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MEMORANDUM

TO:	Jim Singer	REF. NO.:	7431
FROM:	Steve Harris/19	DATE:	January 4, 2000
C.C.:	Jack Michels		
RE:	**Multi-Species Solute Transport Simulations Slip 1 CDF Modeling - Area 5106 Boundary and Treated Sediments Former OCC Tacoma Facility Tacoma, Washington**		

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this memorandum is to present additional sensitivity simulations for the hydrogeologic modeling of the Slip 1 Confined Disposal Facility (CDF) presented in the report entitled, "Column Leach Evaluation Report, Area 5106 Removal Action, Former OCC Tacoma Facility, Tacoma, Washington" (CLT Evaluation) (CRA, 1999[1]). The additional sensitivity simulations were conducted to represent multi-species solute transport accounting for chemical adsorption and the sequential biodegradation of the compounds of concern [tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (DCE), and vinyl chloride (VC)] under anaerobic/aerobic groundwater conditions.

A sensitivity analysis of the hydrogeologic modeling conducted for the CLT Evaluation was presented in the memorandum dated June 14, 1999 (Sensitivity Memorandum) which was submitted to the Port of Tacoma on July 29, 1999. The sensitivity analysis simulations presented herein are an extension of the sensitivity analysis presented in the Sensitivity Memorandum.

This memorandum is organized as follows:

- Section 1.0: presents the purpose and organization of this memorandum;
- Section 2.0: presents the methodology applied to conduct the multi-species solute transport simulations;
- Section 3.0: presents the two-dimensional hydrogeologic model used to assess potential migration pathways for contaminants associated with the Area 5106 boundary and treated sediments placed within the Slip 1 CDF, and used to assess horizontal hydraulic gradients within the Slip 1 CDF to be applied in the one-dimensional solute transport model;

[1] CRA, 1999, Column Leach Evaluation Report, Area 5106 Removal Action. Former OCC Tacoma Facility, Tacoma, Washington, April.

- Section 4.0: presents the multi-species solute transport simulations conducted to evaluate potential solute concentrations discharging with groundwater to the Blair Waterway; and
- Section 5.0: presents the conclusions derived from the sensitivity simulations presented herein.

2.0 METHODOLOGY

Initially, a two-dimensional hydrogeologic model was developed to represent the potential groundwater flow through the end berm of the Slip 1 CDF, and through the existing peninsula between Slips 1 and 5. The two-dimensional model was constructed using average regional hydrogeologic input parameters. The two-dimensional model was applied to simulate transient groundwater flow in the vicinity of the Slip 1 CDF. The two-dimensional model then was applied to conduct particle tracking simulations to assess potential migration pathways toward the Blair Waterway for Area 5106 boundary and treated sediments placed within the Slip 1 CDF. The two-dimensional model also was applied to assess hydraulic gradients within the Slip 1 CDF along identified migration pathways for application in a one-dimensional solute transport model.

The multi-species solute transport simulations were conducted using a one-dimensional hydrogeologic model aligned along the potential migration pathways identified through the results of the particle tracking simulations. The multi-species solute transport simulations considered the sequential biodegradation of PCE to TCE to DCE to VC under anaerobic/aerobic groundwater conditions, and considered solute adsorption to soil particles. An estimate of the aerobic zone inland extent was conducted through the application of a single-species solute transport simulation representing the inland migration of a conservative tracer introduced with recharging seawater. An analysis of the sensitivity of the multi-species solute transport simulation results to biodegradation rate values and organic carbon partitioning coefficient (K_{oc}) values also was conducted.

Groundwater flow for the additional sensitivity simulations were represented using the United States Geological Survey's (USGS's) groundwater flow model MODFLOW-96 (Harbaugh and McDonald, 1996[2]). The particle tracking simulations were conducted using PATH3D (Zheng, 1991[3]). The single-species solute transport simulation associated with the estimation of the aerobic zone inland extent was conducted using the United States Army Corps of Engineers solute transport model MT3DMS (Zheng and Wang, 1998[4]). The multi-species solute transport simulations were conducted using the Pacific Northwest National Laboratory's (PNNLs) reactive solute transport model RT3D (Clement, 1997[5]). RT3D's reaction module 7 was applied in the multi-species solute transport simulations.

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[2] Harbaugh, A.W. and M.G. McDonald, 1996, User's Documentation for MODFLOW-96, an updated to the USGS Modular Finite-Difference Ground-Water Flow Model, United States Geological Survey Open-File Report 96-485, Reston, Virginia.

