ANCHOR QEA
6650 SW Redwood Lane, Suite 333
Portland, Oregon 97224
Phone 503.670.1108
www.anchorqea.com

NEWFIELDS
730 17th St, Suite 925
Denver, CO 80202
Phone 303.294.0950
www.newfields.com

DRAFT TECHNICAL MEMORANDUM

To:	Sean Sheldrake, USEPA	**Date:**	June 18, 2010
From:	Pete Townsend, NewFields Todd Thornburg, Anchor QEA	**Project:**	050332-01
Cc:	Kelly Madalinski, Port of Portland Krista Koehl, Port of Portland		
Re:	Long-Term Groundwater Modeling Results Memorandum Port of Portland Terminal 4 Confined Disposal Facility		

INTRODUCTION

This memorandum presents the results of groundwater modeling for the Terminal 4 confined disposal facility (T4 CDF). Modeling was performed to estimate groundwater chemical concentrations exiting the T4 CDF for evaluation of long-term protection of water quality in the Willamette River.

This memorandum is organized as follows:

- Modeling Approach
- Model Design and Setup
- Model Input Parameters
- Model Calibration
- Model Results and Predictions
- Conclusions

MODELING APPROACH

Visual Modflow (Version 2009.1, Pro.Build: 4.4.0.156; Waterloo Hydrogeologic, Inc.) was used for model construction, execution, and visualization. All groundwater flow simulations were performed with MODFLOW-2000 (Harbaugh et al. 2000). MODFLOW-2000 is a

three-dimensional, block centered finite difference code capable of simulating steady-state and transient flow conditions. MODFLOW-2000 can simulate time-varying boundary conditions and heterogeneous aquifer properties.

Contaminant transport simulations were performed with MT3DMS (Zheng and Wang 1999). MT3DMS uses the flow solution provided by MODFLOW-2000. MT3DMS can simulate changes in concentrations of miscible contaminants in groundwater considering advection, dispersion, diffusion, and some basic chemical reactions, including biodegradation, with various types of boundary conditions and external sources or sinks. This approach is consistent with previous modeling work on the T4 CDF, which also used versions of MODFLOW and MT3D, including modeling work performed as part of the previous 60 Percent Design (Anchor 2006) and Engineering Evaluation/Cost Analysis (EE/CA; BBL 2005).

The MODFLOW/MT3DMS model simulates leaching of chemicals from contaminated dredged sediment placed in the CDF, and subsequent transport of chemicals through the CDF, the underlying aquifer, and the berm, toward the Willamette River. The following contaminant transport and attenuation processes are included in the model:

- Groundwater advection and dispersion
- Mixing of leachate with incident rainfall above and regional groundwater below
- Adsorption and desorption of contaminants onto berm and aquifer matrix materials
- Biodegradation of contaminants

MODEL DESIGN AND SETUP

This section provides a brief review of site hydrogeology and a description of the model structure, grid design, boundary conditions, and simulation period.

Site Hydrogeology

The T4 hydrogeology is summarized in Appendix D of the EE/CA report and presented in detail in the T4 characterization report (BBL 2004). BBL (2005) summarized the geologic stratigraphy adjacent to and beneath the proposed CDF; the stratigraphy consists of the following:

- Upland fill material, consisting of medium to fine sand ranging in thickness from about 5 to 40 feet
- Unconsolidated Alluvial Deposits, consisting of fine sand west of the former shoreline, and interbedded layers of gravel, sand, silt, and clay to the east of the former shoreline, ranging in thickness from 120 to 160 feet
- Troutdale Gravel, encountered at an elevation of approximately -114 to -168 feet Columbia River Datum (CRD)

The regional groundwater flow direction is toward the Willamette River. In nearshore locations, groundwater in the upland fill material and the Unconsolidated Alluvial Deposits is in direct hydraulic connection with the river, and groundwater elevations respond to changes in river stage. The alignment of the CDF is coincident with the general groundwater flow direction.

Model Structure

To estimate concentrations of groundwater chemicals of concern (COCs) at the outer edge of the CDF berm, a two-dimensional (2-D) cross-sectional model was aligned with the critical groundwater flow path through the center of the CDF. The 2-D model structure is shown on Figure 1. The key hydrologic units of the 2-D model include:

- Berm Fill (import sand and gravel comprising the core of the CDF berm)
- Training Dikes (quarry spalls comprising the outer walls of the berm)
- Sediment Fill (contaminated dredged material from Portland Harbor, and the source of contaminants through leaching)
- Imported Fill (imported cover material comprising the unsaturated zone above the Sediment Fill, with physical/chemical characteristics similar to the Berm Fill)
- Aquifer (existing strata at T4 below and adjacent to the CDF; predominantly sand with interbedded silt and clay layers associated with undifferentiated upland fill and Unconsolidated Alluvial Deposits).

Model Grid Design

Figure 1B shows the model grid. The model domain extends 900 feet along the centerline of the CDF. Vertically, the model extends from elevation -65 to +32 feet National

Geodetic Vertical Datum (NGVD). The bottom of the CDF (i.e., the top of the Aquifer) is at elevation -35 feet NGVD, and the top of the CDF (i.e., the base of the Imported Fill) is at elevation +9.5 feet NGVD. The model is discretized into 278 columns and 61 layers. Layer thicknesses range from approximately 1 to 5 feet. Column widths range from approximately 2 to 8 feet. The finest grid spacing is placed over the contact between the contaminated sediment and the berm material, because there are steep gradients in both physical properties (e.g., permeability) and geochemical properties (e.g., partitioning coefficients, leaching potential) across this interface.

Boundary Conditions

The hydrologic boundary conditions are shown on Figure 1C. The Willamette River is represented by constant head cells. River stage information was obtained from the U.S. Geological Survey National Streamflow Information Program, station number 14211720 (Morrison Bridge in Portland, Oregon). Statistics for the stream gage are as follows:

- Mean annual elevation = 7.4 feet NGVD
- Mean monthly low elevation (September) = 4.5 feet NGVD
- 10-year monthly low elevation = 3.8 feet NGVD (based on p = 0.1)

Transient river stages were used in model calibration. The transient boundary is comprised of both seasonal and diurnal tidal fluctuations. Figure 2 shows the superposition of the mean daily river stage (i.e., the mean annual hydrograph) and a typical diurnal tidal cycle.

The head of the CDF is represented by constant head cells. Average groundwater elevations in this area are based on measurements from monitoring wells MW-09 and MW-10 (BBL 2005). A mean annual water level elevation (13.3 feet NGVD) was calculated from measurements between September 2004 and September 2005.

A “no-flow” condition was specified along the upriver and downriver boundaries of the modeling domain (i.e., the sides of the 2-D cross section), since these boundaries are aligned parallel to the groundwater flow direction.

Recharge through the Import Fill is a function of annual precipitation, evaporation, transpiration, ground slope, and grain size of the soils. Man-made surface structures, such as roads, pavement, buildings, and drainage systems, also affect recharge. BBL (2005) used the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1994) to estimate recharge rates at 22.3 and 0.92 inches per year (in/year) for unpaved and paved conditions, respectively. The current model simulations assume an unpaved condition.

Regarding the geochemical boundary conditions, the upstream groundwater concentrations in the regional aquifer and the concentrations in the recharge water are assumed to be zero. The source concentrations in the contaminated sediment fill are initialized based on leaching test results (see the Groundwater Model Input Parameter Memorandum; Anchor QEA and NewFields 2010), then the source concentrations decrease as contaminants are released over time. For most of the hydrophobic COCs being evaluated in the absence of biodegradation, however, the contaminant reduction rates are so slow that the contaminated sediment fill essentially behaves as an infinite source over the design period of the CDF.

Simulation Period

Groundwater model simulations were run for a minimum of 475 years, except for the model simulation involving naphthalene, which peaked and declined much more quickly than the other constituents (see Model Results and Predictions, below). The 475-year simulation period coincides with the longest applicable engineering design standard being applied to the CDF. The design seismic event, corresponding to a 10 percent probability of exceedance in 50 years, or a return period of 475 years, is the longest applicable design standard. Selection of a 475-year simulation period, therefore, reflects consistency between the physical design life of the CDF (e.g., its hydrodynamic or geotechnical stability) and the chemical isolation life of the CDF. For most COCs, model simulations were extended to periods of 1,000 years for informational purposes, to better characterize the shape of the prediction curves.

MODEL INPUT PARAMETERS

Groundwater model input parameters, including COCs, physical and hydraulic properties of CDF building materials, leachate concentrations in the contaminated sediment, chemical partitioning coefficients, and biodegradation rates, are summarized in this section (see Tables 1 and 2). A more detailed discussion of model input parameters and supporting rationale is presented in the Groundwater Model Input Parameter Memorandum.

Constituents of Concern

The following COCs were evaluated in the model:

- Copper
- Naphthalene
- Benzo(a)pyrene
- DDx (sum of DDT, DDD, and DDE)
- Total polychlorinated biphenyls (PCBs)
- PCB-126

Material and Hydraulic Properties

Material and hydraulic properties were established for the CDF building materials, including the Sediment Fill (contaminated dredged sediment from Portland Harbor), Imported Fill (cover material), Berm Fill (sand and gravel), and Training Dikes (quarry spalls), as well as the surrounding Aquifer material (alluvial sand and silt). Material and hydraulic input parameters, and their supporting data and rationale, are summarized in Table 1.

Geochemical Properties

Geochemical input parameters (source concentrations, partitioning coefficients, and biodegradation rates), and their supporting data and rationale, are summarized in Table 2 and discussed below.

Initial Leachate Concentrations. Sequential batch leachate test (SBLT) data from Portland Harbor provide an estimate of the porewater concentrations that are expected to equilibrate with contaminated sediments in the T4 CDF. These data are used to initialize

the source concentrations in the CDF. The source concentrations represent the potential for COCs to be mobilized in groundwater as the COCs move through the CDF (undergoing fate and transport processes) toward the river. The geometric mean, arithmetic mean, and 90th percentile leachate concentrations from Portland Harbor SBLT results (excluding leachate results from areas of potential concern [AOPCs] 9 and 14; see Attachment A of the Groundwater Model Input Parameter Memorandum) provide the minimum, average, and maximum source concentrations, respectively, for setting the initial conditions in the long-term groundwater model. The initial source concentrations for the various groundwater COCs are compiled in Table 2.

Initial Concentrations in Other Materials. The initial concentrations in the Aquifer, Imported Fill, and Berm Fill are assumed to be zero.

Partitioning Coefficients in Dredged Sediment. The ratio of the bulk sediment concentration to the SBLT leachate concentration is used to develop site-specific partitioning coefficients for contaminated sediment placed in the CDF. The partitioning coefficient describes how readily contaminants are desorbed from the sediments, dissolved in groundwater, and made available for transport through the CDF. The derivation of partitioning coefficients from SBLT tests on bulk sediment from Portland Harbor AOPCs is presented in Attachment A of the Groundwater Model Input Parameter Memorandum. Geometric mean partitioning coefficients for the various groundwater COCs are compiled in Table 2.

Partitioning Coefficients in Berm. The physical properties, source characteristics, and thermodynamic conditions in the berm are fundamentally different from those in the contaminated sediment fill material. Applicable partitioning coefficients for metals in the berm were established in NewFields and Anchor (2007). Partitioning coefficients for organic constituents in the berm are adopted from the Lower Willamette Group (LWG) Remedial Investigation Report (LWG 2009, Table E6); these are the same partitioning coefficients proposed for use in the QEA-FATE model for the Portland Harbor Superfund site.

Biodegradation Rates. Published biodegradation rates were compiled and evaluated for use in the T4 CDF model. It is expected that anaerobic degradation processes will prevail in the confined contaminated sediments, whereas aerobic degradation processes will be more important in the berm. For all constituents, zero degradation was evaluated as a worst-case scenario. The long-term model evaluation also includes a scenario with a conservatively protective biodegradation rate from the lower end of published literature values, (i.e., slow rates), with particular emphasis on field studies. Because of the long time period of the model simulations (475 years), biodegradation is likely to be an important process for contaminant attenuation in the CDF (USACE 1996; M. Palermo pers. comm. 2010). Selected biodegradation rates (expressed as half lives, in days) are presented in Table 2, along with supporting literature citations.

Evaluation Criteria

Risk-Based Criteria. Model predicted concentrations in groundwater are compared to the following risk-based criteria (see Table 3):

- Chronic Water Quality Criteria (WQC)
- Fish Consumption Criteria
- Drinking Water Maximum Contaminant Levels (MCLs)

The chronic WQC for copper, DDx, and Total PCBs are from Oregon Table 33A (ODEQ 2005), which is also consistent with the U.S. Environmental Protection Agency (USEPA) National Recommended Water Quality Criteria (USEPA 2010); the chronic criteria for naphthalene and benzo(a)pyrene are from USEPA guidance (USEPA 2003). Human health criteria for fish consumption are from the National Recommended Water Quality Criteria (USEPA 2010). Human health criteria for drinking water are the USEPA MCLs (USEPA 2009a). Human health criteria (both fish consumption and drinking water criteria) for the congener PCB-126 are derived from the criteria for 2,3,7,8-TCDD (dioxin) and a toxicity equivalency factor of 0.1 (USEPA 2009b). There is no chronic criterion for PCB-126.

Background and Technology Limits. In addition to risk-based criteria, upstream background concentrations and analytical reporting limits were also considered in the evaluation, because it is impracticable to control groundwater concentrations below the

ambient upstream concentrations in the river, and compliance decisions cannot reliably be made at concentrations below the limits of analytical technology. High-volume surface water samples were used to define upstream background water quality (LWG 2009, Table 7.4-4). Analytical reporting limits were derived from the Quality Assurance Project Plan for the Round 3A stormwater sampling event based on standard sample volumes (LWG 2007).

