is deposited in layers, preferential pathways may form between layers. Consequently, it is assumed that there will be greater resistance to flow in the vertical direction than in the horizontal direction. This results in a lower vertical hydraulic conductivity than horizontal hydraulic conductivity. Because the drainage layer is relatively coarse and is only 3 feet thick, the vertical hydraulic conductivity was not adjusted for this layer. Values of hydraulic conductivity were estimated from the grain-size specifications for the fill material and the drainage layer, and from grain-size analysis of soils from the source areas. Values selected for the simulations are shown in Table 2.

The hydraulic conductivity is used to compute the overall speed of groundwater flow in the soil. The speed of groundwater flow through the pore spaces between soil particles also requires a measure of the amount of pore spaces. This parameter is the total porosity of the soil. Porosity values were taken from the work by Pacific Groundwater Group (2001) and are shown in Table 2.

In addition to hydraulic conductivity, there are parameters associated with unsaturated flow. The VS2DT code uses the widely accepted van Genuchten method for quantifying the effect of variable saturation conditions on groundwater flow (van Genuchten, 1980). This introduces two parameters for each material type, and these are denoted simply as α and β. The van Genuchten parameters for the general embankment fill were taken from previous work by Pacific Groundwater Group (2001). The van Genuchten parameters for the drainage layer were taken from values provided in the VS2DT documentation for an unconsolidated sand (Lappala *et al.*, 1987). Although the drainage layer is not entirely sand, the sand and finer particles are assumed to dominate the flow characteristics of the drainage layer. This assumption is consistent with well established principles of groundwater flow (Fetter, 1994). The van Genuchten parameters for the drainage layer and general embankment fill material are shown in Table 2.

Finally, there are two parameters that relate to the ability of the soil to hold moisture. These parameters are the specific storage and the residual moisture content. The residual moisture content is the small amount of moisture trapped between soil particles after the water has been drained from the soil. Specific storage is the change in water stored in pore spaces due to the compression or expansion of the aquifer. It is a significant parameter only in thick, saturated aquifers. Since the fill is largely unsaturated and specific storage is not important in this case, the specific storage was set to zero. Residual moisture values were taken from the work by Pacific Groundwater Group (2001) and are provided in Table 2.

4.2.2 Transport Parameters

Transport parameters include parameters related to how fast dissolved substances move through the soil, and parameters that describe the loss of the substances by decay or breakdown processes.

Metals do not decay or breakdown and, therefore, no decay processes were considered for metals. Some organic compounds of interest in this study do decay with time, and the decay process of these compounds was considered. However, to be conservative, the transport analysis of organic compounds was conducted without incorporating decay processes.

Metals form complex interactions with soil particles and consequently may adsorb or desorb from soil particles in contact with groundwater. The primary parameter describing the relationship between the concentration of a substance in soils and the concentration of the same substance in water is the soil-water partitioning coefficient (K_d).

Similarly, organic compounds adsorb to organic carbon in the soil. The partitioning coefficient for organic compounds is affected by both the organic carbon partitioning coefficient (K_{oc}) and the fraction of organic carbon in the embankment fill material.

The site-specific soil-water partitioning coefficients for metals in this study were computed from the results of the analysis of metals in soils and the SPLP testing. The analysis of metals in soils determines the concentration of the specified metals in the soil. The SPLP test on the same soil samples determines the concentration of those metals in water that is in contact with the soil. Therefore, the ratio between the soil concentration and the SPLP concentration is the soil-water partitioning coefficient. Site-specific soil-water partitioning coefficients were developed for soils from the principal source areas for the general embankment fill and the drainage layer (see Attachment C). The results of these computations are shown in Table 3.

The soil-water partitioning coefficients for organic compounds were computed from K_{oc} values found in WAC 173-340, Tables 747-1 and 747-4. These are based on literature values of K_{oc} and are used if site-specific data are not available. The organic carbon content of source area soils was measured through laboratory analysis. The average organic carbon content was measured at 0.17 and 0.39 percent for the general embankment fill and the drainage layer material, respectively. The corresponding K_d values for organic compounds are listed in Table 3.

The partitioning of metals between soil and water using K_d also requires determination of the bulk density of the soil. Bulk density is computed as the product of the mass density of the solids making up the soil (normally 2.65 g/cm^3 for sandy soils; Domenico and Schwartz, 1990) and the solid volume fraction of the soil ($1 - n$, where n is porosity). The bulk densities of general embankment fill and drainage layer material were derived from laboratory measurement from the source areas and are given in Table 3.

In addition to soil-water partitioning, the transport analysis also uses parameters that describe how the dissolved substances spread due to flow around particles and the irregular shape and size of pore spaces. These parameters are the dispersion/diffusion coefficients and include longitudinal and transverse dispersion coefficients and molecular diffusion coefficients. The dispersion coefficients are typically much larger than the molecular diffusion coefficient and, therefore, dominate the spreading process making the diffusion rate insignificant. The dispersion coefficients are taken from literature values and are provided in Table 3.

4.3 Initial and Input Values

Initial values are the conditions established to describe the soil moisture and the concentration of a substance at the start of a simulation. Input values define the inflow and outflow of water and dissolved substances over time.

4.3.1 Flow Values

The primary initial condition for flow is the soil moisture content, and the primary input is infiltration at the land surface (recharge). There are no injection or extraction wells in the embankment fill; therefore, recharge is the only input to the model that varies with time.

Groundwater recharge is applied to the upper surface of the model section. No recharge is applied to the sloping outer face of the model where most of the precipitation is expected to run off. The recharge rate is taken from the average infiltration computed in the HSPF model developed for Miller and Walker Creeks (Pacific Groundwater Group, 2001). The average annual recharge is applied continuously throughout each model run. This is a reasonable application of recharge since transport of metals and other dissolved substances in the fill is a slow process that occurs over a period of years. Consequently, the use of daily recharge rates would add needless complexity to the modeling process without affecting the model results. Based on the HSPF results. a recharge rate of 17 inches per year was applied.

The initial moisture content defines the distribution of soil moisture in the fill at the beginning of a simulation. If the moisture content is high, then water will discharge from the fill sooner than if the moisture content is low. In either case, water eventually discharges from the fill and flows out through the drainage layer. Consequently, the initial moisture content is not a critical parameter for long-term simulations (simulation periods of 1000 years in the present study). A uniform moisture content of half the fully saturated moisture content was selected as a reasonable starting point.

4.3.2 Transport Values

The initial condition for transport is used to set the concentration of dissolved metals and other compounds in the fill. The simulation then predicts how these dissolved compounds move through the fill and the concentration of compounds at the end of the drainage layer.

The concentration of metals in embankment fill soils was defined as equal to the fill criteria specified in the 401 Certification (see Table 1). However. the required input to the model is the initial concentration of a substance in groundwater rather than the concentration in soil. Therefore, the fill criteria are divided by the soil-water partitioning coefficients to compute the initial dissolved concentration conditions in the model. The initial condition for a specific metal in the general embankment fill was computed using the partitioning coefficients computed for that metal (see Table 3). The initial condition for the drainage layer used only the partitioning coefficients and soil concentrations for the Kent-Kangley material since the bulk of the drainage layer material has come from this source area. The initial conditions, fill criteria, and partitioning coefficients for each metal are shown in Table 4.

The concentration of organic compounds included in this study was taken from the results of source area soil testing of fill material that may have been deposited in the embankment. To be conservative, the highest concentration observed in the data from these historic fill sources was assigned to the entire fill volume from these sources.

4.4 Simulations

The VS2D model was applied to three simulations. The first series of simulations were designed to determine if the fill criteria were protective of water quality. These simulations were applied with the metals concentration in the fill set at the 401 Certification fill criteria. The most mobile metal was also tested at concentrations above the fill criteria to test the sensitivity of the model to the fill concentration.

Two simulation scenarios were designed to test whether some of the existing fill could adversely affect water quality in Miller Creek. These scenarios consist of the DOT First Avenue Bridge/Black River Quarry fill and the Hamm Creek fill. These borrow sources have been scrutinized for possibly containing low levels of regulated organic compounds in soils. Each of the model simulations is described in the following sections.

4.4.1 General Embankment Fill

The simulations were conducted for all the metals listed in the 401 Certification fill criteria (see Table 1). The simulations were allowed to run for a simulation time of 1000 years. The concentration of metals in groundwater in the drainage layer and at the end of the drainage layer was monitored to determine the maximum concentration computed over the length of the model run, i.e., at yearly intervals over a period of 1000 years.

4.4.2 Hamm Creek Fill

Samples collected by the U.S. Army Corps of Engineers (USCOE) at the Hamm Creek fill source detected low levels of PCBs and DDTs at maximum concentrations of 0.16 mg/kg and 0.014 mg/kg, respectively. Samples collected by The Boeing Company at this site did not detect these constituents. Hamm Creek data are presented in Attachment B.

Organic carbon partitioning coefficients (K_{oc}) for DDT compounds were taken from WAC 173-340-747, Table 747-1. Among the PCB compounds, only Aroclor 1254 was detected and the K_{oc} value for Aroclor 1254 was taken from literature values (Mackay et al., 1992). The partitioning coefficients and the chemical concentration in soil were used to compute the initial dissolved phase concentration in the Hamm Creek fill. The concentration of chemicals in the fill, the partitioning coefficients, and the initial dissolved concentrations are shown in Table 5.

The Hamm Creek fill is located in the north safety area and extends to the outer edge of the general embankment fill, but is separated from the face of the embankment by the drainage layer on the face of the embankment (see Figure 1). This older fill area does not have drainage layer or drainage layer cover fills. The model setup and location of the Hamm Creek fill is shown in Figure 4.