[3] Zheng, C., PATH3D: A Ground-Water Path and Travel-Time Simulator, S.S. Papadopulos & Associates, Inc., Bethesda, Maryland.

[4] Zheng, C. and P.P. Wang, 1998, MT3DMS: A Modular Three-Dimensional Multispecies Transport Model, United States Army Corps of Engineers, June.

[5] Clement, T.P., 1997, RT3D (Version 1.0), A Modular Computer Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Systems, PNL-SA-11720, PNNL, Richland, Virginia.

3.0 TWO-DIMENSIONAL HYDROGEOLOGIC MODELING

A two-dimensional hydrogeologic model was constructed of the landmass situated between the Blair and Sitcum Waterways. The development of the two-dimensional model is presented in Section 3.1. The application of the two-dimensional model to conduct particle tracking simulations to assess potential migration pathways for Area 5106 boundary and treated sediments placed within the Slip 1 CDF is presented in Section 3.2.

3.1 MODEL DEVELOPMENT

The location of the two-dimensional model domain is presented on Figure 3.1. The finite-difference grid, boundary conditions, and material properties applied in the two-dimensional model are presented on Figure 3.2.

A maximum 100-foot finite-difference grid spacing was applied throughout the model domain. The grid spacing was refined to 50 feet in the vicinity of the Slip 1 CDF (with two model rows having spacing of 20 and 30 feet to represent the 70-foot width of the end berm). A future aquatic habitat area is proposed to the west of the peninsula between Slips 1 and 5. The aquatic habitat area is to be constructed by filling the area with regional sediments. The landmass was extended seaward in this area by approximately 100 feet to reflect the presence of the future aquatic habitat.

A variable hydraulic head boundary condition was applied at the model cells situated around the shoreline of the landmass. The variable hydraulic head boundary condition was developed from Commencement Bay surface water levels measured from February 6, 1997 to February 6, 1998. These data were combined into an annual data set that was repeated for each year simulated. The development of the variable hydraulic head boundary condition is presented in the Sensitivity Memorandum. A no-flow boundary condition was applied at model cells beyond the variable hydraulic head boundary condition. A constant inflow boundary condition was applied at each model cell along the eastern model domain boundary to reflect regional groundwater inflow to the landmass. The inflow specified at each model cell corresponds to the average hydraulic conductivity for the regional sediments [6.0×10^{-4} centimeters per second (cm/s)] multiplied by the average regional upland hydraulic gradient [0.004 feet per foot (ft/ft)] and the cross-sectional area of each model cell perpendicular to groundwater flow. An average 20-foot saturated thickness for the shallow groundwater flow system was applied to determine the cross-sectional area at each model cell.

The material properties (i.e., hydraulic conductivity and porosity) applied in the regional sediments, Slip 1 CDF fill, Area 5106 boundary and treated sediments, peninsula sediments, and end berm are presented on Figure 3.2. The volume of the Area 5106 boundary and treated sediments is approximately 40,000 cubic yards. Assuming a fill thickness of approximately 30 feet within the Slip 1 CDF, the Area 5106 boundary and treated sediments will span an area of approximately 36,000 square feet which corresponds to approximately 14 model cells (with dimensions of 50 feet by 50 feet), as presented on Figure 3.2.

Groundwater flow was simulated under transient conditions for a 10-year period. Initially, steady-state groundwater flow conditions were simulated using a uniform starting hydraulic head of 15 ft Mean Low Low Water (MLLW) level. The steady-state hydraulic head distribution then was applied as the starting condition for the transient solution. The transient hydraulic head distribution simulated at the end of ten years is presented on Figure 3.3. Hydrographs were generated over the 10-year simulation period at six

observation points throughout the model domain. The hydrographs are presented on Figure 3.3, and demonstrate that the simulated hydraulic head within the central portion of the model domain (i.e., observation points 4, 5, and 6) becomes relatively stable near the end of the 10-year simulation period. The simulated hydraulic head at observation point 3 within the center of the Slip 1 CDF demonstrates minor variations related to the tidal fluctuation. Observation points 1 and 2, located in close proximity to the Blair Waterway, demonstrate a significant tidal influence.