Observation Points. Model observation points were selected to characterize model output concentrations at designated locations along the berm face where groundwater exits to the river. Three observation points were considered in this evaluation:

- Peak "centerline" concentrations within surficial CDF berm material
- Spatially averaged concentrations within surficial CDF berm material
- Spatially averaged concentrations in receiving water near point of discharge

Model output concentrations for the observation points within the CDF berm are derived from the last tier of cells in the model adjacent to the river boundary. The CDF berm observation points do not include the riprap layer placed on the outside face of the berm. Because the width and thickness of the terminal model cells are approximately 2 feet, and the reported concentrations represent the average concentration for the entire cell, the mid-point of the observation is located about 1 foot below the berm face (excluding the riprap layer).

The centerline concentration is the peak concentration in the last tier of cells fronting the river. The spatially averaged concentration is the arithmetic mean concentration in all cells along the 2-D cross-section of the berm interface, from elevation -35 feet NGVD (base of the CDF) to elevation +7.4 feet NGVD (mean river stage). No averaging was performed parallel to the river because a 2-D model assumes a uniform concentration distribution in the upstream to downstream direction (i.e., in the third dimension).

For Total PCBs and DDx, an additional observation point 10 centimeters (cm) above the berm face was modeled to characterize the degree of mixing in the receiving water immediately after groundwater exits the berm. Such an observation point might

represent, for example, the quality of the interstitial water in a riprap armor layer placed over the berm face, which includes a significant amount of mixing with river water.

MODEL CALIBRATION

The seasonal and tidal variations in the Willamette River stage result in river water moving into and out of the berm during high and low tides, and during seasonal high and low river stages, respectively. These periodic reversals in groundwater flow direction will enhance the mechanical mixing of groundwater in the berm. Following the USEPA-approved model calibration procedure for the T4 CDF (NewFields 2007a), the effect of a transient river boundary will be approximated using an effective dispersion factor in the transport simulations. The calibration of effective dispersion was updated to match the current model structure and hydraulic conductivity values of the hydrogeologic units. The use of a calibrated effective dispersion value in a steady-state flow field greatly simplifies the modeling calculations, whereas the computational time required to simulate a transient boundary with twice-daily tides for 475 years is unmanageable.

To calibrate the effective dispersion, a transport simulation is performed using a transient flow field and transient boundary at the Willamette River. The transient boundary consists of the average annual hydrograph (compilation of mean daily river stages) superimposed with typical diurnal tidal variations, as shown in Figure 2. A conservative (non-attenuating and non-reactive) contaminant source is assigned to the Sediment Fill at concentration of 1 (i.e., 100 percent). Dispersivity is set to a small value (2.0 feet) over the entire model domain. The transient model is then run until peak concentrations are observed at the berm-river interface. To finalize the calibration process, the model is run again using a steady-state flow field with the same conservative contaminant source. A constant head boundary condition is assigned at the river boundary, represented by the long-term average river stage (7.44 feet). Dispersivity for the berm materials is then adjusted (calibrated) in the steady-state flow field case until the peak concentrations match the transient case.

Figure 3 shows the arrival curve for the conservative tracer for the transient model, with centerline concentrations ranging from 0.02 and 0.12 (2 to 12 percent of the source concentration) after arrival of the tracer at the river interface. The long-term average concentration from the transient model (0.08, or 8 percent) provides the target concentration

for estimating the effective dispersivity in the steady-state model. As shown in Figure 3, increasing dispersivity results in earlier arrival times and smaller peak concentrations. A dispersivity factor of 6.5 feet provided the best approximation of the long-term average concentration in the transient model. It should be noted that the steady-state approximation of the transient boundary condition generates an arrival curve that is accelerated by about a factor of two (i.e., arriving in about 200 days in the steady-state simulation compared to 400 days in the transient simulation). In this respect, the use of a steady-state approximation is conservative (i.e., protective).

MODEL RESULTS AND PREDICTIONS

Groundwater Flow and Residence Time in the CDF

Groundwater transport pathways and residence times in the contaminated sediments are shown on Figure 4. Transport pathways are dominated by downward vertical flow through the contaminated sediment toward the underlying aquifer and laterally into the berm. This results from mounding of infiltrated rainwater at the contact between the Sediment Fill and the Imported Fill, near elevation +9.5 feet NGVD. Once groundwater leaves the CDF, it flows horizontally toward the river in the underlying aquifer, and then upwells into the berm and training dikes along the contact with the contaminated sediments.

The groundwater residence time in the contaminated sediments varies from less than 20 years along the front and bottom of the CDF, to greater than 200 years at the upper rear of the CDF (Figure 4). As a result, contaminated sediments in the upper rear of the CDF are likely to have less effect on groundwater exit concentrations.

Long-Term Groundwater Quality

Figures 5A through 5F present the predicted groundwater exit concentrations for copper, naphthalene, benzo(a)pyrene, DDx, Total PCBs, and PCB-126, respectively. These charts show the model prediction curves for the 475-year design period; in all cases but naphthalene, the model simulation period was projected out to 1,000 years to better define the shape of the concentration trends. Prediction curves are presented for the peak centerline concentration, as well as the spatially averaged concentration for the last row of cells in the berm. For DDx and Total PCBs, an additional observation point 10 cm

above the berm face was modeled to characterize incipient mixing in the receiving water immediately after groundwater exits the berm (see Figures 5D and 5E). Such an observation point might represent, for example, the quality of the interstitial water in a riprap armor layer placed over the berm face, which includes a significant amount of mixing with river water.

Initial leachate concentrations are plotted on the charts, along with chronic WQC, maximum contaminant levels (MCLs), and fish consumption criteria, as appropriate. In addition, the region at or below analytical reporting limits is shaded in gray, and the region at or below ambient background concentrations is shaded in yellow. For relevant organic COCs, model predictions are presented both with and without biodegradation. The cross-sectional contaminant distributions at 475 years for DDx and Total PCBs are presented in Figures 6A and 6B, respectively.

Copper (Figure 5A). Centerline copper concentrations are below both chronic WQC and upstream background concentrations during the 475-year design period of the CDF. Therefore, no adverse effects are predicted for copper.

Naphthalene (Figure 5B). Centerline naphthalene concentrations are well below the chronic guideline during the 475-year design period of the CDF. This was anticipated prior to conducting the model simulation since the initial leachate concentration was already below this criterion. Naphthalene concentrations are also predicted to remain below the analytical reporting limit. Therefore, no adverse effects are predicted for naphthalene.

It should be noted that the naphthalene prediction curves reach their maximum concentration at the berm face within years, rather than decades or centuries as is more typical of the other COCs, because naphthalene has a much lower partitioning coefficient and is, therefore, more mobile. As a result, model predictions for naphthalene were terminated early (i.e., after 20 years), because groundwater concentrations had already reached their maximum value and were starting to decline.

Benzo(a)pyrene (Figure 5C). The benzo(a)pyrene centerline concentration remains well below the chronic guideline, and the spatially averaged concentration remains well below the MCL and fish consumption criteria during the 475-year design period of the CDF. The model predicted concentrations are also below the analytical reporting limit. Therefore, no adverse effects are predicted for benzo(a)pyrene. For comparison, model predictions using a conservative biodegradation rate (41-year half life) are also presented; when biodegradation is included, benzo(a)pyrene results are many orders of magnitude below WQC.

DDx (Figure 5D). The DDx centerline concentration remains well below the chronic WQC, and the spatially averaged concentration remains well below the fish consumption criteria during the 475-year design period of the CDF. The model predicted concentrations are also below the analytical reporting limit. Therefore, no adverse effects are predicted for DDx. For comparison, model predictions using a conservative biodegradation rate (90-year half life) are also presented; when biodegradation is included, DDx results are many orders of magnitude below WQC.

Significantly more attenuation will be caused by rapid initial mixing in the receiving water immediately after groundwater exits the berm, because the groundwater seepage rate (8.9 E-7 meters per second [m/sec]) is approximately 50,000 times slower than the ambient river current velocity (5 E-2 m/sec). Using a simple groundwater-surface water mixing calculation, the effect of the CDF groundwater discharge on receiving water concentrations at 10 cm from the berm face is determined to be imperceptible. This distance could conceivably represent the quality of interstitial water in the riprap armor layer placed over the berm face. As shown on Figure 5D, there is no discernible change in the ambient background concentration in the river as a result of groundwater discharge from the CDF. At Year-475, the background concentration at 10 cm from the berm face is predicted to increase by only 0.0001 percent. Negligible receiving water effects would similarly be expected for other COCs as well, including Total PCBs, as discussed below.

Total PCBs (Figure 5E). Total PCB centerline concentrations remain well below the chronic WQC, and spatially averaged concentrations remain well below the MCL during

the 475-year design period of the CDF. Spatially averaged Total PCB concentrations are predicted to reach the fish consumption criterion (6.4 E-5 micrograms per liter [µg/L]) at 466 years, and rise slightly above the criterion at 475 years (7.2 E-5 µg/L). However, PCB concentrations remain below the upstream background concentration and the analytical reporting limit during the design period, although concentrations eventually rise above these levels at very long time periods. Therefore, no adverse effects on ambient water quality are predicted for Total PCBs during the design period.

In consideration of biodegradation, WQC for Total PCBs are not likely to be exceeded at any time. Model predictions using a conservative biodegradation rate (60-year half life) indicate Total PCB results are orders of magnitude below all WQC at all times.

Significantly more attenuation will be caused by rapid initial mixing in the receiving water immediately after groundwater exits the berm, because the groundwater seepage rate (8.9 E-7 m/sec) is approximately 50,000 times slower than the ambient river current velocity (5 E-2 m/sec). Simple mixing calculations were performed to estimate water concentrations at 10 cm from the berm face, as described above for DDx. This distance could conceivably represent the quality of interstitial water in the riprap armor layer placed over the berm face. As shown on Figure 5E, there is no discernible change in the ambient background concentration in the river as a result of groundwater discharge from the CDF. At Year-475, the background concentration is predicted to increase by only 0.01 percent.

PCB-126 (Figure 5F). The spatially averaged PCB-126 concentrations are well below the fish consumption criteria and the MCL during the 475-year design period. PCB-126 concentrations also remain well below the analytical reporting limit. Therefore, no adverse effects are predicted for PCB-126. For comparison, model predictions using a conservative biodegradation rate (10-year half life) are also presented; when biodegradation is included, predicted PCB-126 concentrations are virtually zero (1 E-20 µg/L). It should be noted that PCB-126 is the most toxic of the PCB congeners (USEPA 2009b), and biodegradation (i.e., dechlorination) will transform this congener to a less toxic and, likely, a noncarcinogenic species.

Sensitivity Analysis

Model sensitivity analysis was conducted to determine which input parameters have the greatest effects on model predictions, and the relative range of those effects. Estimated minimum and maximum values for evaluating sensitivity were provided in the Groundwater Model Input Parameter Memorandum, and are reprinted in Tables 2 and 3. Total PCBs and DDx were the COCs selected for sensitivity analysis. The following parameters were evaluated:

- Sediment Fill Permeability
- Sediment Fill Source Concentration (Total PCBs and DDx)
- Berm Permeability
- Berm Fraction Organic Carbon [foc]
- Berm Partitioning Coefficient [Koc] (Total PCBs and DDx)

Results of the sensitivity analysis are presented in Table 4. Results include the minimum, average (base case), and maximum concentrations at the end of the 475-year design period. Results are presented for both the peak centerline concentration and the spatially averaged concentration. The geometric deviation, or multiplier (plus or minus), from the average base case concentration is also tabulated.

In many cases, model results were not particularly sensitive to the designated ranges in input parameter values. Model results varied by less than plus 2.5 times and minus 4.0 times the base case concentration as a result of variability in sediment fill permeability, sediment fill source concentration, and berm foc. An increase in the berm permeability did not cause a corresponding increase in predicted concentrations, but in contrast, a reduction in the berm permeability value resulted in substantially lower concentrations at the berm face (minus 16x).

A higher degree of sensitivity was observed for berm Koc values; in particular, significantly higher concentrations were observed for Total PCBs (plus 35x) and DDx (plus 504x) at the 475-year design period when extremely low literature values were applied. These results show that the minimum Koc value accelerates the arrival time of the contaminants at the berm face, and the maximum Koc value retards the arrival time. Other lines of evidence, however, indicate that such low literature values are not

representative of Portland Harbor sediments, and the average Koc values selected for the T4 CDF base case simulations are appropriate. These other lines of evidence include partitioning coefficients calculated from Willamette River surface water data (i.e., particulate and dissolved fractions), and partitioning coefficients calibrated as part of the QEA-FATE modeling effort (Kevin Russell pers. comm. 2010). For example, the calibrated Log Koc values for the QEA-FATE model for DDx (geometric mean of DDD, DDE, and DDT isomers) and PCBs (geometric mean of tetra- through hepta-homolog groups) are 6.3 and 6.5 liters per kilogram (L/kg), respectively, which compare very well with the T4 CDF base case values of 6.4 and 6.4 L/kg, respectively (see Table 2).

The most sensitive input parameter is the biodegradation rate (Table 4). Considering the long design period of the CDF (475 years), even very slow biodegradation rates can have a profound effect on model results, as is clearly illustrated in Figure 5. By not including biodegradation, Total PCB predictions at the 475-year design period may be overestimated by about 248x (spatially averaged), and DDx predictions may be overestimated by 34x (spatially averaged).

Mass Loading Estimates

Mass loadings for the T4 CDF were calculated and compared to mass loadings from other sources in Portland Harbor, including upstream, stormwater, atmospheric, and groundwater sources, as well as inputs from in situ contaminated sediments in Portland Harbor via porewater advection and resuspension (LWG 2009, Table 6.1-11). The magnitude of the CDF mass loadings in comparison to other sources provides another line of evidence to assess the potential impacts of the CDF on the water quality in the river.