4.4.3 First Avenue Bridge Fill and Black River Quarry Fill

Concerns have been raised regarding the presence of total petroleum hydrocarbons (TPH) in fill from the First Avenue Bridge and Black River Quarry fill sources. The data from these sites are provided in Attachment B and are summarized below:

- At the First Avenue Bridge fill source, a maximum concentration of 810 mg/kg TPH in the heavy oil range was detected at the fill source. The TPH-impacted area of this source was isolated, and soils from this location were not imported to the Third Runway. The maximum concentration detected in soil imported to the Third Runway was 99 mg/kg TPH in the heavy oil range.
- Some of the early material placed at the Third Runway from the Black River Quarry contained incidental asphaltic material. Samples collected of this material contained a maximum of 270 mg/kg TPH in the heavy oil range.

The First Avenue Bridge and early Black River Quarry fill were placed near the upper east end of the fill (see Figure 1). The model setup and the location of the First Avenue Bridge/Black River Quarry fill are shown in Figure 5.

The transport simulation for the First Avenue Bridge/Black River Quarry fill material was based on the conservative assumption that the entire First Avenue Bridge and Black River Quarry fill material with detected TPH concentration contained a heavy oil concentration in soil of 270 mg/kg, the highest of all detected concentrations. The initial dissolved concentration was computed using WAC 173-340-747 and information on the composition of the heavy oil range in TPH analysis (San Juan and Park, unpublished data). The parameters used in the computations and initial dissolved concentration are shown in Table 6.

4.4.4 Sensitivity Analysis

A sensitivity analysis was conducted to see how model results change, if different input parameters are used. The sensitivity of model results to input parameters was tested by varying two of the most critical transport parameters: soil-water partitioning coefficient and the concentration of a compound in fill soil. A low partitioning coefficient indicates that the compound is more readily transported. It also results in a higher initial dissolved concentration in groundwater. As the soil concentration increases and the partitioning coefficient decreases, the compound is both more mobile and is simulated with a higher initial dissolved concentration in the model.

For the sensitivity simulation, the most mobile metal (lowest partitioning coefficient) was selected. To make the analysis conservative, the lowest partitioning coefficient from the source area data was selected. Consequently, arsenic was the metal selected for the analysis with a partitioning coefficient (K_d) of 178 L/kg. The soil concentration of arsenic was set at 5 times and 10 times the fill criteria of 20 mg/kg, or 100 and 200 mg/kg, respectively.

The model setup was the same as the general embankment fill setup, but with transport parameters corresponding to the low K_d and high arsenic concentration in the fill (see Table 4).

4.5 Modeling Results

4.5.1 Transport of Metals

For each of the simulations performed, the maximum metal concentrations at the drainage layer seepage face over the entire simulation are summarized on Table 7. In all cases, the contribution of metals leached from the fill to seepage along the drainage layer is negligible. The reason for this is the high adsorption capacity of both fill and drainage layer material, which effectively limits transport of metals in groundwater over any reasonable time scale. The metal concentrations in seepage reflect metals derived from within the drainage layer material and are below ambient water-quality criteria.

Simulation results are also presented in Table 7 for the sensitivity analysis for arsenic, the most mobile of the metals considered, where the minimum (rather than mean) calculated soil-water partitioning coefficient values were used. The sensitivity analysis shows that model results are unaffected by substantial changes in the partitioning coefficients or the fill criteria. These results indicate that the fill criteria are very conservative and that model results would not change with any reasonable changes made to model parameters.

4.5.2 Transport from the Hamm Creek Fill

Results for the Hamm Creek fill are presented in Table 8. Simulations were conducted for DDD and PCB (Aroclor 1254). Model results show that the attenuation capacity of the embankment fill is large compared to the volume of Hamm Creek soil and the high K_d values for these compounds. Consequently, neither compound is expected to discharge from the embankment fill.

Simulations were not conducted for DDE or DDT. These compounds were detected at lower concentrations than DDD and are less mobile (higher K_{oc} value). Therefore, they are less likely than DDD to be in water discharging from the embankment fill. Consequently, there is no need to simulate these compounds in order to predict their concentration in the embankment discharge.

4.5.3 Transport from the First Avenue Bridge/Black River Quarry Fill

Results for the First Avenue Bridge/Black River Quarry fill are presented in Table 8. Simulations were conducted for the lightest range of aromatic compounds associated with heavy oil TPH (TPH-O). The aromatic compounds are more mobile than the aliphatic compounds due to the high K_{oc} values for aliphatics. The lower K_{oc} for aromatic compounds also means that the computed initial concentration for aromatics is higher than for aliphatics. Therefore, simulation of the aromatic compounds is conservative as they are both more mobile and have a higher initial concentration.

The TPH compounds are subject to decay through chemical and microbiological processes. This is particularly the case for the lighter aromatic ranges. To be conservative, the simulations were conducted without including decay process.

Based on the simulations, bw concentrations are predicted in the discharge from the embankment fill in several hundred years. The predicted concentration of representative TPH compounds in groundwater is below applicable water quality criteria. Based on the predicted time frame for the discharge to occur, even very low decay rates would result in elimination of the TPH compounds prior to discharging form the embankment fill.

Section 5.0
Conclusions

The modeling effort discussed in this report was used to simulate metals and organic compounds potentially found in the embankment fill material. In the case of metals, the entire embankment fill was modeled at the fill criteria. Arsenic was also modeled at concentrations well above the fill criteria to test the sensitivity of the model. In the case of organic compounds, historic fill areas that may have detectable levels of organic compounds were included based on fill locations provided by the construction contractors.

In all cases simulated, the discharge from the embankment fill is less than applicable surface water criteria. These simulations are conservative as they do not account for further attenuation and dilution between the embankment fill and surface water bodies by mixing and attenuation in the perched aquifer, attenuation during seepage through the till, mixing and attenuation in the underlying regional aquifer, attenuation in peat and other soils with relatively high organic carbon content, or mixing, sorption and settling in stormwater systems.

5.1 Drainage Layer

The transport simulations indicate that dissolved metals concentrations in seepage from the drainage layer will be very low, derived almost exclusively from the leachable metals content of the drainage layer material. Any metals leached from fill by infiltrating groundwater will be strongly attenuated both within the fill and within the drainage layer, and will not impact concentrations observed at the seepage face.

5.2 Fill Criteria and Seepage Quality

Metals occurring in the fill at concentrations equal to or below the fill criteria will not result in concentrations in the seepage from the embankment in excess of the applicable water-quality criteria. This conclusion holds even if the entire fill is modeled for the most mobile metal (arsenic) at concentrations of ten times higher than the fill criteria, and indicates that the fill criteria are indeed protective with respect to potential impacts from metals.

5.3 Impacts from Historic Fill Sources

Historic fill material that may contain detectable concentrations of some organic compounds do not pose a threat to water quality. Heavier organic compounds, such as DDD and PCBs, were found in low concentrations in some samples collected at the Hamm Creek fill source, but these compounds have a low potential for mobility. Consequently, even modeling the entire Hamm Creek fill at the highest detected concentrations of DDD and PCB did not show any transport of these compounds through the fill and discharging from the embankment.

Lighter organic compounds, associated with the lighter ranges of petroleum hydrocarbons, have a greater potential to migrate through the fill. However, even in the absence of chemical or microbiological decay, these compounds are not expected to occur in discharge above applicable water-quality criteria. If chemical or microbiological decay is considered, and given the long time frame for discharge to occur, it is highly unlikely that petroleum hydrocarbons from the historic fill sources will be found in discharge from the embankment fill.

Section 6.0
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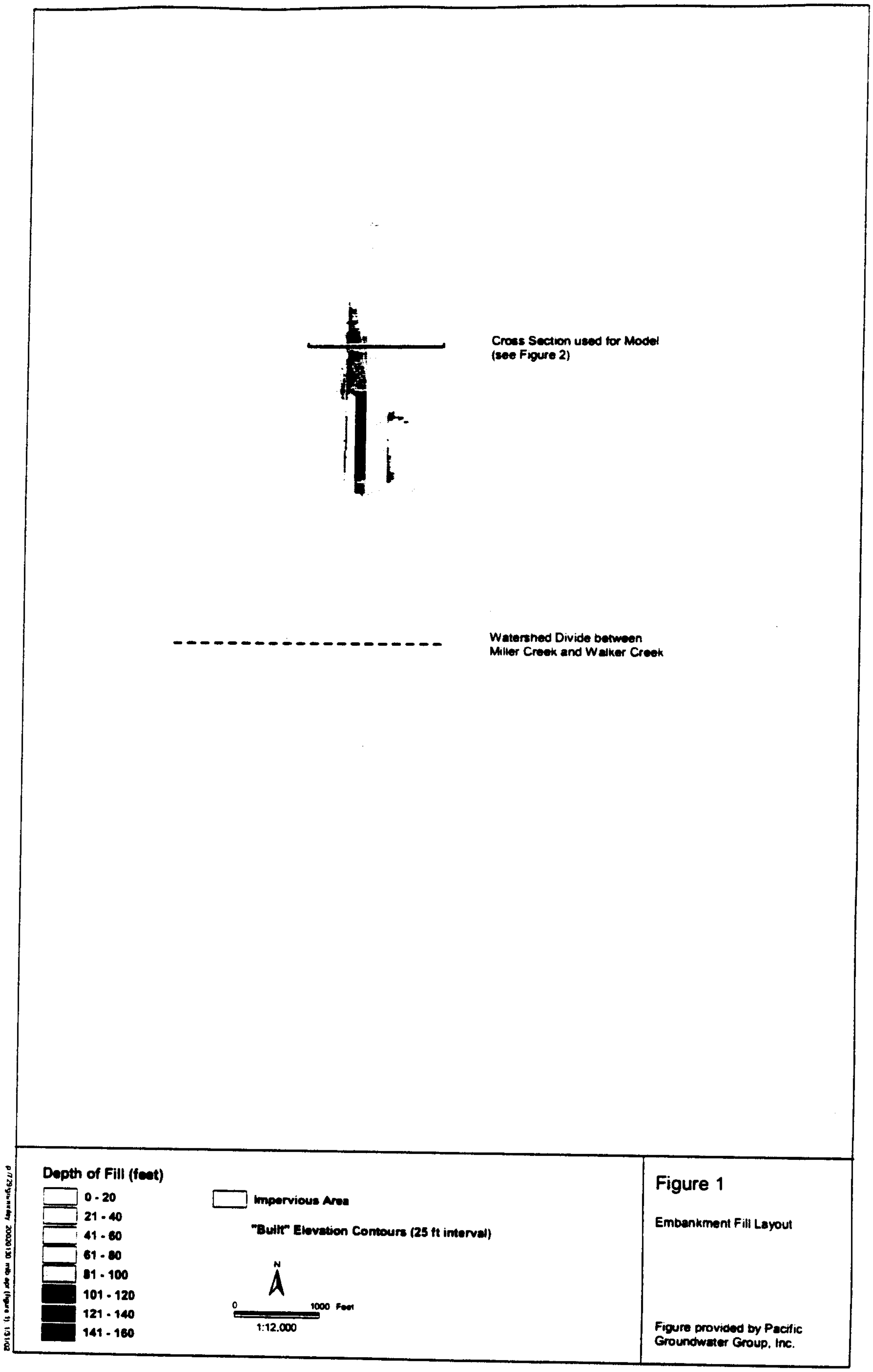

Figure 1

Embankment Fill Layout

Figure provided by Pacific Groundwater Group, Inc.

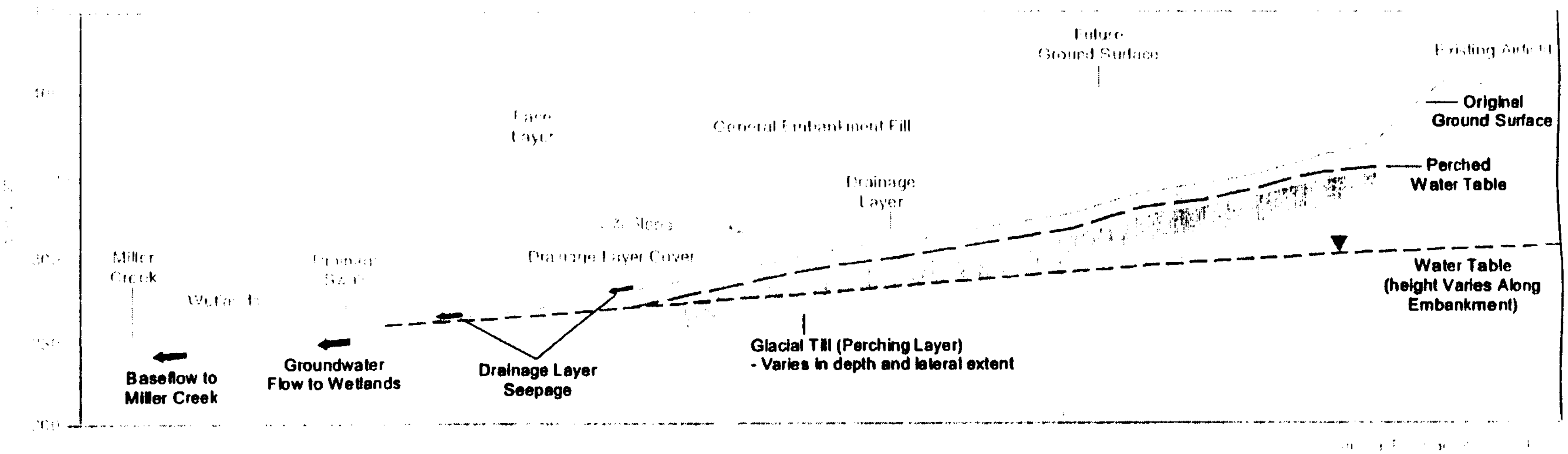

Figure 2 Typical Cross-Section Through the Embankment Fill

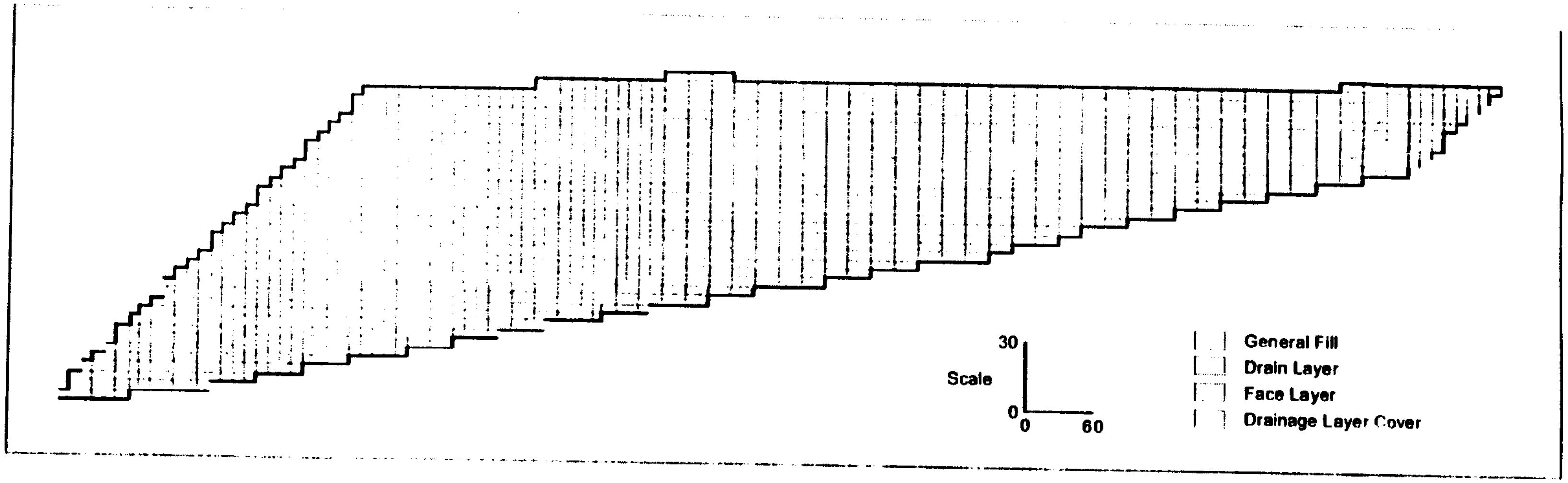

Figure 3 Model Cross-Section for General Embankment Fill Simulations

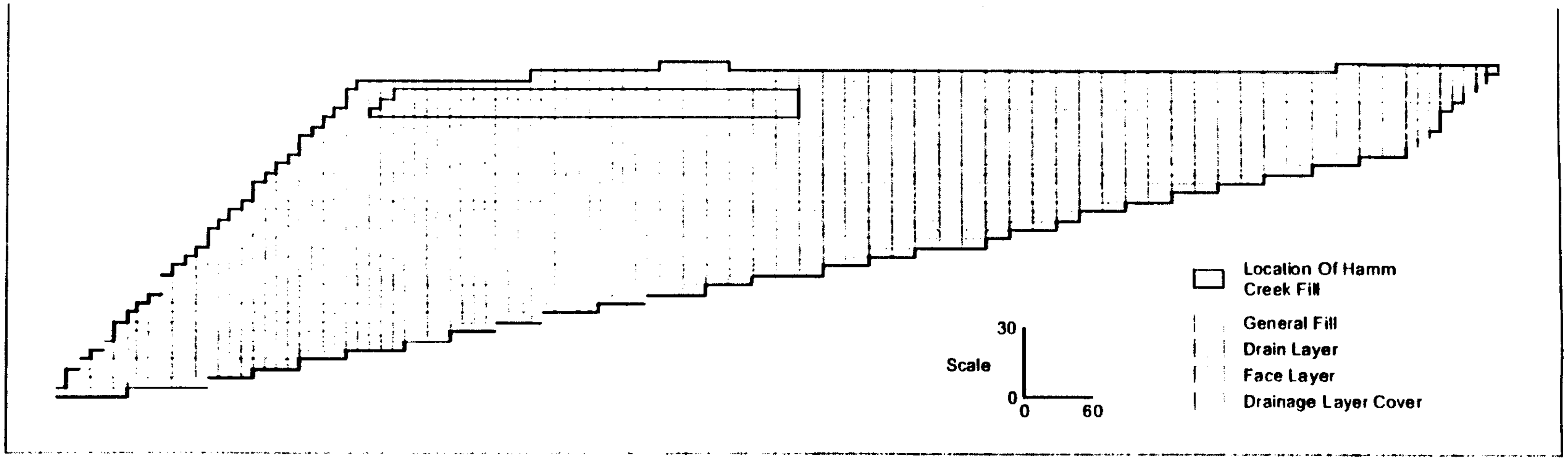

Figure 4 Model Cross-Section for Hamm Creek Fill Simulations

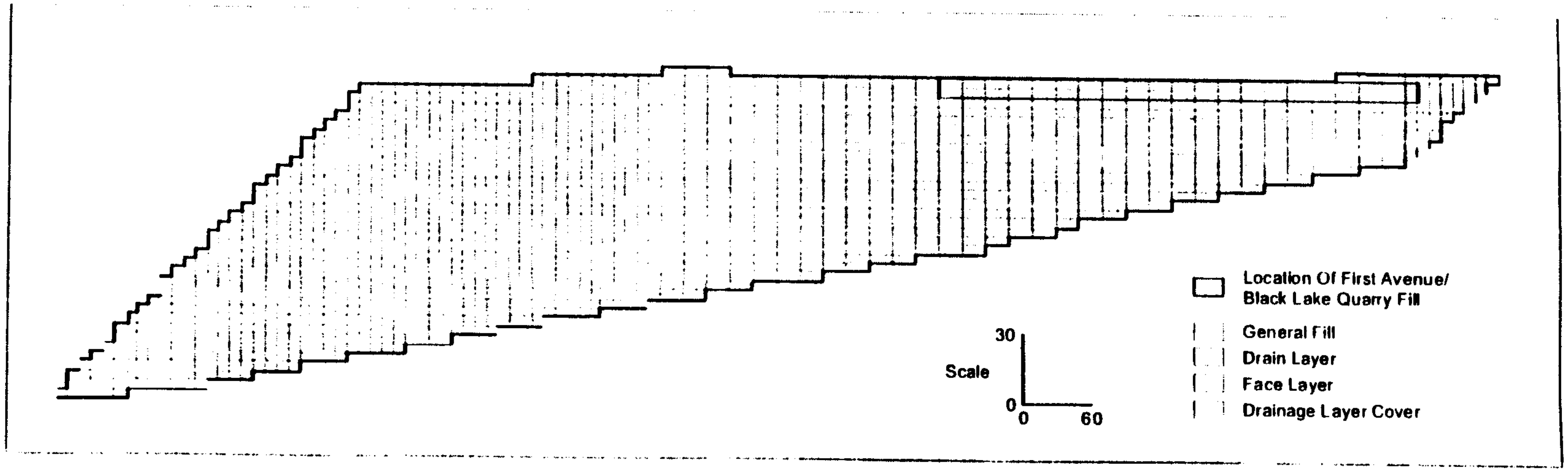

Figure 5 Model Cross-Section for First Avenue / Black Lake Quarry Fill Simulations

Table 1
Comparison of Water Quality and Fill Criteria

Constitutent	Ambient Water Quality Criteria[1] (µg/L)	Recommended Thresholds[2] (µg/L)	Soil Fill Criteria[3]	
			Type 1 Fill[4] (mg/kg)	General Embankment Fill[5] (mg/kg)
Antimony	NA	30	16	16
Arsenic	190		7	20
Barium	NA	1450	12000	NS
Beryllium	NA	51	0.6	0.6
Cadmium	1.03		1	2
Chromium	178		42	2000
Chromium(+6)	10		19	19
Copper	11.4		36	36
Lead	2.5		24	250
Mercury	0.012		0.07	2
Nickel	157		48	110
Selenium	5		5	5
Silver	NA	0.12	5	5
Thallium	NA	55	2	2
Zinc	104		85	85

NA: Ambient Water Quality Criteria not available in WAC 173-201A.
NS: Not specified.

1) WAC 173-201A, using hardness of 100 mg/L.
2) See Attachment A
3) From 401 Water Quality Certification, Attachment E.
4) Includes drainage layer, drainage layer cover and embankment face material.

5) The U.S. Fish and Wildlife Service ecological criteria for the top three feet of the embankment are not included in this modeling effort. The ecological criteria applied to the top three feet of the embankment are lower than the general embankment fill criteria and therefore will leach at lower concentrations than the remainder of the fill.

Table 2
Hydraulic and Physical Parameters of Embankment Material

Parameter	Units	General Embankment Fill	Type 1 Fill[1]
Hydraulic Conductivity	ft/day	3.8	25
α (van Genuchten parameter)	1/ft	2.7	2.3
β (van Genuchten parameter)	-	1.35	9.0
Porosity	-	0.25	0.40
Specific Storage	-	0.00	0.00
Residual Moisture Content	-	0.02	0.05

1) Includes drain layer, drain layer cover, and embankment face material

Table 3
Parameters used in the Transport Analysis

Parameter	Units	General Embankment Fill	Type 1 Fill[1]
Bulk Density (ρ_b)	kg/L	2.0	1.6
Dispersion			
Longitudinal (α_L)	ft	25	25
Transverse (α_T)	ft	2.5	2.5
Fraction Organic Carbon		0.0017	0.0039
Partitioning Coefficient (K_d)[2]	L/kg		
Antimony		5,240	74,800
Arsenic		1,570	22,900
Beryllium		34,100	105,000
Cadmium		4,650	14,900
Chromium		5,630	31,200
Copper		7,130	48,100
Lead		6,610	16,700
Mercury		2,200	23,000
Nickel		10,400	62,300
Selenium		1,400	1,400
Silver		54,400	136,000
Thallium		43,500	121,000
Zinc		9,420	22,000
DDD		77.9	178.6
DDE		146.9	337.0
DDT		1,152	2,644
PCB (Arochlor 1254)		908.3	2,084
TPH Aromatic EC 10-12		4.3	9.8
TPH Aromatic EC 12-16		8.5	19.5
TPH Aromatic EC 16-21		26.9	61.6
TPH Aromatic EC 21-34		214.2	491.4

1) Includes drain layer, drain layer cover, and embankment face material

2) K_d's for metals developed from sampling of source area material.

K_d's for organics based on WAC 173-340 using organic carbon partitioning coefficient and fraction organic carbon.

Table 4
Initial Conditions for Soil and Groundwater, Fill Criteria and Partitioning Coefficients used in the General Embankment Fill Simulations

	Soil Concentration[1] (mg/kg)	K_d[2] (L/kg)	Initial Concentration[3] (µg/L)
General Embankment Fill			
Antimony	16	5,240	3.1
Arsenic	20	1,570	12.7
Beryllium	0.6	34,100	0.02
Cadmium	2	4,650	0.4