The CDF mass loadings for Total PCBs and DDx are summarized in Table 5 and Figure 7. Figure 7 shows the annualized mass loadings (kg/yr) over time in groundwater exiting the CDF, as well as the cumulative percent of the initial CDF contaminant mass that enters the river (kg). These estimates show that the annual mass loadings of Total PCBs and DDx from the CDF constitute a negligible percentage of the upstream background load entering Portland Harbor (0.0003 and 0.00001 percent, respectively) at the end of the design period. Similarly, they constitute a negligible percentage of the existing load from in situ contaminated sediments in Portland Harbor (0.007 and 0.001 percent, respectively)

at the end of the design period. In other words, dredging the contaminated sediments in the Harbor and placing them in the CDF is expected to result in greater than 99.99 percent reduction in the mass loadings of PCBs and DDx to the river. In addition, a negligible percentage of the initial contaminant mass of PCBs and DDx in the CDF is predicted to enter the river by the end of the design period (approximately 0.0002 and 0.0001 percent of the initial mass, respectively). Although this analysis is specific to dredging and confined disposal, it is expected that reductions in mass loadings relative to current conditions would also be realized for other remedial technologies, such as capping.

CONCLUSIONS

The following conclusions are indicated by the modeling results:

- Groundwater transport pathways are dominated by downward vertical flow through the contaminated sediment toward the underlying aquifer and laterally into the berm.
- The groundwater residence time in the contaminated fill material varies from less than 20 years along the front and bottom of the CDF, to greater than 200 years at the upper rear of the CDF. Therefore, contaminated sediments in the upper rear of the CDF are likely to have less effect on groundwater exit concentrations.
- During the design period of 475 years, the centerline and spatially averaged concentrations of all COCs remained below their respective evaluation criteria, including chronic WQC, fish consumption criteria, and drinking water MCLs, with the exception of Total PCBs, which was predicted to reach its fish consumption criterion at 466 years, slightly before the end of the design period. In addition, copper remained below upstream background concentrations, and all organic COCs remained below analytical reporting limits at 475 years.
- When conservatively slow rates of biodegradation are incorporated into model simulations for organic compounds, spatially averaged concentrations at the end of the design period are reduced by orders of magnitude (e.g., 34x reduction for DDx, 248x reduction for Total PCBs, and even greater reductions for benzo[a]pyrene and PCB-126).
- The sensitivity analysis indicates that predicted concentrations at the end of the 475-year design period are typically 1x to 2.5x higher at the top end of the sensitivity range compared to base case predictions, and about 1x to 16x lower at the bottom end of the sensitivity range for most of the model parameters, including sediment fill

permeability, sediment fill source concentrations, berm permeability, and berm foc. The model is more sensitive to variations in the berm Koc, in which lower and higher Koc values accelerate or retard, respectively, the arrival of groundwater COCs at the berm face. However, other lines of evidence, including partitioning coefficients derived from Willamette River surface water data, and partitioning coefficients calibrated as part of the QEA-FATE modeling effort, indicate that the average berm Koc values used in the T4 CDF base case simulations are representative of Portland Harbor sediments, rather than the more extreme Koc values reported in the literature.

- The estimated annual mass loadings of Total PCBs and DDx from the CDF at the end of the 475-year design period constitute a negligible percentage of the upstream load to Portland Harbor, as well as a negligible percentage of the existing load from in situ contaminated sediments in the Harbor. Dredging the contaminated sediments in the Harbor and placing them in the CDF is expected to result in greater than 99.99 percent reduction in the mass loading of PCBs and DDx to the river.
- Based on the groundwater modeling results, the CDF as designed will be effective in controlling leachate and protective of water quality in the Willamette River consistent with the design period of the facility (475 years). Therefore, the current CDF design will be carried forward in the upcoming 60 Percent CDF Design submittal.

Tables

Table 1 Physical and Hydraulic Properties of CDF Materials
Table 2 Geochemical Properties of Chemicals of Concern
Table 3 Groundwater Evaluation Criteria
Table 4 Sensitivity Matrix for T4 CDF Model Parameters
Table 5 Comparison of Portland Harbor and T4 CDF Mass Loadings

Figures

Figure 1 Model Structure
A Key Hydrogeologic Units
B Model Grid
C Boundary Conditions
Figure 2 Willamette River Seasonal and Diurnal Tidal Fluctuations
Figure 3 Effective Dispersion Calibration
Figure 4 CDF Groundwater Flow Characteristics
A Groundwater Flow Paths and Residence Times
B Groundwater Velocity Vectors
Figure 5 Model Predictions
A Copper
B Naphthalene
C Benzo(a)pyrene
D DDx
E Total PCB
F PCB-126
Figure 6 Contaminant Distributions at 475 Years
A DDx
B Total PCBs
Figure 7 CDF Mass Loading
A Total PCB
B DDx

REFERENCES

Anchor Environmental, L.L.C. (Anchor). 2006. Design Analysis Report (Prefinal 60 Percent Design Deliverables): Terminal 4 Early Action, Port of Portland, Portland, Oregon. Prepared for the Port of Portland. December.

Anchor. 2007a. Technical Memorandum: Dredged material permeability evaluation for Portland Harbor sediments. May 4, 2007.

Anchor. 2007b. Borrow source analytical results. June 8, 2007.

Anchor QEA and NewFields. 2010. Groundwater Model Input Parameter Memorandum. Port of Portland Terminal 4 Confined Disposal Facility. Prepared for the Port of Portland. April 1, 2010.

Bach, Q-D, S-J Kim, S-C Choi, and Y-S Oh. 2005. Enhancing the Intrinsic Bioremediation of PAH-Contaminated Anoxic Estuarine Sediments with Biostimulating Agents. Journal of Microbiology, 43(4):319-324.

Beurskens, J.E.M. and P.B.M. Stortelder. 1995. Microbial Transformation of PCBs in Sediments: What can we Learn to Solve Practical Problems? Wat. Sci. Tech. 31(8):99-107.

Blasland, Bouck & Lee, Inc. (BBL). 2004. Characterization Report, Terminal 4 Early Action, Port of Portland, Oregon. September 17.

BBL. 2005. Terminal 4 Early Action Engineering Evaluation/Cost Analysis, Public Review Draft. Port of Portland, Oregon.

Chang, B.V., J.S. Chang, and S.Y. Yuan. 2001. Degradation of Phenanthrene in River Sediment Under Nitrate-Reducing Conditions. Bulletin of Environmental Contamination & Toxicology. 67: 898-905.

Coates, J.D., R.T. Anderson, D.R. Lovley. 1996a. Oxidation of Polycyclic Aromatic Hydrocarbons under Sulfate-Reducing Conditions. Applied and Environmental Microbiology. 62(3):1099-1101.

Coates, J.D., R.T. Anderson, J.C. Woodward, E.J.P. Phillips, and D.R. Lovley. 1996b. Anaerobic Hydrocarbon Degradation in Petroleum-Contaminated Harbor Sediments under Sulfate-Reducing and Artificially Imposed Iron-Reducing Conditions. Environmental Science & Technology. 30(9): 2784-2789.

Coates, J.D., J. Woodward, J. Allen, P. Philp, and D.R. Lovley. 1997. Anaerobic Degradation of Polycyclic Aromatic Hydrocarbons and Alkanes in Petroleum-Contaminated Marine Harbor Sediments. Applied and Environmental Microbiology. 63(9):3589-3593.

Davis, J.A. 2004. The Long-Term Fate of Polychlorinated Biphenyls in San Francisco Bay (USA). Environmental Toxicology and Chemistry, 23(10):2396-2409. 2004 SETAC.

Eganhouse, R.P., J. Pontolillo, and T.J. Leiker. 2000a. Diagenetic fate of organic contaminants on the Palos Verdes Shelf, California. Marine Chemistry 70(2000):289-315.

Eganhouse, R.P. and J. Pontolillo. 2000b. Depositional history of organic contaminants on the Palos Verdes Shelf, California. Marine Chemistry 70(2000):317-338

Freeze, R.A., and Cherry, J.A. 1979. Groundwater. Prentice Hall, 604 pages.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G. 2000. MODFLOW-2000, the U.S. Geological Survey modular ground-water model – User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Heitkamp M A. and C.E. Cerniglia. 1987. The effects of chemical structure and exposure on the microbial degradation of polycyclic aromatic hydrocarbons in freshwater and estuarine ecosystems. Environ Toxicol Chem. 1987;**6**:535–546.

Holtz, R.D. and Kovacs, W.D. 1981. Introduction to Geotechnical Engineering. Prentice Hall, 733 pages.

Lower Willamette Group (LWG). 2007. Round 2 Quality Assurance Project Plan, Addendum 8: Round 3A Stormwater Sampling, Portland Harbor RI/FS.

LWG. 2009. Portland Harbor Superfund Site Draft Remedial Investigation Report. October.

Mackay, D., M. Diamond, F. Gobas, and D. Dolan. 1994. A Rate Constant Model of Chemical Dynamics in a Lake Ecosystem: PCBs in Lake Ontario. J. Great Lakes Res. 20(4):625-642.

Magar, V.S., R. Brenner, G. Johnson, and J. Quensen, III. 2005. Long-Term Recovery of PCB-Contaminated Sediments at the Lake Hartwell Superfund Site: PCB

Dechlorination. 2. Rates and Extent. Environmental Science and Technology 39(10):3548-3554.

NewFields. 2007a. Technical Memorandum: Explanation of Effective Dispersion Calculation. Prepared for USEPA, Region 10. April 4.

NewFields. 2007b. Technical Memorandum: Cadmium, copper, and lead partition coefficients for berm materials in T4 CDF groundwater transport models. June 20, 2007.

NewFields and Anchor. 2007. Technical Memorandum: Cadmium, Copper, and Lead Partition Coefficients for Berm Materials in T4 CDF Groundwater Transport Models. Prepared for USEPA, Region 10. June 20.

Oregon Department of Environmental Quality (ODEQ). 2005. Table 33A: Water Quality Criteria Summary. February 15, 2005. www.deq.state.or.us/wq/rules/div041/table33a.pdf.

Palermo, M. 2010. Personal communication with Mike Palermo of Mike Palermo Consulting, Inc., Vicksburg, MS, on March 29, 2010.

Rothermich, M.M., L.A. Hayes, and D.R. Lovely. 2002. Anaerobic, Sulfate-Dependent Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediment. Environmental Science & Technology. 36(22):4811-4817.

Russell, K. Personal communication with Kevin Russell of Anchor QEA, LLC, Syracuse, NY, on June 16, 2010.

Schroeder, P.R, T.S. Dozier, P.A Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3. EPA/600/R-94/168b, U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C., September.

Sinkkonen, S. and J. Paasivirta. 2000. Degradation half-life times of PCDDs, PCDFs and PCBs for environmental fate modeling, 2000. Chemosphere 40(2000):943-949.

U.S. Army Corps of Engineers (USACE). 1996. Natural Processes for Contaminant Treatment and Control at Dredged Material Confined Disposal Facilities. Environmental Effects of Dredging Technical Notes, EEDP-02-19, Vicksburg, MS.

U.S. Environmental Protection Agency (USEPA). 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic

Organisms: PAH Mixtures. Office of Research and Development, Washington, D.C., EPA-600-R-02-013.

USEPA. 2005. Partition Coefficients for Metals in Surface Water, Soil, and Waste. Office of Research and Development, Washington D.C., EPA/600/R-05/074.

USEPA. 2009a. Drinking Water Contaminants, EPA 816-F-09-0004. May 2009. www.epa.gov/safewater/contaminants/index.html.

USEPA. 2009b. Recommended Toxicity Equivalency Factors (TEFs) for Human Health Risk Assessments of Dioxin and Dioxin-Like Compounds. External Review Draft prepared by the Risk Assessment Forum.

USEPA. 2010. National Recommended Water Quality Criteria, www.epa.gov/waterscience/criteria/wqctable.

van Dort, H.M., L. Smullen, R. May, and D. Bedard. 1997. Priming Microbial meta-Dechlorination of Polychlorinated Biphenyls that have persisted in Housatonic River Sediments for Decades. Environmental Science & Technology. 31(11):3300-3307.

Zheng, Chunmiao and P. Patrick Wang. 1999. MT3DMS, A modular three-dimensional multi-species transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems; documentation and user's guide, U.S. Army Engineer Research and Development Center Contract Report SERDP-99-1, Vicksburg, MS, 202 p.

TABLES

Table 1
Physical and Hydraulic Properties of CDF Materials

Material	Units	Material Property Values for Sensitivity Analysis			Data Source/Rationale
		Min.	Average	Max.	
Sediment Fill					
Fraction organic carbon	-	0.010	0.015	0.018	LWG (2009), Measured pH bulk sediment: 10% / Average / 90%
Porosity	-	-	0.35	-	Anchor (2006)
Hydraulic conductivity	ft/d	0.00017	0.00085	0.0028	Anchor (2007a); Consolidation tests from T4 and Region 10
Bulk density	g/cm^3	-	1.3	-	BBL (2005; Table 4-4); Consolidation tests from T4
Imported Fill					
Fraction organic carbon	-	0.0005	0.0006	0.0007	Anchor (2007b), Measured import from local quarries
Porosity	-	-	0.30	-	Anchor (2006)
Hydraulic conductivity	ft/d	-	28	-	Freeze and Cherry (1979; Table 2.2); clean sand
Bulk density	g/cm^3	-	2.0	-	Holz and Kovacs (1981; Table 2-1)
Berm Fill					
Fraction organic carbon	-	0.0005	0.0006	0.0007	Anchor (2007b), Measured import from local quarries
Porosity	-	-	0.30	-	Anchor (2006)
Hydraulic conductivity	ft/d	30	280	450	Hazen's approximation based on gradation specification for Select Fill
Bulk density	g/cm^3	-	2.0	-	Holz and Kovacs (1981; Table 2-1)
Dispersion - Horizontal	-	-	40	-	Anchor (2006); NewFields (2007a): Dynamic model calibration
Dispersion - Vertical	-	-	0.4	-	Anchor (2006); NewFields (2007a): Dynamic model calibration
Training Dikes					
Fraction organic carbon	-	-	0.00006	-	Assumed 10 percent of Berm Fill value
Porosity	-	-	0.30	-	Anchor (2006)
Hydraulic conductivity	ft/d	-	2,800	-	Freeze and Cherry (1979; Table 2.2); clean gravel
Bulk density	g/cm^3	-	2.2	-	Holz and Kovacs (1981; Table 2-1)
Aquifer					
Fraction organic carbon	-	-	0.003	-	BBL (2005); Average measured value in Slip 1 aquifer material
Porosity	-	-	0.30	-	Anchor (2006)
Hydraulic conductivity (K)	ft/d	-	65	-	Hart Crowser (2000); Pumping test results, as reported in BBL (2005)
Bulk Density	g/cm^3	-	2.0	-	Holz and Kovacs (1981; Table 2-1)

Table 2
Geochemical Properties of Chemicals of Concern

Material	Units	Values for Sensitivity Analysis			Data Source/Rationale
		Min.	Average	Max.	
Initial Source Concentrations in Contaminated Sediment Pore Waters					
Copper	µg/L	4	8	14	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Naphthalene	µg/L	0.04	0.07	0.15	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Benzo(a)pyrene	µg/L	0.12	0.23	0.52	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Total DDX	µg/L	0.014	0.058	0.076	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Total PCB Aroclors	µg/L	0.22	0.87	2.17	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
PCB-126	ng/L	0.08	0.27	0.68	LWG (2009); Geometric Mean, Arithmetic Mean, and 90th Percentile of SBLT results
Metal Partitioning Coefficient [Kd]					
Copper [Sediment]	L/kg	-	8,900	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Copper [Berm, Cap]	L/kg	100	165	-	NewFields (2007b)
Copper [Quarry Spall]	L/kg	1	20	-	USEPA (2005; Table 3); Minimum and 1st Percentile Kd
Log Organic Partitioning Coefficient [Koc] - Sediment					
Naphthalene	Log L/kg-OC	-	4.97	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Benzo(a)pyrene	Log L/kg-OC	-	5.18	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Total DDX	Log L/kg-OC	-	4.87	-	Anchor QEA and Newfields (2010); LWG (2009); Geometric Mean of AOPCs
Total PCB Aroclors	Log L/kg-OC	-	4.86	-	Anchor QEA and Newfields (2010); LWG (2009); Linear Isotherm Model
PCB-126	Log L/kg-OC	-	4.80	-	Anchor QEA and Newfields (2010); LWG (2009); Linear Isotherm Model
Log Organic Partitioning Coefficient [Koc] - Berm					
Naphthalene	Log L/kg-OC	3.12	3.30	3.53	LWG RI Report Table E6 (2009)
Benzo(a)pyrene	Log L/kg-OC	5.68	6.01	6.67	LWG RI Report Table E6 (2009)
Total DDX	Log L/kg-OC	5.08	6.44	6.62	LWG RI Report Table E6 (2009); Geometric Mean of DDT, DDE, and DDD
Total PCB Aroclors	Log L/kg-OC	5.96	6.39	7.59	LWG RI Report Table E6 (2009); Geometric Mean of Ar-1254 and Ar-1260
PCB-126	Log L/kg-OC	6.27	6.57	6.88	LWG RI Report Table E6 (2009)
Biodegradation Half Life in Sediment [Anaerobic]					
Naphthalene	days	40	110	1,100	Mean, 95% UCL, and 0.1 x UCL, from Bach et al. (2005); Coates et al. (1996a, 1996b, 1997);
Benzo(a)pyrene	days	470	1,500	15,000	Chang et al. (2001); Heitkamp & Cerniglia (1987); Rothermich et al. (2002)
Total DDX	days	11,000	33,000	Infinite	Eganhouse et al. (2000a, 2000b)
Total PCB Aroclors	days	-	22,000	Infinite	Magar et al. (2005); van Dort et al. (1997); Mackay et al. (1994); Davis (2004)
PCB-126	days	2,400	3,700	Infinite	Sinkkonen & Paasivirta (2000); Beurskens & Stortelder (1995)

Table 3
Groundwater Evaluation Criteria

Criteria (µg/L)	Copper	Naphthalene	Benzo(a)pyrene	DDx	Total PCBs	PCB-126
Chronic WQC[1]	2.7	194	0.96	0.001	0.014	N/A
Drinking Water MCL[2]	1,300	N/A	0.2	N/A	0.5	3.0E-04
Fish Consumption Criteria[3]	N/A	N/A	0.018	0.00022	6.4E-05	5.1E-08
Upstream Background[4]	3.1	N/A	N/A	0.00059	3.9E-04	4.7E-08
Analytical Reporting Limit[5]	0.1	0.02	0.02	0.00050	2.0E-04	5.0E-06

Notes:

1. Copper, DDx, and Total PCBs from ODEQ 2005, Table 33A, www.deq.state.or.us/wq/rules/div041/table33a.pdf and USEPA 2010, National Recommended Water Quality Criteria, www.epa.gov/waterscience/criteria/wqctable; Criteria for naphthalene and benzo(a)pyrene from USEPA 2003.
2. USEPA 2009a, www.epa.gov/safewater/contaminants/index.html
3. USEPA 2010, National Recommended Water Quality Criteria, www.epa.gov/waterscience/criteria/wqctable
4. LWG 2009, Portland Harbor Draft RI Report, Table 7.4-4.
5. LWG 2007, Round 2 QAPP, Addendum 8, Table 3-2, for all constituents except Total PCBs; Total PCBs based on 90th percentile laboratory blank contamination levels (using LWG 2009 data).

N/A = Not applicable

Table 4
Sensitivity Matrix for T4 CDF Model Parameters

A. CENTERLINE CONCENTRATION

		Concentration at 475 yr (µg/L)			Geometric Deviation	
Physical Properties - PCBs		**MIN**	**AVG (BASE)**	**MAX**	**Plus** /	**Minus**
Sediment Fill	K	2.56E-04	2.80E-04	3.53E-04	1.3 X	1.1 X
Berm	foc	6.66E-04	2.80E-04	1.19E-04	2.4 X	2.4 X
Berm	K	1.77E-05	2.80E-04	2.32E-04	0.8 X	15.8 X
Geochemical Properties - PCBs						
Sediment Fill	Source Conc	7.08E-05	2.80E-04	6.98E-04	2.5 X	4.0 X
Berm	Koc	9.82E-03	2.80E-04	5.32E-17	35 X	5.E+12 X
Geochemical Properties - DDx						
Sediment Fill	Source Conc	2.10E-06	6.00E-06	1.16E-05	1.9 X	2.9 X
Berm	Koc	3.02E-03	6.00E-06	5.94E-07	504 X	10 X
Biodegradation		**MIN**	**AVG**	**MAX (BASE)**		
PCBs		N/M	1.13E-06	2.80E-04	N/A	247 X
DDx		N/M	4.75E-08	6.00E-06	N/A	126 X

B. SPATIAL AVERAGE CONCENTRATION

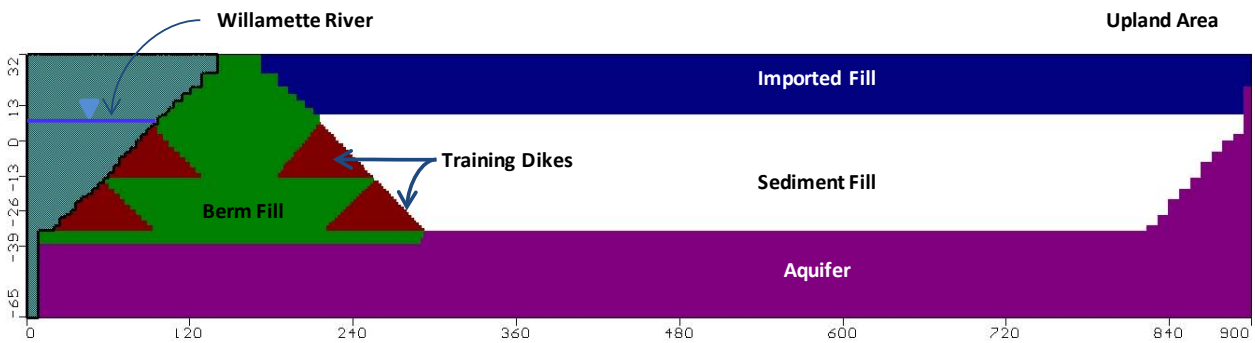
		Concentration at 475 yr (µg/L)			Geometric Deviation	
Physical Properties - PCBs		**MIN**	**AVG (BASE)**	**MAX**	**Plus** /	**Minus**
Sediment Fill	K	6.60E-05	7.20E-05	9.10E-05	1.3 X	1.1 X
Berm	foc	1.70E-04	7.20E-05	3.00E-05	2.4 X	2.4 X
Berm	K	4.60E-06	7.20E-05	5.60E-05	0.8 X	15.7 X
Geochemical Properties - PCBs						
Sediment Fill	Source Conc	1.80E-05	7.20E-05	1.80E-04	2.5 X	4.0 X
Berm	Koc	2.80E-03	7.20E-05	1.20E-17	39 X	6.E+12 X
Geochemical Properties - DDx						
Sediment Fill	Source Conc	5.30E-07	1.60E-06	2.90E-06	1.8 X	3.0 X
Berm	Koc	7.20E-04	1.60E-06	1.50E-07	450 X	11 X
Biodegradation		**MIN**	**AVG**	**MAX (BASE)**		
PCBs		N/M	2.90E-07	7.20E-05	N/A	248 X
DDx		N/M	4.70E-08	1.60E-06	N/A	34 X

Notes:
N/A = Not applicable
N/M = Scenario was not modeled

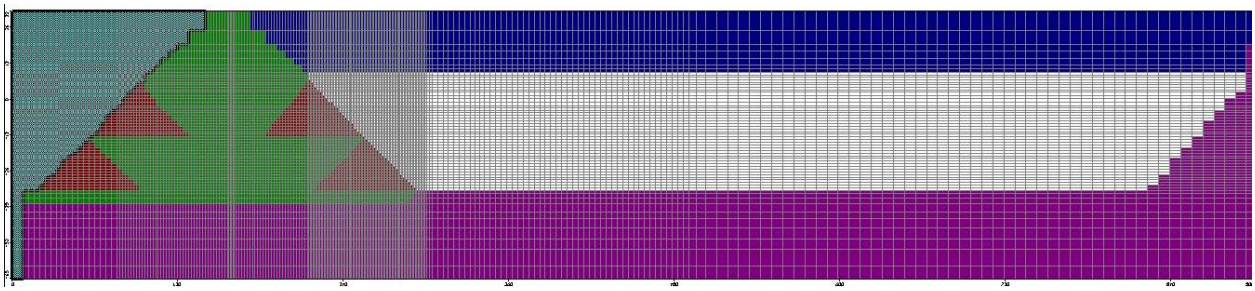
Table 5
Comparison of Portland Harbor and T4 CDF Mass Loadings

	Annual Load (kg/yr)	
Portland Harbor Mass Load	**Total PCBs**	**DDx**
Upstream	4.71	7.53
Stormwater	2.03	0.40
Atmospheric	0.63	0.17
Groundwater	0.00	0.02
Sediment (subsurface)	0.08	0.02
Sediment (surface)	0.12	0.01
TOTAL	**7.57**	**8.15**
T4 CDF Mass Load		
CDF Mass Load @ 475 years	1.4E-05	4.1E-07
Percent of Upstream Load	0.0003%	0.00001%
Percent of Sediment Load	0.007%	0.001%