Chromium	2,000	5,630	355
Copper	36	7,130	5.0
Lead	250	6,610	37.8
Mercury	2	2,200	0.9
Nickel	110	10,400	10.6
Selenium	5	1,400	3.6
Silver	5	54,400	0.09
Thallium	2	43,500	0.05
Zinc	85	9,420	9.0
Type 1 Fill			
Antimony		74,800	0.0063
Arsenic		22,900	0.25
Beryllium		105,000	0.0063
Cadmium		14,900	0.0056
Chromium		31,200	0.80
Copper		48,100	0.77
Lead		16,700	0.25
Mercury		23,000	0.0015
Nickel		62,300	0.41
Selenium		1,400	0.25
Silver		136,000	0.0018
Thallium		121,000	0.0018
Zinc		22,000	2.5
Sensitivity Analysis - Arsenic			
Low K_d and General Fill Soil Concentration at 5x Fill Criteria			
General Fill	100	178[4]	56
Type I Fill		18600[4]	0.25
Low K_d and General Fill Soil Concentration at 10x Fill Criteria			
General Fill	200	178[4]	112
Type I Fill		18600[4]	0.25

1) Soil concentrations for general fill set at the 401 Soil Fill Criteria as given in Table 1 unless otherwise noted

2) Soil-water partitioning coefficient (geometric mean values from Attachment B)

3) For general fill, calculated from soil concentration and K_d; for Type 1 fill, taken as the mean value of SPLP leachate concentrations for Kent-Kangley samples

4) Lowest K_d value calculated from soil and SPLP leachate concentrations

Table 5
Initial Conditions for Soil and Groundwater, Fill Criteria and Partitioning Coefficients used in the Hamm Creek Simulations

	Soil Concentration (µg/kg)	K_{oc}[1] (L/kg_{oc})	foc[2]	K_d[3] (L/kg)	Initial Concentration[4] (µg/L)
Hamm Creek Fill[5]					
DDD	6.7	45800	0.0017	77.9	0.086
DDE	3.7	86405	0.0017	146.9	0.025
DDT	3.6	677934	0.0017	1152	0.003
PCB[6]	160	534291	0.0017	908.3	0.176
General Embankment Fill					
DDD	0.0	45800	0.0017	77.9	0.0
DDE	0.0	86405	0.0017	146.9	0.0
DDT	0.0	677934	0.0017	1152	0.0
PCB	0.0	534291	0.0017	908.3	0.0
Embankment Face Material					
DDD	0.0	45800	0.0039	178.6	0.0
DDE	0.0	86405	0.0039	337.0	0.0
DDT	0.0	677934	0.0039	2644	0.0
PCB	0.0	534291	0.0039	2084	0.0

1) Soil organic carbon-water partitioning coefficient (from WAC 173-340, Table 747-1 for DDT compounds and geometric mean from literature values for PCB Arochlor 1254 [Mackay et al., 1992]).

2) Fraction organic carbon (from soil testing of embankment fill source areas).

3) Soil-water partitioning coefficient (= Koc x foc).

4) Initial concentration in the model (= soil concentration / Kd).

5) Soil concentrations are highest levels detected in soil sampling of Hamm Creek fill material.

6) Only Arochlor 1254 detected in soil samples.

Table 6

Initial Conditions for Soil and Groundwater, Fill Criteria and Partitioning Coefficients used in the First Avenue Bridge/Black River Quarry Simulations

	Soil Concentration[1] (mg/kg)	K_{oc}[2] (L/kg_{oc})	foc[3]	K_d[4] (L/kg)	Initial Concentration[5] (µg/L)
First Avenue Bridge/Black River Quarry Fill[6]					
Aromatic EC 10-12	1.54	2510	0.0017	4.3	361
Aromatic EC 12-16	2.24	5010	0.0017	8.5	263
Aromatic EC 16-21	12.10	15800	0.0017	26.9	450
Aromatic EC 21-34	56.78	126000	0.0017	214.2	265
General Embankment Fill					
Aromatic EC 10-12	0.0	2510	0.0017	4.3	0.0
Aromatic EC 12-16	0.0	5010	0.0017	8.5	0.0
Aromatic EC 16-21	0.0	15800	0.0017	26.9	0.0
Aromatic EC 21-34	0.0	126000	0.0017	214.2	0.0
Drainage Layer, Drainage Layer Cover and Embankment Face Material					
Aromatic EC 10-12	0.0	2510	0.0039	9.8	0.0
Aromatic EC 12-16	0.0	5010	0.0039	19.5	0.0
Aromatic EC 16-21	0.0	15800	0.0039	61.6	0.0
Aromatic EC 21-34	0.0	126000	0.0039	491	0.0

1) Soil concentratrions computed from percent composition of Heavy Oil in TPH (San Juan and Parks).