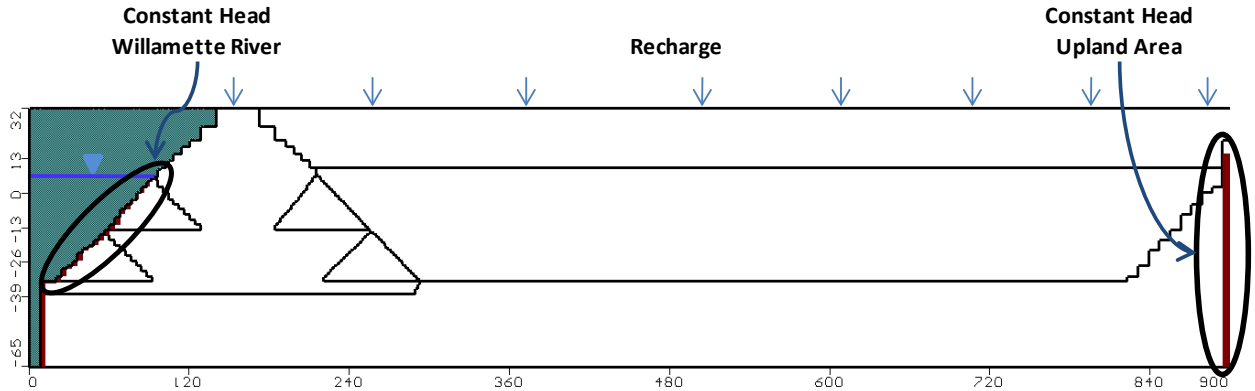
FIGURES



A. Key Hydrogeologic Units



B. Model Grid



C. Boundary Conditions

Figure 1
Model Structure
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

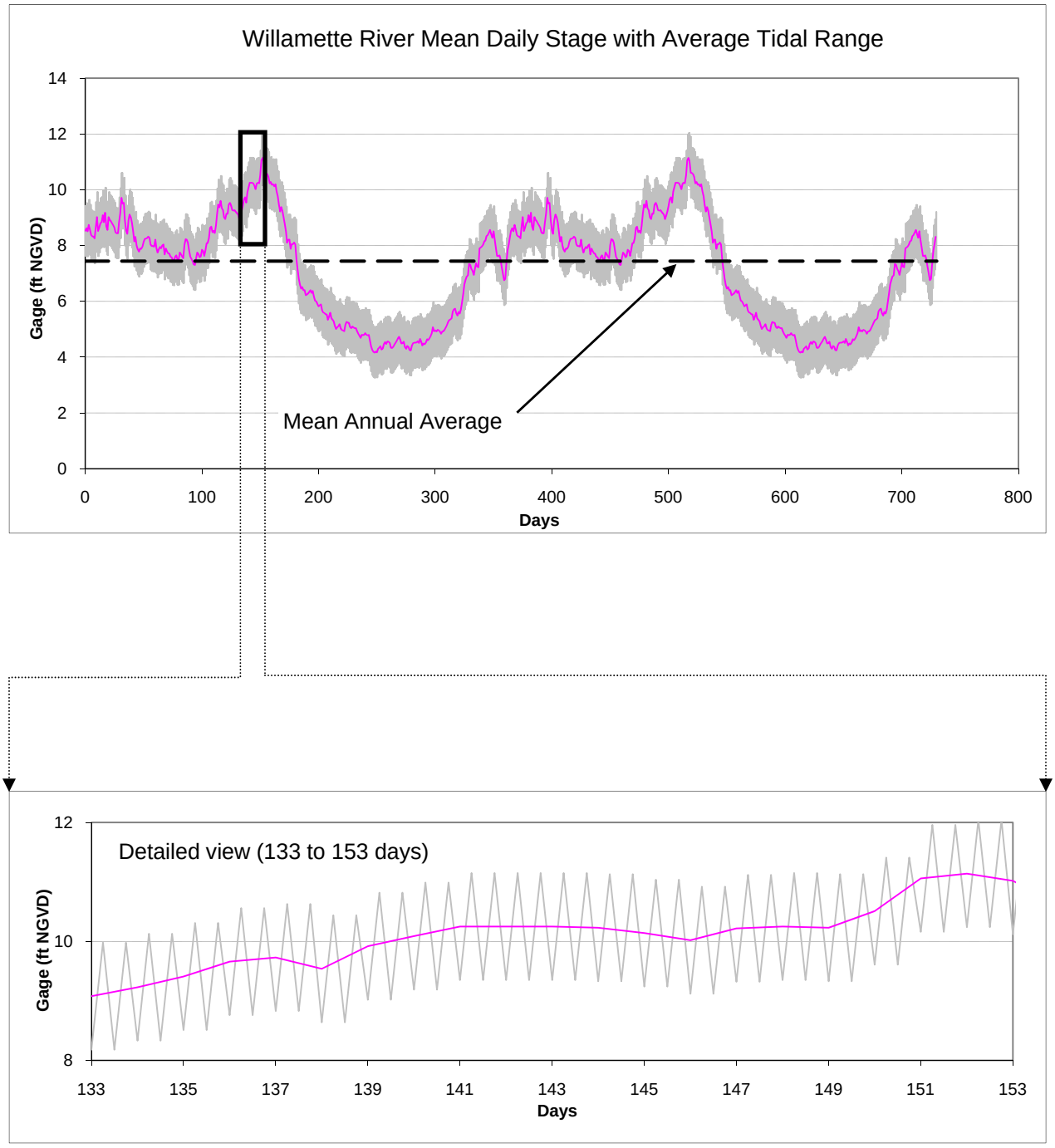


Figure 2

Willamette River Seasonal and Diurnal Tidal Fluctuations
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

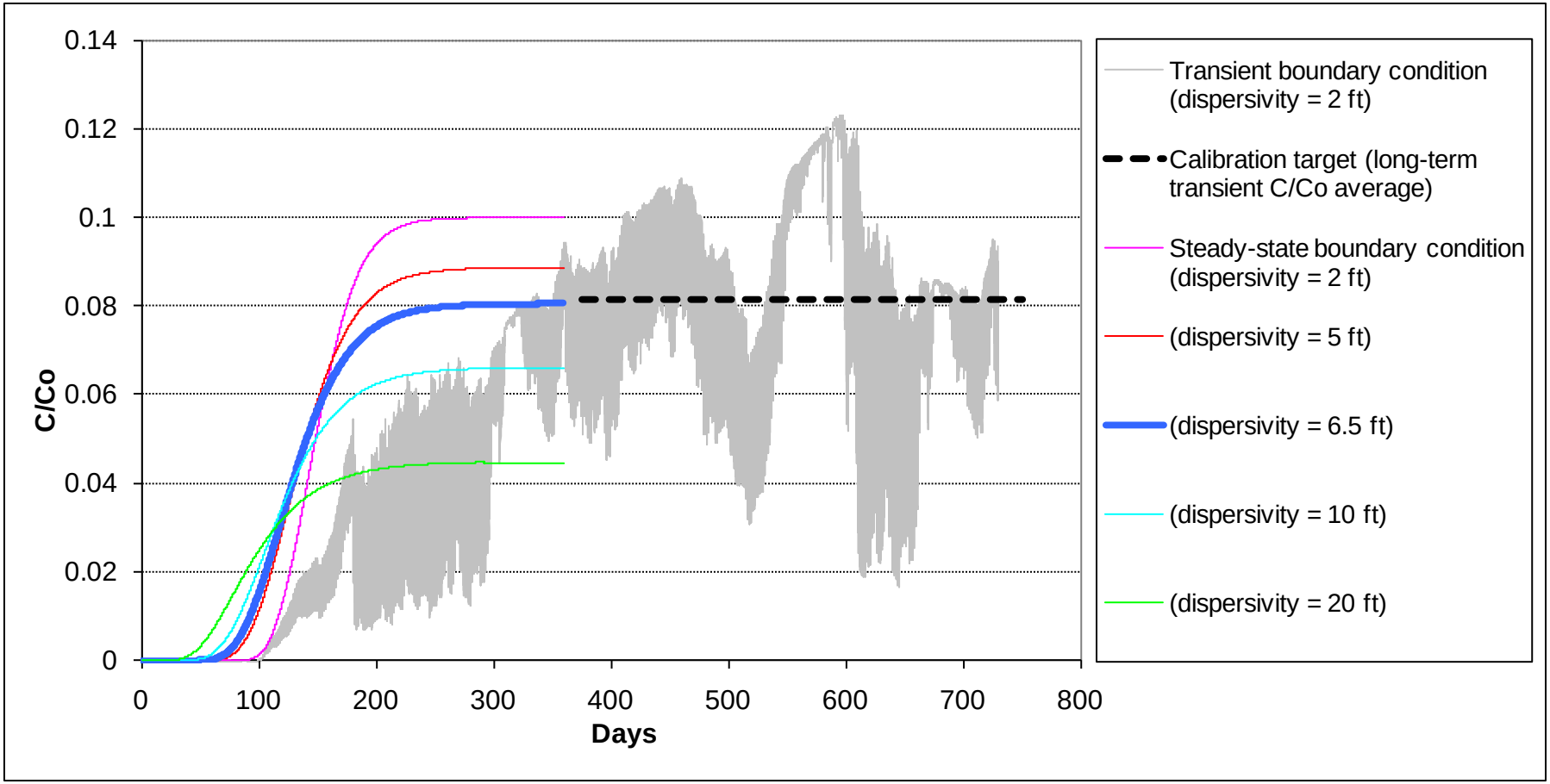
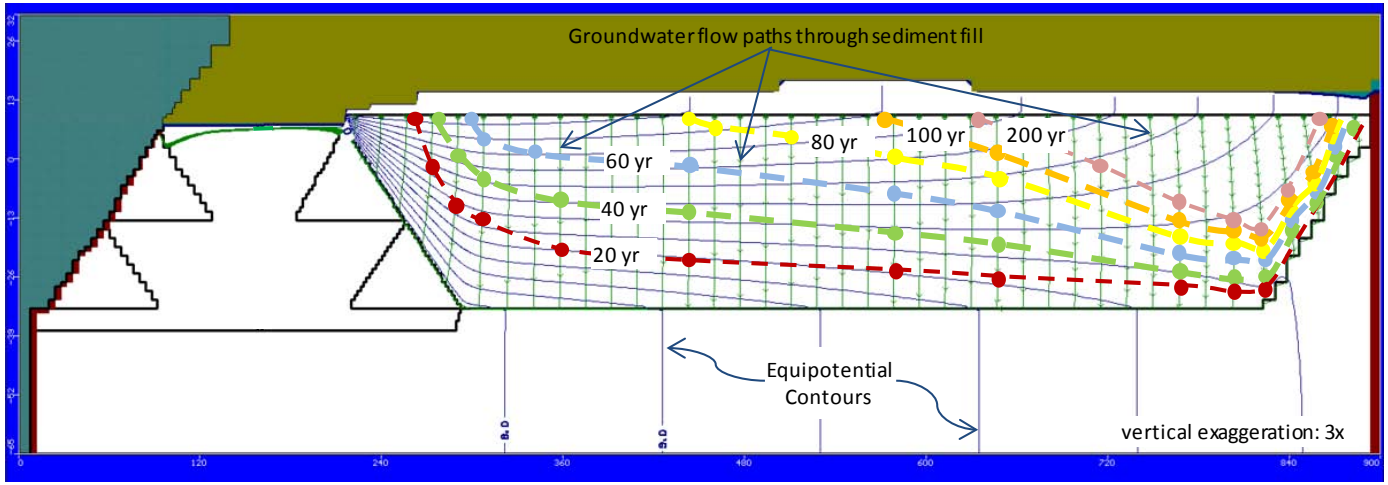
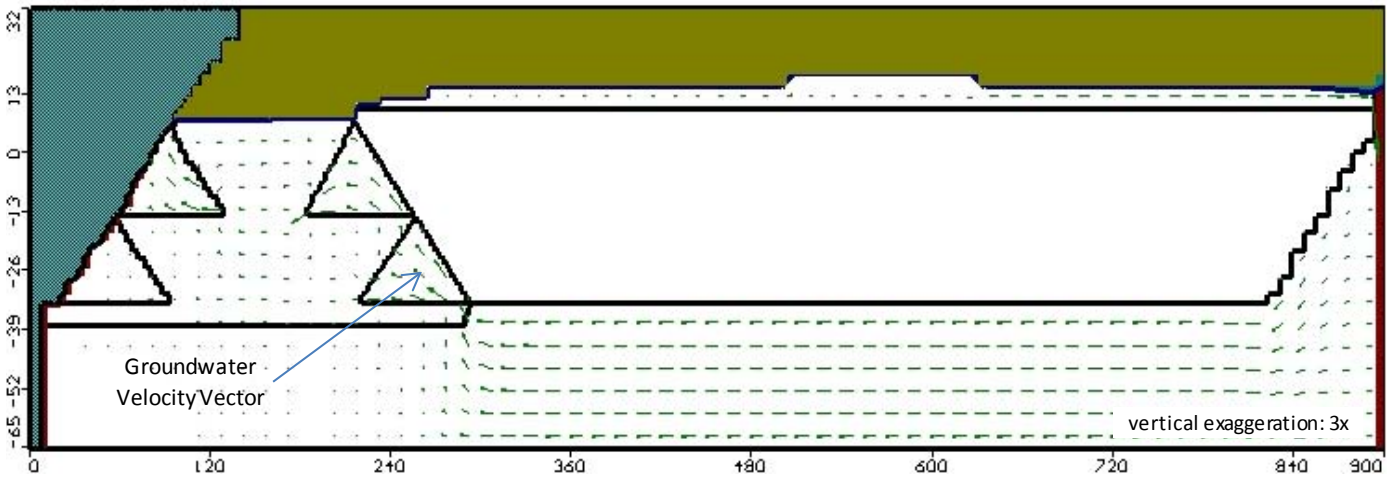


Figure 3
Effective Dispersion Calibration
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