2) Soil organic carbon-water partitioning coefficient (from WAC 173-340, Table 747-4).

3) Fraction organic carbon (from soil testing of embankment fill source areas).

4) Soil-water partitioning coefficient (= Koc x foc).

5) Initial concentration in the model (= soil concentration / Kd x 1000).

6) Soil concentrations are highest detected concentration in soil sampling of First Avenue Bridge and Black River Quarry fill material. Only TPH-O was detected and highest concentration was 270 mg/kg.

Table 7

Model Results for the Transport of Metals from General Embankment Fill

Metal	Maximum Discharge Concentration[1] (µg/L)	Threshold[2] (µg/L)	Comments
Antimony	0.0063	30	
Arsenic	0.25	190	
Beryllium	0.0063	51	
Cadmium	0.0056	1.03	
Chromium	0.80	178	
Copper	0.77	11.4	
Lead	0.25	2.5	
Mercury	0.0015	0.012	
Nickel	0.41	157	
Selenium	0.25	5.0	
Silver	0.0018	0.12	
Thallium	0.0018	55	
Zinc	2.5	104	
Sensitivity Analysis Results			
Arsenic	0.25	190	Lowest K_d and General Fill Soil Concentration of 100 mg/kg (5x Fill Criteria)
Arsenic	0.25	190	Lowest K_d and General Fill Soil Concentration of 200 mg/kg (10x Fill Criteria)

1) Maximum concentration in discharge from the drainage layer over a 1000-yr simulation.

2) Ambient water quality criteria (AWQC) or recommended threshold from Table 1.

Table 8
Model Results for the Transport of Organics from Hamm Creek and First Avenue Bridge/Black River Quarry Fills

	Maximum Discharge Concentration[1] (µg/L)	Ambient Water Quality Criteria[2] (µg/L)	Comments
Hamm Creek Fill			
DDD	0.0000	0.001	AWQC for sum of DDD, DDE and DDT
DDE	--		Not simulated as less mobile and at lower concentration than DDD
DDT	--		Not simulated as less mobile and at lower concentration than DDD
PCB (Arochlor 1254)	0.0000	0.014	AWQC for total PCBs
First Avenue Bridge/Black River Quarry Fill			
TPH Aromatic EC 10-12	15.3	320	CLARC II for Naphthalene. Maximum occurs after 325 years.
TPH Aromatic EC 12-16	10.9	1610	CLARC II for Acenaphthene. Maximum occurs after 610 years.
TPH Aromatic EC 16-21	4.9	225	CLARC II for Fluoranthene. Maximum at end of simulation (1000 years)
TPH Aromatic EC 21-34	--		Not simulated as less mobile and at lower concentration than EC 16-21

1) Maximum concentration in discharge from the drainage layer over a 1000-yr simulation.
2) Ambient water quality criteria (AWQC) from lower of WAC 173-201A or WAC 173-340, CLARC II database.
Ambient water quality criteria for TPH ranges is taken from representative compound within range (see comments).

Attachment A

Recommended Thresholds for Chemicals with Potential to Leach from Fill Soils

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TECHNICAL MEMORANDUM

Date: February 6, 2002
To: Tanya Barnett, Merret and Brown.
From: Charlie Wisdom. Parametrix
Subject: Effects Thresholds for Port of Seattle
cc: Mike Riley, S.S. Papadopulos & Associates

Project Number: 556-2625-002
Project Name: Port of Seattle Permit Appeal

This memo outlines the steps taken to determine appropriate effect thresholds for antimony, barium, beryllium. silver and thallium.

EFFECT THRESHOLD DEVELOPMENT

In each case, criteria proposed by either Washington State Department of Ecology (WDOE) or the United States Environmental Protection Agency (USEPA) were set as thresholds for evaluating water quality of environments potentially receiving fill leachate. When neither agency had proposed a criterion, acute and chronic effects thresholds were based on a search of the AQUIRE database maintained by USEPA. The AQUIRE database was established by USEPA in 1981, and contains information (e.g., toxicity data) on lethal and sublethal effect concentrations for aquatic organisms. The majority of the toxicity data reported in AQUIRE were published primarily between 1970 and the present. Table 1 identifies the database source of the effect threshold identified for each metal.

Table 1. Database source used to develop acute and chronic effects thresholds for each metal

Metal	Database Source
Antimony	USEPA Proposed Criterion Document
Barium	AQUIRE database
Beryllium	AQUIRE database
Silver	Acute – Washington Administrative Code Chronic - USEPA Proposed Criterion Document
Thallium	AQUIRE database

For chemicals without proposed acute criteria, appropriate acute thresholds were determined by dividing the lowest freshwater LC50[1] by two to estimate a low effect level. This is consistent with the USEPA's approach for deriving

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[1] The LC50 is the chemical concentration that resulted in mortality of 50% of the organisms tested.

acute water quality criteria (WQC) (Stephan et al. 1985). For chemicals without proposed chronic criteria, chronic thresholds were determined by identifying the lowest chronic toxicity value for freshwater organisms, when available. For example, the chronic threshold of 51 µg/L for beryllium was based on a life cycle study with the cladoceran *Daphnia magna*. For thallium, the lowest toxicity value identified was a 7-day LC50 of 110 µg/L for survival of toad (*Gastrophryne carolinensis*) embryos. Although this study was not a complete early life stage test, it did encompass the earliest life stages of the toad and was the lowest appropriate value identified. Because the result was reported as an LC50 of 110 µg/L, the recommended threshold of 55 µg/L was determined by dividing the LC50 by two (see acute discussion above for basis). Finally, no appropriate chronic toxicity data were identified for barium for sensitive species. Consequently, the chronic effect threshold was estimated from the lowest acute LC50 for barium using a generic acute-chronic ratio (ACR) of 10. Use of an ACR is consistent with the USEPA methodology for deriving chronic WQC (Stephan et al. 1985). Furthermore, assuming a generic ACR of 10 in the absence of chemical-specific data is also consistent with USEPA guidance (USEPA 1991). Using this approach the recommended chronic effect threshold for barium was estimated to be 1450 µg/L. A complete list of the proposed effects thresholds can be found in Table 2.

TOXICITY DATA SEARCH METHODOLOGY

To select the best values to base the acute and chronic effects thresholds, it was necessary to determine which AQUIRE data were acceptable to identify these thresholds. The AQUIRE database contains a wide spectrum of toxicity data that vary in quality and types of information reported. The following outlines the guidelines used to review AQUIRE toxicity data for acceptability.

For toxicity data obtained from the AQUIRE database to be used to calculate an effect threshold, a minimum set of data quality requirements were established. These requirements were generally based on guidance established by the USEPA (Stephan et al. 1985). The AQUIRE database reports information that allows the user to evaluate the quality of the toxicity data provided. The following summarizes the key information categories reported by AQUIRE (termed fields) that were evaluated, and types of information in each field considered acceptable for the screening evaluation process.

Exposure Duration

This field provides the period of time test organisms were exposed to a chemical or stressor. As such, exposure duration determines whether the toxicity test was acute (i.e., short-term) or chronic (i.e., long-term). Only data derived from tests that used exposure durations appropriate to the test species and type of toxicity test were used. For example, acute toxicity tests for most species are typically 96 hours in duration; however, 48 hours is considered sufficient for some species and types of tests (e.g. waterflea survival tests). Tests conducted over other short-term exposure durations (e.g., 24 hours) were used only if data from standard acute test durations (i.e., 48-96 hours) were not available. Ideally, chronic toxicity tests should encompass the life cycle of an organism through reproduction. This may be difficult to test in the laboratory for many organisms (particularly certain fish species, especially anadromous fish), so partial life cycle (e.g., juveniles through reproduction) or early life stage tests (embryo-larval life stages) were also considered acceptable.

Exposure Type

The effects thresholds identified through this process are generally only appropriate to evaluate direct water column exposure to water column chemicals. Toxicity tests based on non-relevant exposure routes, such as injection, were not considered in this evaluation. Laboratory toxicity test exposure scenarios may be static, static-renewal, or flow-through. In static exposures, the exposure media (and associated chemical concentrations) is not renewed during the course of the test. In static-renewal exposures, the exposure media (and associated chemical concentrations) are renewed at regular intervals over the duration of the test. In flow-through tests, chemical concentrations are continuously renewed. Preference was given to data derived from flow-through tests because organisms are likely exposed to a relatively constant chemical concentration. Acceptable acute tests could be based on any of these exposure types, but chronic toxicity data should be based on static-renewal exposures, or ideally, flow-through exposure conditions.

Chemical Analysis

Analytical verification of exposure concentrations in test solutions ensures that test organisms are actually exposed to nominal concentrations and also ensures that exposure levels are not fluctuating significantly over the course of the test. It is not essential that exposure concentrations be verified for acute data to be acceptable, although data from tests where chemical concentrations were verified may have been given preference over data derived from nominal concentrations. Given the relatively long duration of chronic toxicity tests, chemical concentrations should be analytically verified for data from these tests to be acceptable.

Controls

Negative control organisms are reared in the same dilution water and conditions as test organisms, but are not exposed to stressors being evaluated. The negative control ensures test organisms are healthy and that observed responses in treated organisms are due to particular test conditions (e.g., test chemical). Negative control responses should meet acceptability guidelines published by. In AQUIRE, control responses are typically identified as "satisfactory," "unsatisfactory," or "indeterminate." For this evaluation, data were used only if controls were identified as "satisfactory" or "indeterminate."

Dilution Water

The dilution water used in toxicity tests should not be of unusual origin or contain excessive organic carbon or suspended matter that may reduce bioavailability of chemicals to test organisms. In addition, dilution water should have a pH, temperature, salinity, and dissolved oxygen level relevant to the organisms being tested. Again, ASTM (1998) has published test protocols for acceptable dilution water conditions. These protocols were consulted to determine if toxicity test data were appropriate for use as effects thresholds.

Endpoints

The endpoints considered for selection of acute data were primarily restricted to mortality, immobilization, and larval development. These endpoints are reported as either LC50 (median lethal concentration) or EC50 (median effect concentration) values in the AQUIRE database. For chronic test data, endpoints were based on mortality, reproduction, development, or growth. These results are typically expressed as the no observed effects concentration (NOEC)[2] and lowest observed effects concentration (LOEC)[3], but may also be reported as LC50 or EC50 values.

Species

Data for species from unusual environments (e.g., the Great Salt Lake) were not used to identify effects thresholds.

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[2] The NOEC is the highest tested concentration that did not result in statistically significant effects when compared to the control.

[3] The LOEC is the lowest tested concentration that resulted in statistically significant effects when compared to the control.

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Table 2. Recommended acute and chronic effect thresholds for chemicals with potential to leach from fill soil.

Chemical	Acute/Chronic	Species	Duration (days)	Hardness (mg/L)	Endpoint	Conc. (µg/L)	Recommended Threshold (µg/L)	Reference
Antimony	Chronic	-	-	-	-	-	30^c	USEPA 1988
	Acute	-	-	-	-	-	87.5	USEPA 1988
Barium	Chronic	Daphnia magna (water flea)	2	45	EC50 (Immobilization)	14500	1450^b	Biesinger and Christiansen 1972
	Acute	Daphnia magna (water flea)	2	45	EC50 (Immobilization)	14500	7250^a	Biesinger and Christiansen 1972
Beryllium	Chronic	Daphnia magna (water flea)	21	100	Chronic Value (Reproduction)	51	51	Buikema 1986
	Acute	Caenorhabditis elegans (nematode)	4	-	LC50	140	70^a	Williams and Dusenbery 1990
Silver	Chronic	-	-	-	-	-	0.12^c	USEPA 1987
	Acute	-	-	50	-	-	1.0	WAC 173-201A
Thallium	Chronic	Gastrophryne carolinensis (toad)	7	-	LC50	110	55^a	Birge 1978
	Acute	Daphnia magna (water flea)	4	-	LC50	905	453^a	Kimball 1978

[a] LC50 divided by two to estimate low effect concentration.

[b] Acute EC50 divided by generic ACR of 10.

[c] Proposed USEPA water quality criterion.

LC50 = Median lethal concentration

EC50 = Median effect concentration

Attachment B

Soil Sampling Results

Table B-1
Metal Concentrations In Fill Source Soils (mg/kg)

Source/Sample ID	Date Sampled	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
Black River Quarry															
BRQ-SP-Comp1	10/3/01	0.4 U	1.47	28.2	0.4 U	0.4 U	36.7	97.5	2.35	0.2 U	41.8	0.580	0.4 U	0.4 U	58.8
BRQ-SP-Comp2	10/3/01	0.4 U	1.17	41.3	0.4 U	0.4 U	44.7	115.0	2.21	0.2 U	49.3	0.479	0.4 U	0.4 U	64.5
BRQ-SP-Comp3[2]	10/3/01	0.271	5.20	25.2	0.477	0.063	32.7	107.0	2.82	0.0234	70.5	0.487	0.209	0.127	66.9
BRQ-SP-Comp4	10/3/01	0.5 U	0.866	27.8	0.5 U	0.5 U	42.0	131.0	1.84	0.2 U	42.5	0.555	0.5 U	0.5 U	67.3
BRQ-SP-Comp5	10/3/01	0.5 U	0.839	29.1	0.5 U	0.5 U	18.8	131.0	2.60	0.2 U	45.5	0.554	0.5 U	0.5 U	58.1
BRQ-SP-Comp6[2]	10/3/01	0.267	0.927	27.2	0.609	0.061	46.3	111.0	1.85	0.0290	44.4	0.639	0.242	0.088	57.6
BRQ-S1	2/2/01	--	2.16	46.9	--	0.289	36.3	79.9	4.24	0.1 U	40.3	0.402	0.109	--	90.7
BRQ-S2	2/2/01	--	4.14	51.3	--	0.345	26.5	56.3	5.87	0.1 U	36.7	0.624	0.09 U	--	78.6
BRQ-S3	2/2/01	--	0.953	24.6	--	0.229	34.1	98.0	2.87	0.1 U	39.8	0.455	0.08 U	--	62.4
CTI Pit #3															
CTI Comp 1[2]	6/29/01	0.585	4.37	36.2	0.777	0.067	23.8	24.0	2.82	0.00694	11.8	0.4 U	0.240	0.360	38.8
CTI Comp 2	6/29/01	0.5 U	3.10	31.7	0.5 U	0.3 U	15.1	21.2	2.47	0.2 U	12.3	0.3 U	0.3 U	0.5 U	36.4
CTI Comp 3	6/29/01	0.5 U	2.24	25.7	0.5 U	0.4 U	21.6	13.2	1.70	0.2 U	17.3	0.4 U	0.4 U	0.5 U	26.0
CTI Comp 4	6/29/01	0.5 U	3.09	31.6	0.5 U	0.4 U	22.1	15.9	1.85	0.2 U	15.4	0.4 U	0.4 U	0.5 U	33.6
CTI Comp 5	6/29/01	0.5 U	2.80	27.2	0.5 U	0.4 U	16.7	18.8	1.76	0.2 U	18.7	0.4 U	0.4 U	0.5 U	34.0
CTI Comp 6	6/29/01	0.5 U	2.95	48.1	0.5 U	0.4 U	17.0	36.5	3.20	0.2 U	12.0	0.415	0.4 U	0.5 U	43.9
Kent Kangley Pit															
TP-1 Comp 1[2]	7/3/01	0.528	5.49	96.5	0.846	0.052	28.6	26.5	6.97	0.0706	29.4	0.409	0.320	0.282	65.7
TP-2 Comp 1	7/3/01	0.4 U	6.77	63.0	0.473	0.4 U	31.1	38.8	7.02	0.2 U	46.9	0.4 U	0.4 U	0.4 U	63.3
TP-3 Comp 1	7/3/01	0.5 U	6.36	64.3	0.538	0.4 U	25.2	30.0	6.32	0.2 U	42.1	0.4 U	0.4 U	0.5 U	58.0
Westface Comp 1	7/3/01	0.4 U	6.78	51.9	0.4 U	0.4 U	24.9	35.2	5.51	0.2 U	45.8	0.4 U	0.4 U	0.4 U	48.6
Midface Comp 1	7/3/01	0.4 U	6.51	76.5	0.4 U	0.4 U	31.1	30.2	5.56	0.2 U	33.8	0.458	0.4 U	0.4 U	50.8
Eastface Comp 1[2]	7/3/01	0.525	5.71	54.0	0.614	0.187	30.5	38.6	7.98	0.0484	34.9	0.4 U	0.253	0.212	75.6
KK-S1	2/2/01	--	6.46	55.5	--	0.353	34.0	39.8	5.31	0.1 U	28.8	0.4 U	0.09 U	--	63.3
KK-S2	2/2/01	--	6.20	48.2	--	0.2 U	21.6	49.2	3.42	0.1 U	25.3	0.4 U	0.09 U	--	52.4
KK-S3	2/2/01	--	4.66	50.2	--	0.432	21.0	25.9	4.04	0.1 U	23.5	0.3 U	0.08 U	--	50.3
Lakeland Hills Pit															
LH Comp 1	6/29/01	0.5 U	3.80	65.1	0.5 U	0.4 U	22.3	22.9	3.18	0.2 U	21.7	0.4 U	0.4 U	0.5 U	40.6
LH Comp 2	6/29/01	0.5 U	3.86	75.2	0.5 U	0.4 U	19.4	18.6	3.07	0.2 U	20.1	0.4 U	0.4 U	0.5 U	38.8
LH Comp 3	6/29/01	0.4 U	3.93	59.9	0.4 U	0.3 U	19.7	22.3	2.67	0.2 U	22.0	0.448	0.3 U	0.4 U	38.9
LH Comp 4	6/29/01	0.5 U	3.33	54.1	0.5 U	0.4 U	22.0	20.6	2.67	0.2 U	17.5	0.4 U	0.4 U	0.5 U	34.3
LH Comp 5	6/29/01	0.4 U	4.52	50.3	0.4 U	0.4 U	22.7	20.0	2.96	0.2 U	17.9	0.411	0.4 U	0.4 U	35.4
LH Comp 6[2]	6/29/01	0.608	3.91	63.3	0.613	0.052	22.0	22.7	2.73	0.0228	20.5	0.403	0.190	0.403	37.9
Lincoln-Summit Stockpile															
BRQ-LS-Comp1	10/4/01	0.4 U	2.73	74.5	0.4 U	0.605	36.8	26.4	3.12	0.2 U	41.8	0.4 U	0.4 U	0.4 U	42.7
BRQ-LS-Comp2	10/4/01	0.4 U	3.00	76.9	0.4 U	0.525	36.0	26.7	3.37	0.2 U	41.9	0.4 U	0.4 U	0.4 U	42.6
BRQ LS-Comp3[2]	10/4/01	0.653	3.22	85.1	0.702	0.114	40.3	22.9	4.12	0.0333	45.9	0.4 U	0.319	0.228	44.6
BRQ-LS-Comp4	10/4/01	0.4 U	2.23	63.5	0.4 U	0.451	30.4	17.3	5.29	0.2 U	38.7	0.4 U	0.4 U	0.4 U	34.6
BRQ-LS-Comp5	10/4/01	0.3 U	2.45	59.9	0.3 U	0.433	31.7	15.0	3.55	0.2 U	39.2	0.3 U	0.3 U	0.3 U	33.6
BRQ-LS-Comp6	10/4/01	0.4 U	2.47	64.5	0.4 U	0.4 U	32.4	17.6	4.16	0.2 U	37.4	0.4 U	0.4 U	0.4 U	37.5