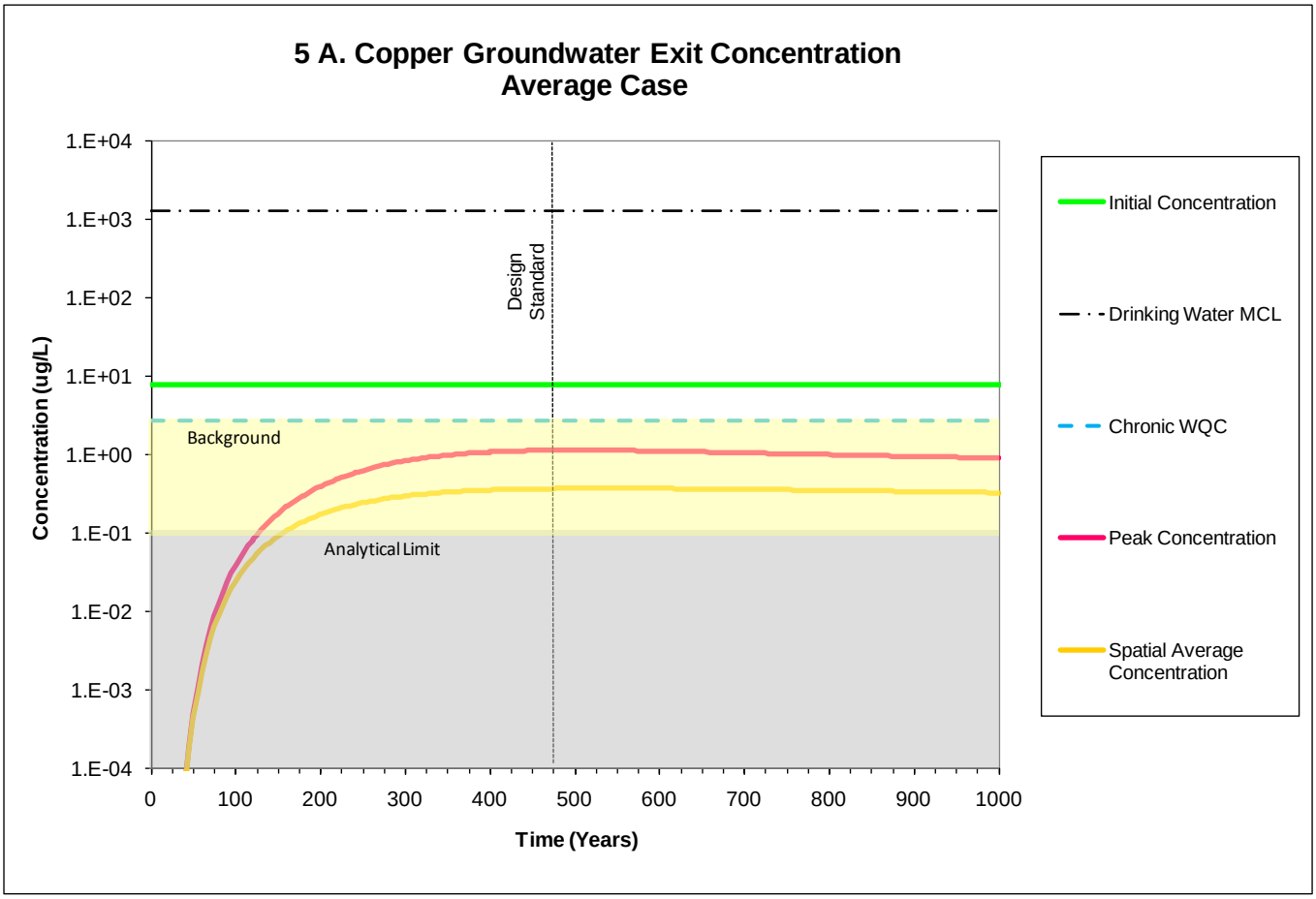


A. Groundwater Flow Paths and Residence Times



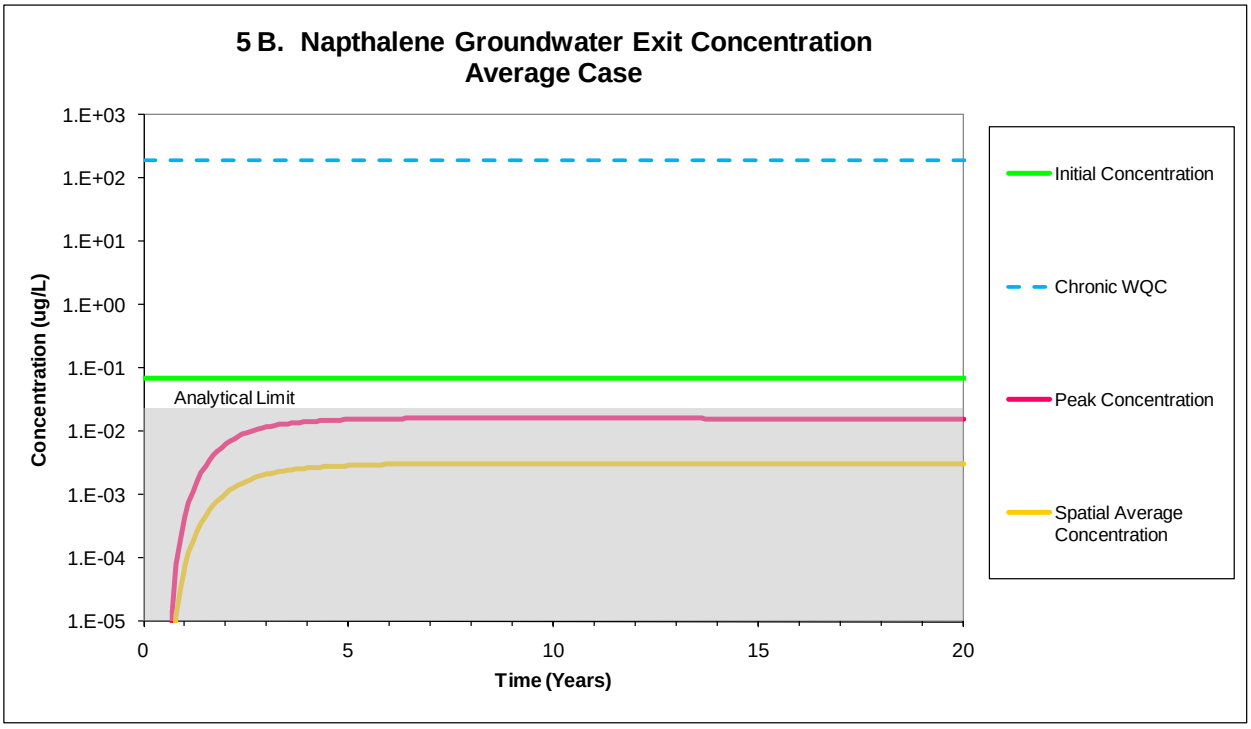
B. Groundwater Velocity Vectors

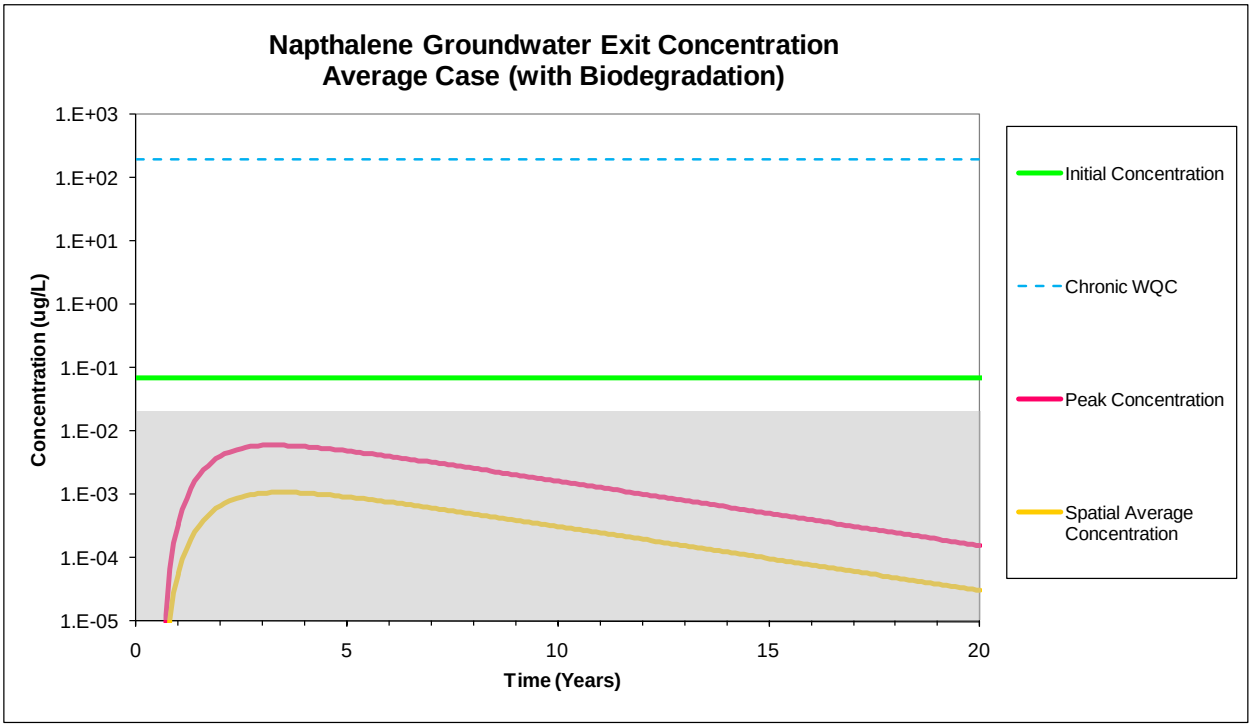
Figure 4
CDF Groundwater Flow Characteristics
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility



Note: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

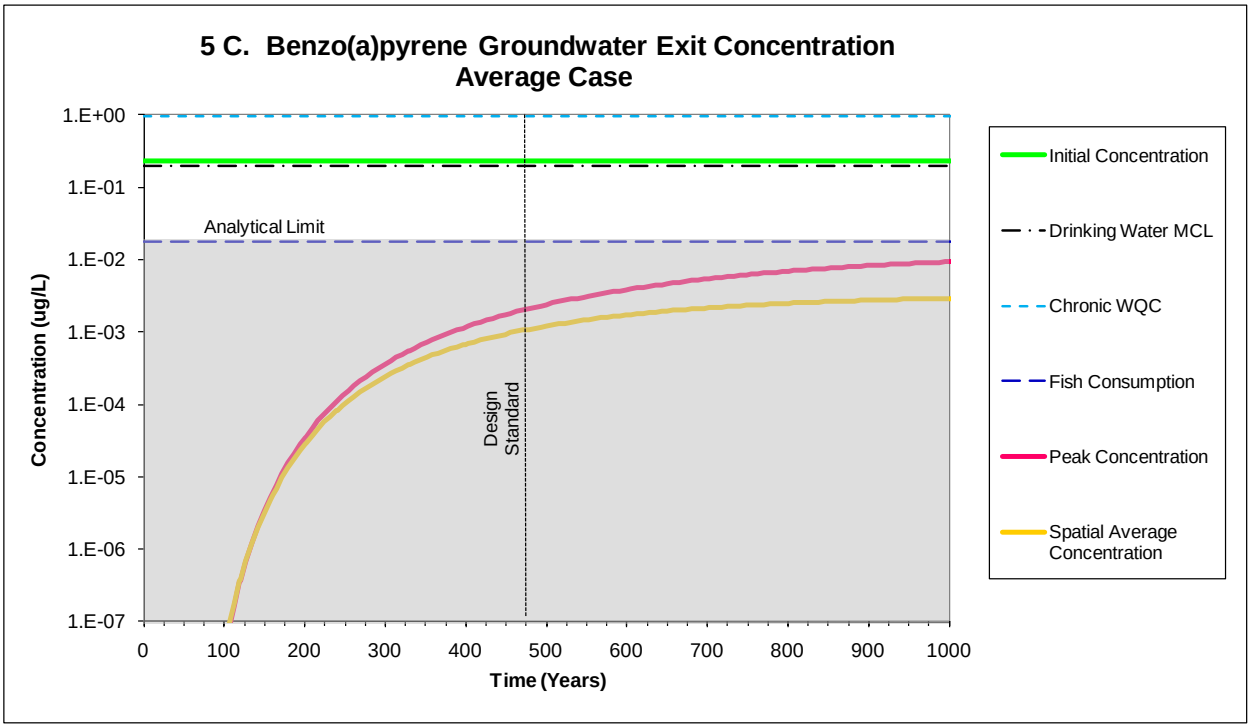
Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

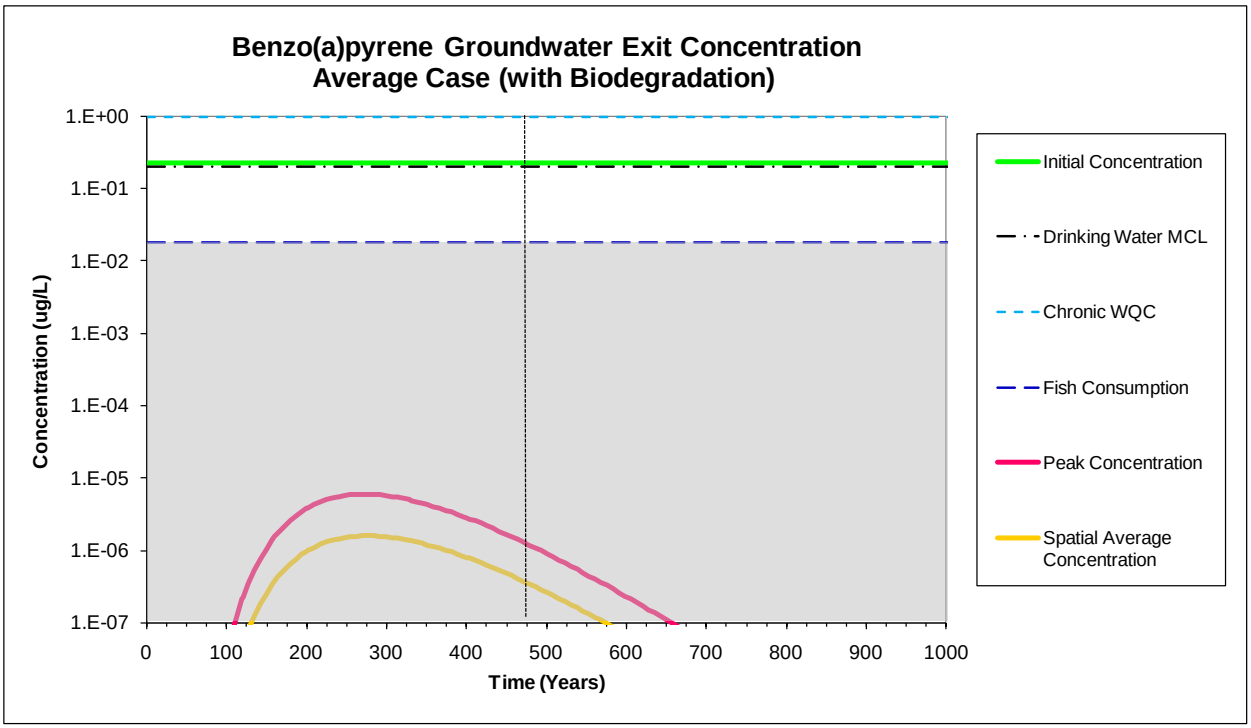




Notes: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.
Naphthalene predictions were terminated early after it was observed that exit concentrations had peaked and were subsequently declining.