Table B-1
Metal Concentrations in Fill Source Soils (mg/kg)

Source/Sample ID	Date Sampled	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
Marine View Pit - Type 1B Soil															
MVP-1B-Comp1[2]	10/4/01	0.378	2.59	60.6	0.553	0.052	25.0	16.8	3.11	0.0110	29.1	0.4 U	0.186	0.185	39.0
MVP-1B-Comp2	10/4/01	0.5 U	2.94	74.6	0.5 U	0.5 U	21.2	16.0	2.36	0.2 U	24.6	0.5 U	0.5 U	0.5 U	31.8
MVP-1B-Comp3	10/4/01	0.4 U	2.88	55.1	0.4 U	0.4 U	28.9	12.5	2.19	0.2 U	31.8	0.4 U	0.4 U	0.4 U	33.7
MVP-1B-Comp4	10/4/01	0.4 U	1.36	59.6	0.4 U	0.748	25.1	13.4	2.20	0.2 U	27.9	0.4 U	0.4 U	0.4 U	34.9
MVP-1B-Comp5	10/4/01	0.4 U	2.30	47.7	0.4 U	0.783	26.0	13.2	2.04	0.2 U	27.2	0.4 U	0.4 U	0.4 U	33.7
MVP-1B-Comp6	10/4/01	0.3 U	2.48	57.5	0.340	0.818	23.5	19.1	5.00	0.2 U	27.5	0.3 U	0.3 U	0.3 U	40.0
Marine View Pit - Type 2 Soil															
MVP-Comp1	10/3/01	0.5 U	1.83	92.7	0.5 U	0.5 U	20.9	24.5	4.36	0.2 U	12.0	0.5 U	0.5 U	0.5 U	36.8
MVP-Comp2	10/3/01	0.4 U	1.73	128	0.583	0.4 U	21.7	25.2	5.52	0.2 U	12.8	0.4 U	0.4 U	0.4 U	38.8
MVP-Comp3	10/3/01	0.5 U	1.40	163	1.01	0.5 U	30.0	20.1	6.58	0.2 U	17.7	0.5 U	0.5 U	0.5 U	27.6
MVP-Comp4	10/3/01	0.5 U	1.82	89.5	0.5 U	0.5 U	21.5	25.8	4.46	0.2 U	13.0	0.5 U	0.5 U	0.5 U	36.2
MVP-Comp5	10/3/01	0.4 U	1.80	92.4	0.602	0.4 U	19.3	27.3	5.10	0.2 U	11.6	0.4 U	0.4 U	0.4 U	38.3
MVP-Comp6	10/3/01	0.3 U	1.87	96.8	0.572	0.3 U	22.7	24.7	4.98	0.2 U	12.2	0.3 U	0.3 U	0.3 U	35.9
Port Borrow Areas															
BA1-S2	2/2/01	--	10.1	88.0	--	0.585	27.3	17.8	19.8	0.18	26.5	0.4 U	0.109	--	75.1
BA3-S1	2/2/01	--	9.34	54.0	--	0.442	21.5	11.4	5.45	0.1 U	25.5	0.4 U	0.09 U	--	31.9
BA4-S1	2/2/01	--	3.40	99.4	--	0.343	29.7	15.0	6.95	0.1 U	31.5	0.3 U	0.08 U	--	37.5
BA4-S2	2/2/01	--	2.23	58.2	--	0.3 U	35.4	13.5	3.28	0.1 U	30.1	0.4 U	0.1 U	--	29.4
Segale and Dupont															
Composite 1	10/4/01	0.3 U	2.15	46.4	0.3 U	0.447	31.0	16.2	2.11	0.2 U	18.7	0.3 U	0.3 U	0.3 U	29.3
Composite 2	10/4/01	0.4 U	2.92	37.1	0.4 U	0.592	17.0	19.3	2.49	0.2 U	16.2	0.4 U	0.4 U	0.4 U	39.1
Composite 3	10/4/01	0.3 U	2.10	39.0	0.3 U	0.403	16.2	20.2	2.59	0.2 U	14.1	0.3 U	0.3 U	0.3 U	30.2
Composite 4	10/4/01	0.3 U	2.10	44.5	0.3 U	0.556	18.2	18.6	2.12	0.2 U	19.3	0.3 U	0.3 U	0.3 U	35.6
Composite 5	10/4/01	0.4 U	3.18	43.8	0.4 U	0.520	16.9	21.2	2.78	0.2 U	17.1	0.4 U	0.4 U	0.4 U	35.9
Composite 6	10/4/01	0.3 U	2.51	52.9	0.3 U	0.3 U	20.3	19.3	2.75	0.2 U	19.0	0.3 U	0.3 U	0.3 U	36.5

Notes:

1) Unless otherwise noted, laboratory analyses were performed by North Creek Analytical, Bothell, WA.

2) Laboratory analyses for antimony, beryllium, cadmium, mercury, silver and thallium performed by Frontier Geosciences, Seattle, WA.

U Not detected; value given is reporting limit

-- Not analyzed

Table B-2
Soil Testing Results for Hamm Creek Fill Source (µg/kg)

Compound	Station Number	
	C1	C2
Total DDT	14	11.3
4,4'-DDE	3.7	2.9
4,4'-DDD	6.7	5.3
4,4'-DDT	3.6	3.1
Lindane	0.52 U	0.55 U
Heptachlor	0.52 U	0.55 U
Aldrin	2.4	1.3
Dieldrin	6.1	6
Chlordane	4.4	1.5
Arochlor 1016	8.6 U	9.2 U
Arochlor 1221	34 U	37 U
Arochlor 1232	8.6 U	9.2 U
Arochlor 1242	8.6 U	9.2 U
Arochlor 1248	8.6 U	9.2 U
Arochlor 1254	160	76
Arochlor 1260	8.6 U	9.2 U
Total PCBs	160	76

Notes:

1) Samples C1 and C2 are from the US Corp of Engineers Hamm Creek Restoration Project.
2) C1 Collected 16-Jun-97, Lab Number 97-A008101
3) C2 Collected 16-Jun-97, Lab Number 97-A008102

U Not detected

Table B-3
Maximum TPH Concentrations Detected in First Avenue Bridge and Black River Quarry Fills (mg/kg)

Location/Sample ID	Date Sampled	TPH-D	TPH-O
Black River Quarry			
S-4	9/29/00	10 U	270
S-4	10/2/00	10 U	230
First Avenue Bridge			
001 WSDOT	10/01/99	29 U	99
002 WSDOT	10/01/99	27 U	73
004 WSDOT	10/01/99	26 U	85

Notes:

U Not detected

Table B-4
Adsorption Capacity of Soil Samples

Sample	Extractable Oxides[a]		Cation Exchange Capacity[a]	Clay Mineralogy[b]		Total Organic Carbon[a]
	Iron mg/kg	Aluminum mg/kg	mEq/kg	Major	Minor	wt %
3RWS1,13,14,15, Composite	4,440	623	77	montmorillonite, kaolinite		0.08
A4-TP1,2,3 Composite	9,990	1,680	216	kaolinite, montmorillonite	montmorillonite, muscovite or illite	0.11
BRQ-LS-Comp 3	6,560	1,270	152	kaolinite, montmorillonite		0.22
BRQ-SP-Comp 2	12,100	1,900	241	montmorillonite	celadonite/illite or kaolinite	0.19
CTI Comp 6	7,610	853	122	montmorillonite	kaolinite, illite or muscovite	ND
LH Comp 5	10,300	1,690	191	montmorillonite, kaolinite, illite		0.08
MVP-1B-Comp 1	9,510	1,210	190		montmorillonite, muscovite or illite	0.09
MVP-Comp 3	10,300	2,060	398	poor crystallinity	montmorillonite, illite	0.17
TP-2 Comp 1	6,080	2,710	93	montmorillonite, kaolinite		0.39

Notes:
1) Laboratory analyses performed by Columbia Analytical Services, Kelso, WA.
2) X-ray diffraction and electron microprobe analyses performed by Rosa Environmental and Geotechnical Laboratory, Seattle, WA.

ND Not detected

Attachment C

SPLP Testing and Development of Site-Specific Partitioning Coefficients

Development of Site-Specific Soil-Water Partition Coefficients for Metals

Soil-water partition coefficients (K_d) for the metals antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc were determined for specific source areas being used for the embankment fill. For each metal, K_d values (L/kg) were determined according to

$$K_d = C_S/C_{SPLP}$$

where C_S is the metal concentration in a sample (mg/kg) and C_{SPLP} is the metal concentration in the SPLP leachate of the same sample (mg/L, as determined by EPA Method 1312). Soil metal concentrations are summarized in Table B-1, and SPLP test results are summarized in Table C-1. K_d values for each metal were computed using data from samples in which the metal was present at a concentration above the detection limit. Additionally, in cases where the leachate concentration was below the detection limit for the metal, a leachate concentration of one-half the detection limit was assumed for computation of the K_d value. Ranges and geometric mean values of K_d for the thirteen metals in general embankment and Type 1 fill materials are presented in Table C-2.

Justification of Site-Specific Metals K_d Values

The metal soil-water partition coefficients tabulated in Table C-2 are high in comparison to ranges of K_d for these metals in contaminated soils (USEPA, 1996; 1999). The explanation for the apparent disparity in metal K_d values between the present study and those published by USEPA lies in the nature and objectives of the studies.