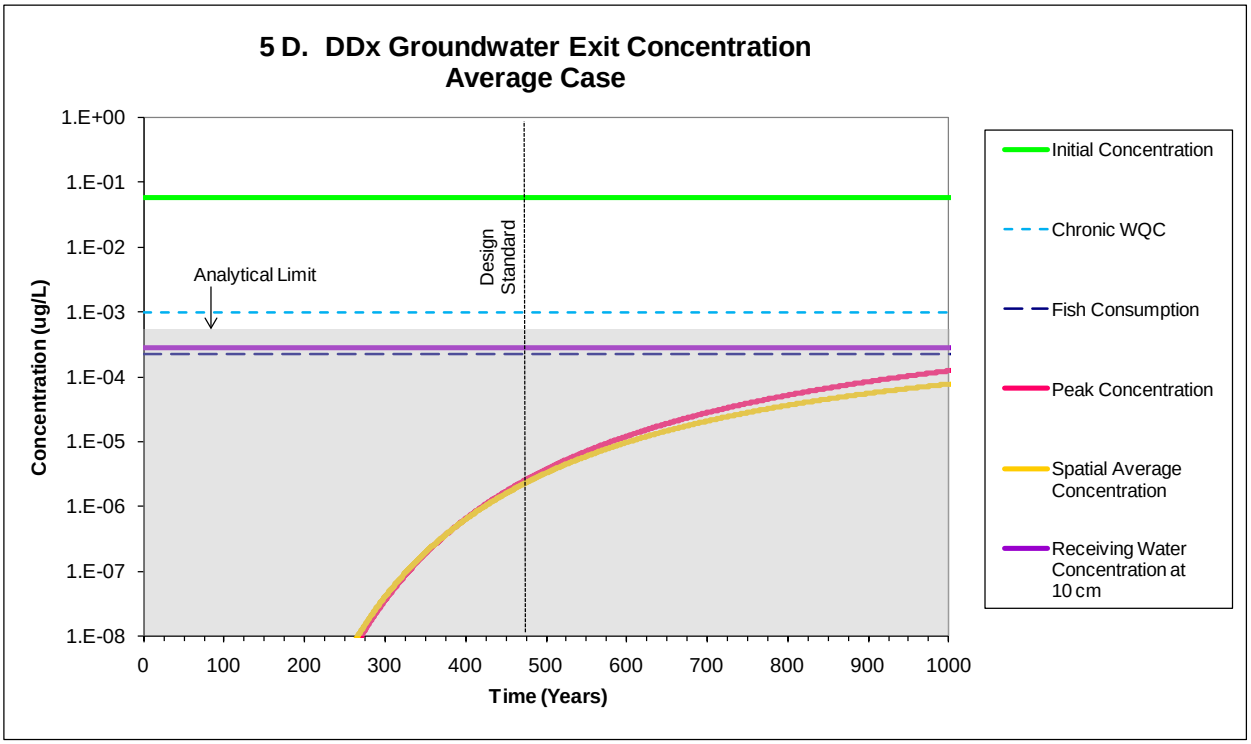
Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

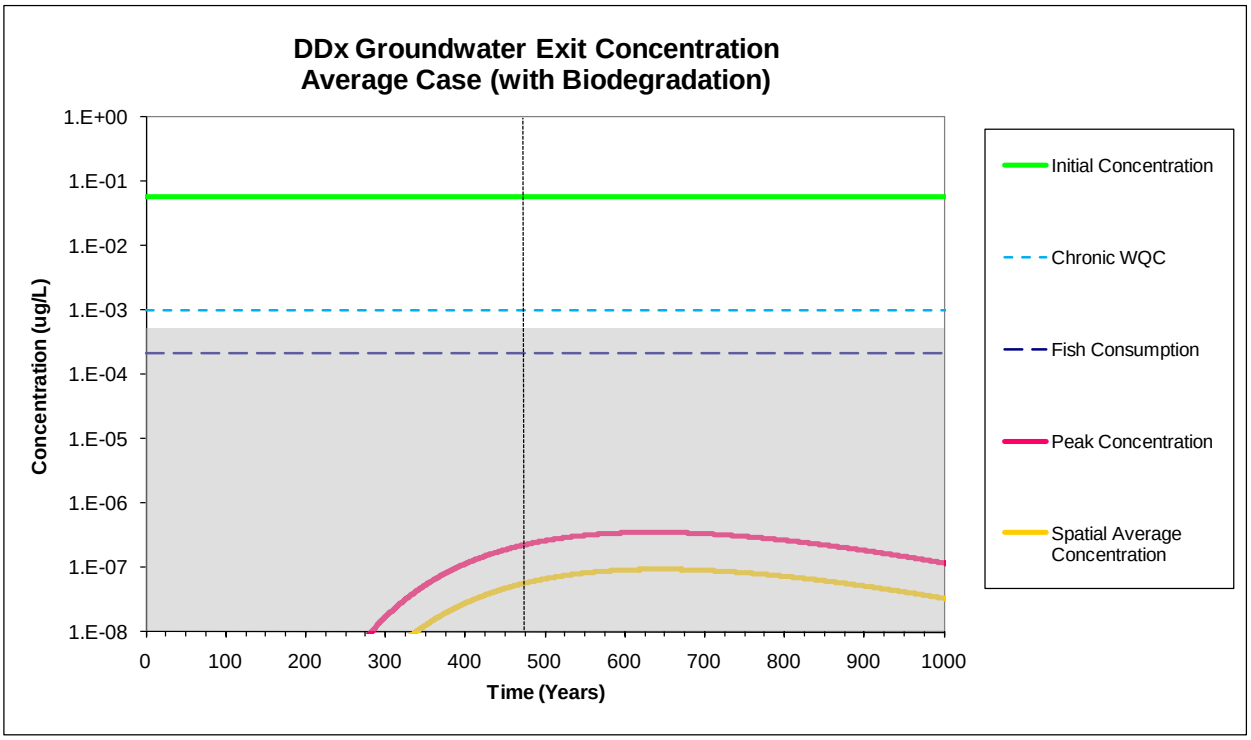




Note: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

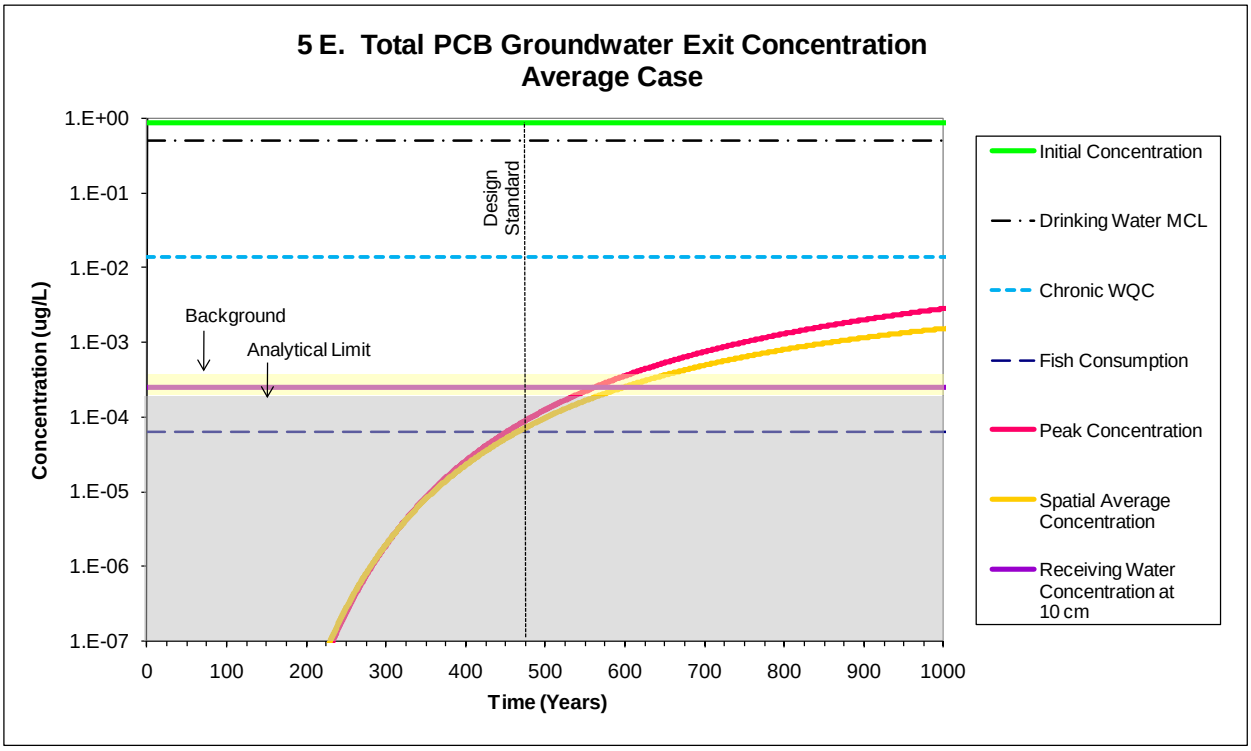
Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

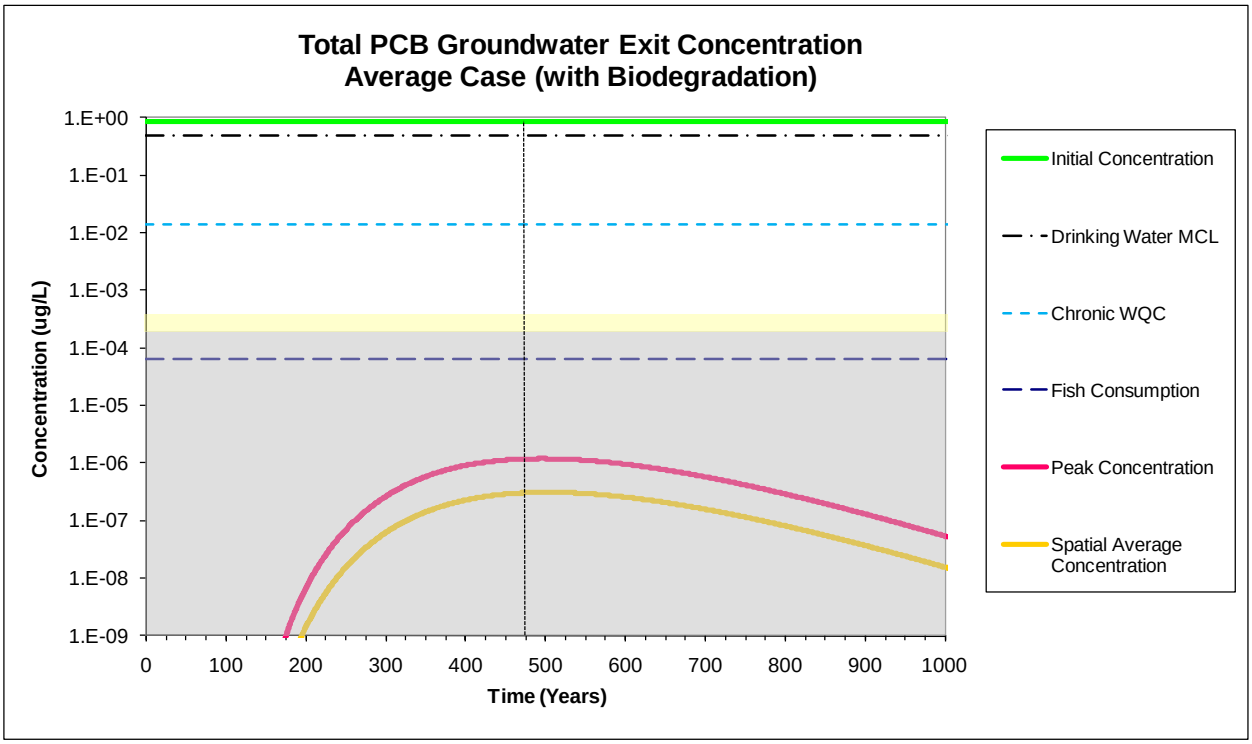




Note: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

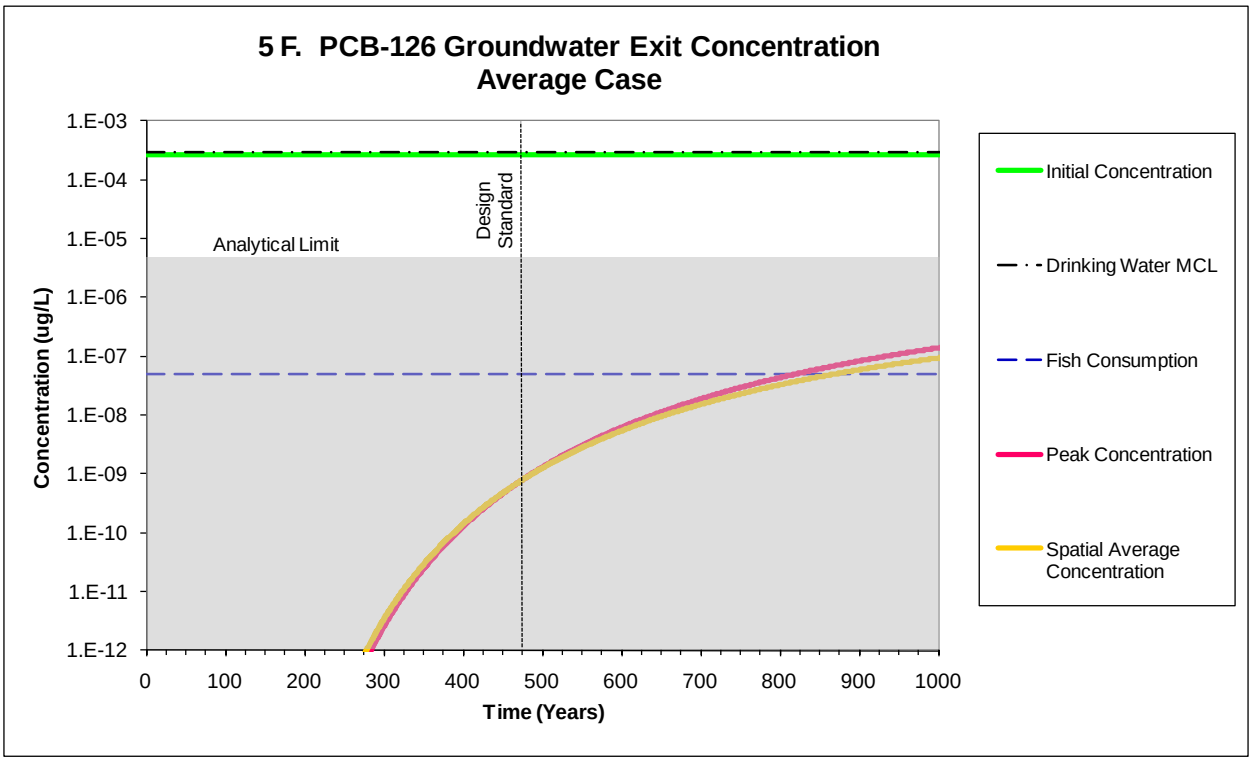
Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

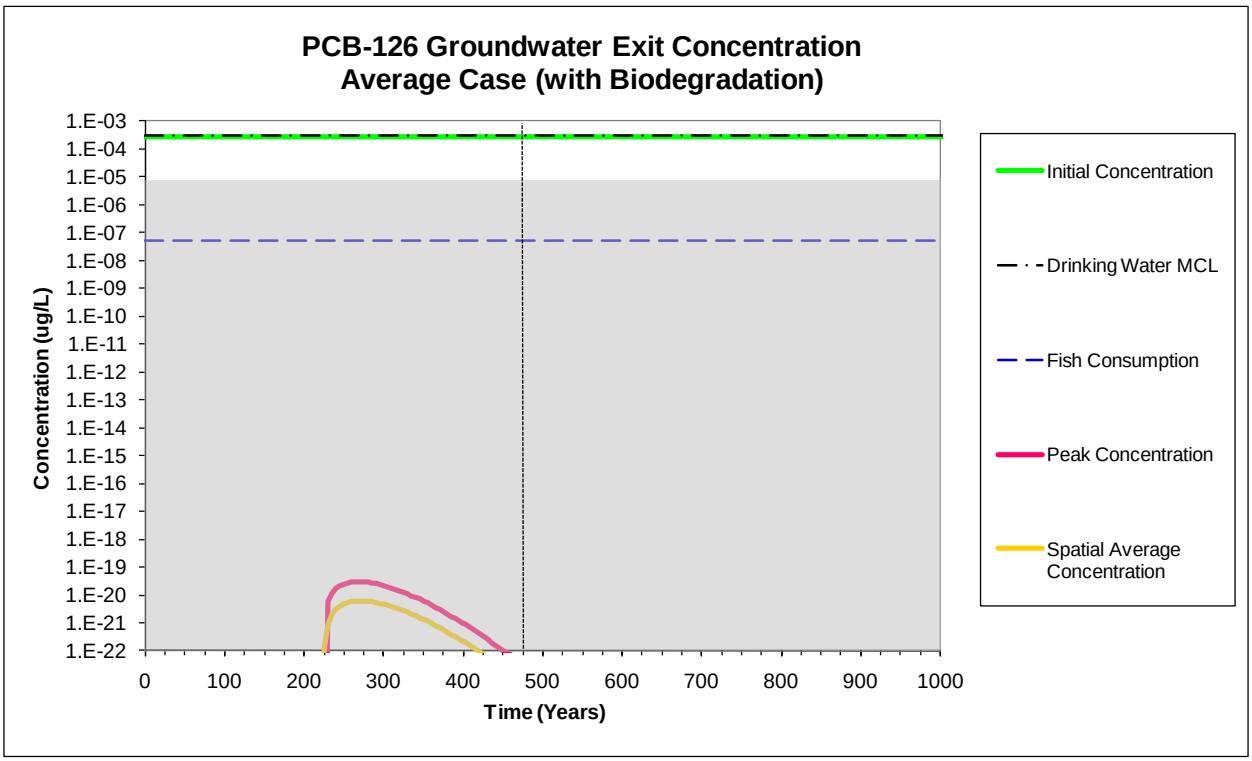




Note: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

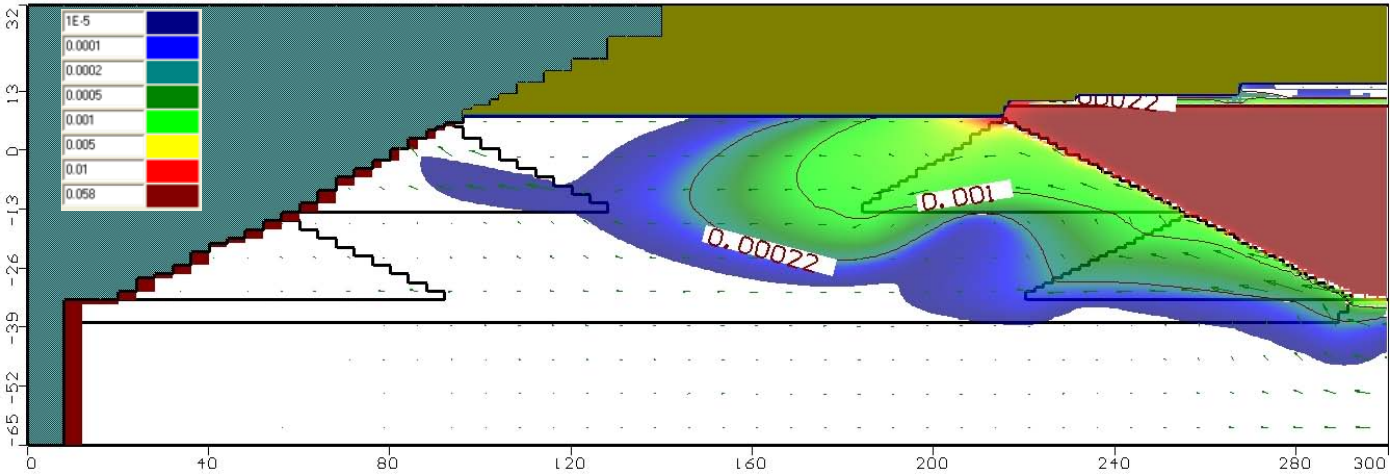




Note: Groundwater observation point is the predicted concentration in last model cell adjacent to river boundary, approximately one foot below the berm face.

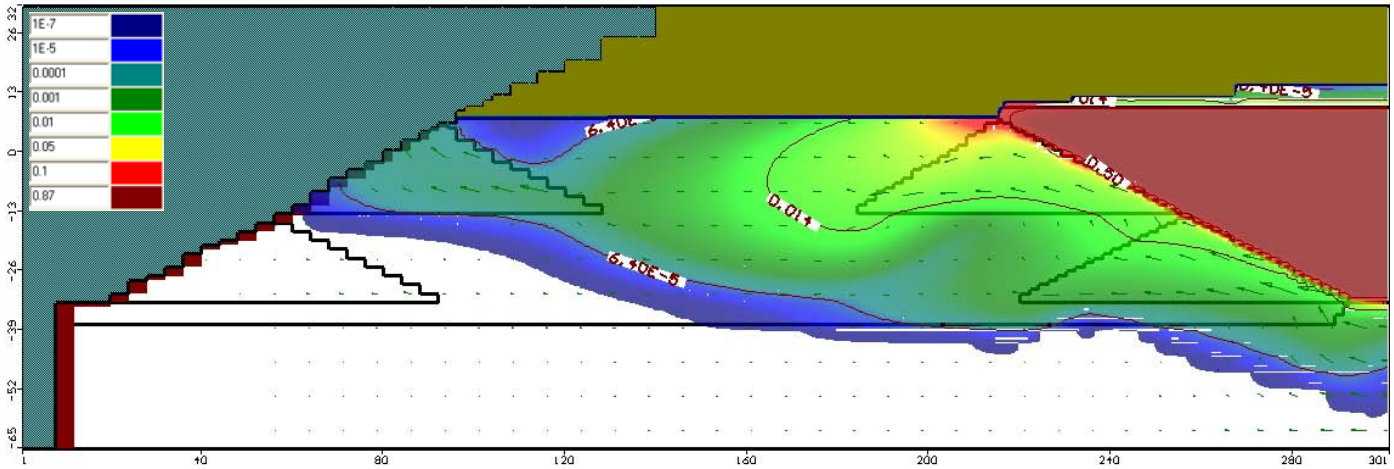
Figure 5
Model Predictions
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility

DDx at 475 years (in µg/L)



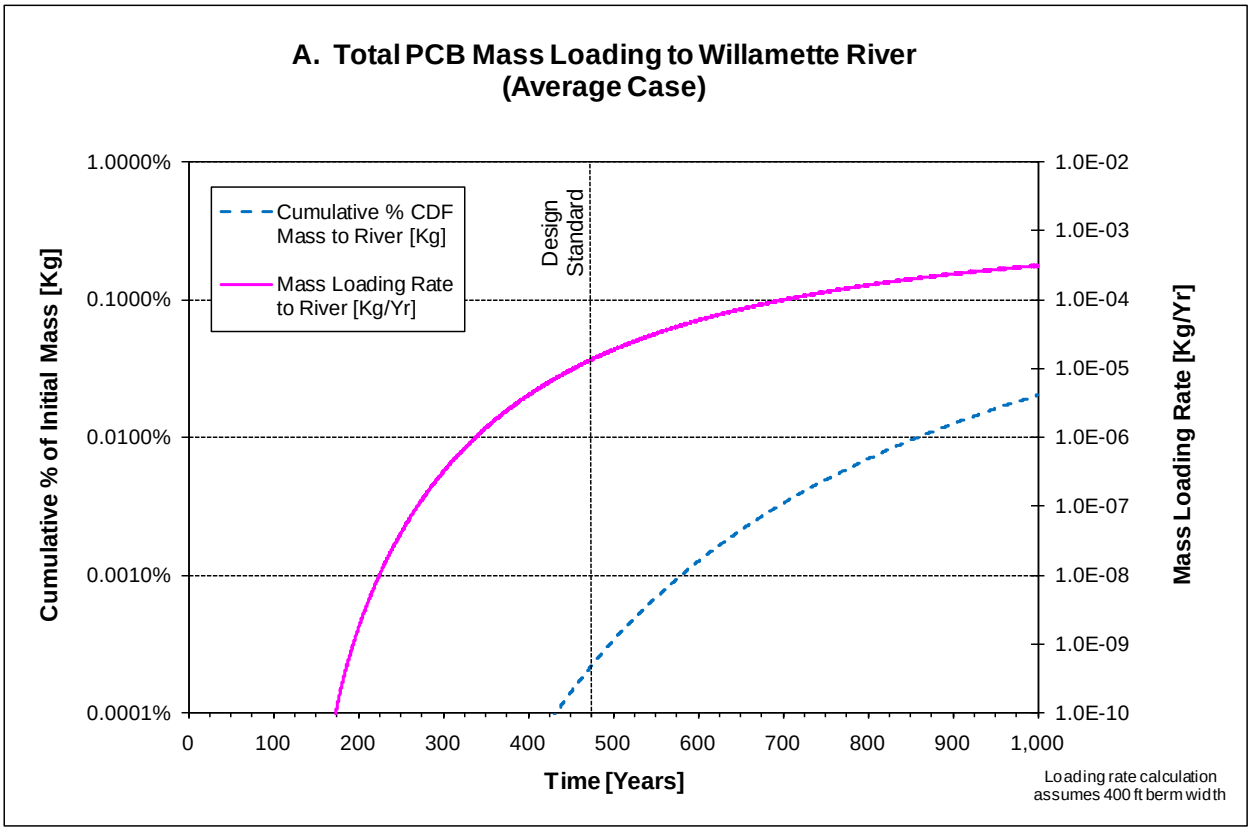
A. DDx

Total PCBs at 475 years (in µg/L)



B. Total PCBs

Figure 6
Contaminant Distributions at 475 Years
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility



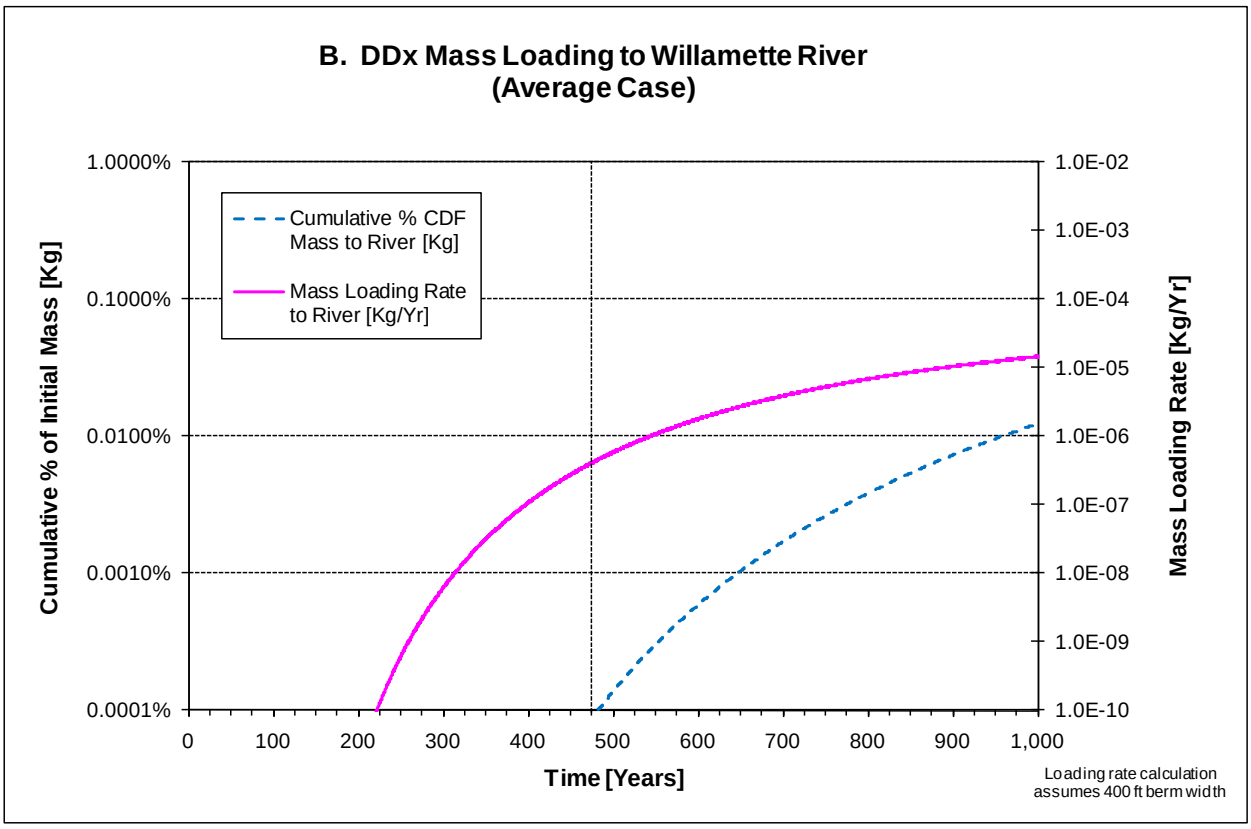


Figure 7
CDF Mass Loading
Long-Term Groundwater Modeling Results Memorandum
Port of Portland Terminal 4 Confined Disposal Facility