The so-called 'default' K_d values adopted for purposes of evaluating health risks from soils at contaminated sites are largely based on the USEPA Soil Screening Guidance (USEPA, 1996). These values were developed based on (1) compilations of published K_d values in the scientific literature, and (2) values derived from chemical reaction computer models based on adsorption equilibrium. For the most part, the experimental procedures for determination of metal partitioning coefficients for these purposes generally involve bringing a sample of the soil in contact with an aqueous solution containing the metal of interest at a known concentration and measuring the amount removed from the solution after some time has been allowed for equilibration. Similarly, K_d values derived from modeling using equilibrium speciation codes such as MINTEQA2 generally assume that the metal is distributed between chemical species dissolved in water and species that are adsorbed on the surfaces of specific soil particles such as iron and aluminum hydroxides, clay minerals and organic matter.

Although this approach to determining K_d values may be conceptually valid for evaluating behavior and transport of metals in soils where the metals have been introduced as pollutants, it would be conceptually incorrect to adopt such a conceptual model for the case of the embankment fill materials. Metals occur naturally in soils at trace level concentrations similar to those observed in the fill soils (Alloway, 1990). Metals at these low concentrations are likely to bound as trace impurities in detrital mineral grains, such as feldspars and micas derived from erosion and weathering of rocks. Mineral grains such as these that are based on silicate chemical structure are very resistant to leaching and dissolution by water. This also effectively limits the leachability of the naturally occurring trace metals present in these grains. The low SPLP leachate concentrations observed for the fill soils (Table C-1) and resulting high site-specific K_d values are consistent with this hypothesis.

References Cited

Alloway, B.J., 1990. *Heavy Metals in Soils*. Halsted, 339 pp.

USEPA, 1996. Soil Screening Guidance: Technical Background Document. U.S. Environmental Protection Agency, EPA/540/R95/128.

USEPA, 1999. Understanding variation in partition coefficient K_d values, Volume II: Review of geochemistry and available K_d values for cadmium, cesium, chromium, lead, plutonium, radon, strontium, thorium, tritium, and uranium. U.S. Environmental Protection Agency, EPA 401-R-99-004B.

Table C-1
SPLP Metals Results for Fill Source Soil Samples (mg/L)

Source/Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
First Round (February 2001)														
Black River Quarry Pit														
BRQ-S1	--	0.00672	0.0071	--	0.0005 U	0.00283	0.00310 B	0.00051	0.001 U	0.00171	0.0005 U	0.0005 U	--	0.0342
BRQ-S2	--	0.00080	0.0130	--	0.0005 U	0.0207	0.00427 B	0.0005 U	0.001 U	0.00137	0.00072	0.0005 U	--	0.01 U
BRQ-S3	--	0.00536	0.0077	--	0.0005 U	0.00484	0.00867 B	0.00068	0.001 U	0.00384	0.0005 U	0.0005 U	--	0.0102
Kent Kangley Pit														
KK-S1	--	0.0005 U	0.005 U	--	0.0005 U	0.00084	0.00083 B	0.0005 U	0.001 U	0.0005 U	0.0005 U	0.0005 U	--	0.01 U
KK-S2	--	0.0005 U	0.005 U	--	0.0005 U	0.00085	0.00066 B	0.0005 U	0.001 U	0.00053	0.0005 U	0.0005 U	--	0.01 U
KK-S3	--	0.0005 U	0.0052	--	0.0005 U	0.00071	0.00083 B	0.0005 U	0.001 U	0.00053	0.0005 U	0.0005 U	--	0.01 U
Port Borrow Areas														
BA1-S2	--	0.00239	0.0161	--	0.0005 U	0.00353	0.00372 B	0.00912	0.001 U	0.00334	0.0005 U	0.0005 U	--	0.0131
BA3-S1	--	0.00584	0.0140	--	0.0005 U	0.00384	0.00372 B	0.00259	0.001 U	0.00346	0.0005 U	0.0005 U	--	0.01 U
BA4-S1	--	0.00083	0.0211	--	0.0005 U	0.00398	0.00332 B	0.00104	0.001 U	0.00434	0.0005 U	0.00159	--	0.01 U
BA4-S2	--	0.00079	0.0241	--	0.0005 U	0.00736	0.00365 B	0.00056	0.001 U	0.00643	0.0005 U	0.0005 U	--	0.01 U
Second Round (November 2001)														
Black River Quarry Pit														
BRQ-SP-Comp1	--	--	--	--	--	--	0.05 U	--	--	--	--	--	--	--
BRQ-SP-Comp2	--	--	--	--	--	0.05 U	0.05 U	--	--	0.05 U	--	--	--	--
BRQ-SP-Comp3[2]	0.000782	--	--	0.0000154	0.0000278	--	0.05 U	--	0.00000791	0.05 U	--	0.0000198	0.0000056	--
BRQ-SP-Comp4	--	--	--	--	--	--	0.05 U	--	--	--	--	--	--	--
BRQ-SP-Comp5	--	--	--	--	--	--	0.05 U	--	--	--	--	--	--	--
BRQ-SP-Comp6[2]	0.0000246	--	--	0.0000137	0.0000084	0.05 U	0.05 U	--	0.00000867	--	--	0.0000054	0.0000019	--
CTI Pit #3														
CTI Comp 6[2]	0.0000172	--	--	0.0000215	0.0000145	--	0.05 U	--	0.00000521	--	--	0.0000044	0.0000007	--
Kent Kangley Pit														
TP1-Comp1[2]	0.0000027 U	0.05 U	0.5 U	0.0000058 U	0.0000061 U	0.05 U	0.05 U	0.05 U	0.00000029	0.05 U	0.05 U	0.0000006 U	0.0000018	0.5 U
TP2-Comp2	0.05 U	0.05 U	0.5 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.001 U	0.05 U	0.05 U	0.05 U	0.05 U	0.5 U
TP3-Comp3	0.05 U	0.05 U	0.5 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.001 U	0.05 U	0.05 U	0.05 U	0.05 U	0.5 U
Westface Comp1	0.05 U	0.05 U	0.5 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.001 U	0.05 U	0.05 U	0.05 U	0.05 U	0.5 U
Midface Comp1	0.05 U	0.05 U	0.5 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.001 U	0.05 U	0.05 U	0.05 U	0.05 U	0.5 U
Eastface Comp1[2]	0.000010	0.05 U	0.5 U	0.0000058 U	0.0000061 U	0.05 U	0.05 U	0.05 U	0.00000039	0.05 U	0.05 U	0.0000038	0.0000049	0.5 U
Lakeland Hills Pit														
LH Comp6[2]	0.0000278	--	--	0.000160	0.0000671	--	--	--	0.0000688	--	--	0.0000109	0.0000112	--
Lincoln-Summit Stockpile														
BRQ-LS-Comp3[2]	0.000463	--	--	0.0000058 U	0.0000061 U	--	--	--	0.00000284	0.05 U	--	0.0000006	0.0000285	--
Marine View Pit (Type 2 Soil)														
MVP-Comp3	--	--	--	0.05 U	--	--	--	--	--	--	--	--	--	--
MVP-Comp5	--	--	--	0.05 U	--	--	--	--	--	--	--	--	--	--
Marine View Pit (Type 1B Soil)														
MVP-1B-Comp1[2]	0.0000179	--	--	0.0000295	0.0000194	--	--	--	0.0000272	--	--	0.0000052	0.0000007	--

Notes:

1) Unless otherwise noted, laboratory analyses for first and second rounds performed by North Creek Analytical, Bothell, WA.

2) SPLP and laboratory analyses for antimony, beryllium, cadmium, mercury, silver and thallium for selected second round samples were performed by Frontier Geosciences, Seattle, WA

-- Not analyzed

U Not detected, value given is reporting limit

B Analyte was detected in laboratory blank; reported value biased high

Table C-2
Summary of Site-Specific Metal K_d's (L/kg)

Metal	General Embankment Fill				Type 1 Fill[a]			
	Geometric Mean	Minimum	Maximum	n[b]	Geometric Mean	Minimum	Maximum	n[b]
Antimony	5,240	347	34,000	5	74,800	21,100	377,000	3
Arsenic	1,570	178	5,160	7	22,900	18,600	25,800	3
Beryllium	34,100	3,830	242,000	5	105,000	18,700	292,000	3
Cadmium	4,650	775	36,800	5	14,900	2,680	60,300	3
Chromium	5,630	1,280	12,800	7	31,200	25,300	40,700	3
Copper	7,130	3,060	25,800	7	48,100	31,100	74,500	3
Lead	6,610	3,390	23,500	7	16,700	13,700	21,200	3
Mercury	2,200	331	11,700	5	23,000	404	244,000	3
Nickel	10,400	4,680	26,800	7	62,300	44,200	115,000	3
Selenium	1,400	870	1,800	3	--[c]	--[c]	--[c]	0
Silver	54,400	10,600	1,060,000	5	136,000	35,800	1,070,000	3
Thallium	43,500	8,000	514,000	5	121,000	43,000	264,000	3
Zinc	9,420	2,650	31,400	7	22,000	20,100	25,300	3

Notes:

1) K_d values for each metal were obtained by dividing the soil concentration (data in Table B-1) by the SPLP leachate concentration (data in Table
2) For a given metal, only data from samples with soil concentrations above the detection limit were used.
3) For samples with SPLP results below detection limits, a leachate concentration of one half the reporting limit was assumed.
4) Second round SPLP test results reported by North Creek Analytical were not used in developing K_d values, due to elevated detection limits associated with the the laboratory analyses.

a) Includes drain layer, drain layer cover, and embankment face material
b) Number of samples used to calculate mean value
c) Not calculated (Not analyzed in SPLP tests and/or not detected in any soil samples)