3.2 PARTICLE TRACKING SIMULATIONS

With the exception of areas in close proximity of the waterways, relatively stable or steady-state groundwater flow conditions were achieved throughout the majority of the Slip 1 CDF at the end of the 10-year transient groundwater flow simulation. As a result, the simulated hydraulic head distribution at the end of the 10-year period was applied to conduct the particle tracking simulations under steady-state conditions. The Area 5106 boundary and treated sediments initially were placed approximately in the middle of the Slip 1 CDF, as presented on Figure 3.2. Particles were released at the center of each model cell where the Area 5106 boundary and treated sediments are positioned on Figure 3.2. The simulated particle pathways from the Area 5106 boundary and treated sediments over a 700-year period are presented on Figure 3.4. Arrowheads are plotted on each particle pathway at a travel time interval of 50 years (see Figure 3.4, Detail A). Particles within the eastern portion of the Area 5106 boundary and treated sediments travel out the end berm to the Blair Waterway within approximately 70 to 330 years. Particles released within the western portion of the Area 5106 boundary and treated sediments travel toward the peninsula between Slips 1 and 5 and reach a stagnation zone within approximately 600 to 700 years. These particles do not travel beyond the stagnation zone. The stagnation zone arises from the transient effects of the tidal fluctuations and is an artifact of applying the hydraulic head distribution at the end of the 10-year transient simulation as a steady-state condition. The significant time taken for particles to reach the stagnation point demonstrates that migration through the peninsula between Slips 1 and 5 is not a significant pathway. However, the placement of the Area 5106 boundary and treated sediments was revised by shifting the sediments eastward, and the particle tracking analysis was repeated. The simulated particle pathways from the revised placement of the Area 5106 boundary and treated sediments are presented on Figure 3.5. All particles travel through the end berm and reach the Blair Waterway within approximately 70 to 330 years (see Figure 3.5, Detail A).

The particle tracking simulations demonstrate that the Area 5106 boundary and treated may be placed within the Slip 1 CDF such that migration of contaminants associated with the sediments will occur through the end berm.

4.0 MULTI-SPECIES SOLUTE TRANSPORT SIMULATIONS

The particle tracking simulations identified that the potential migration pathway of concern for the Area 5106 boundary and treated sediments is directed out the end berm of the Slip 1 CDF. Therefore, the one-dimensional model applied to conduct the multi-species solute simulations was oriented along this potential migration pathway. The orientation of the one-dimensional model domain is presented on Figure 3.5. The development of the one-dimensional model is presented in Section 4.1. The one-dimensional model was applied to simulate the sequential biodegradation of PCE to TCE to DCE to VC under anaerobic/aerobic groundwater conditions. Anaerobic groundwater conditions are expected to prevail throughout the majority of the Slip 1 CDF, however aerobic groundwater conditions are expected

near the end berm due to the recharge of aerated seawater under high tide. The one-dimensional model initially was applied to estimate the potential inland extent of aerobic conditions within the Slip 1 CDF, as presented in Section 4.2. The application of the one-dimensional model to conduct the multi-species solute transport simulations is presented in Section 4.3.

4.1 MODEL DEVELOPMENT

The one-dimensional model was extended inland 450 feet from the Blair Waterway, which approximately corresponds to the furthest inland location of the Area 5106 boundary and treated sediments. The location and orientation of the one-dimensional model domain is presented on Figure 3.5. The finite-difference grid, boundary conditions, and material properties applied in the one-dimensional model are presented on Figure 4.1.

A 1-foot finite-difference grid spacing and a 5-foot model domain width were applied. The variable hydraulic head boundary condition utilized in the two-dimensional model was applied at the downgradient limit of the one-dimensional model corresponding to the Blair Waterway. As described in Section 3.1, the variable hydraulic head boundary condition corresponding to the Blair Waterway is based on measured Commencement Bay surface water elevations, and the development of the variable head boundary condition is presented in the Sensitivity Memorandum. A constant inflow boundary condition was applied at the upgradient limit of the one-dimensional model. The inflow boundary condition was determined from the simulated hydraulic gradient over the length of the Slip 1 CDF multiplied by the hydraulic conductivity of the fill material and the cross-sectional area perpendicular to groundwater flow. The cross-sectional area was determined using an average 30-foot saturated fill material thickness for the Slip 1 CDF. A hydraulic gradient of 0.0028 ft/ft was applied to determined the inflow boundary condition which corresponds to the average hydraulic gradient through the center of the Slip 1 CDF simulated at the end of 10 years using the two-dimensional model (see Figure 3.5).

The material properties (i.e., hydraulic conductivity and porosity) applied in the Slip 1 CDF fill, Area 5106 boundary and treated sediments, and end berm are presented on Figure 4.1. The end berm was represented as having a 70-foot width perpendicular to groundwater flow. A 30-foot buffer zone between the end berm and Area 5106 boundary and treated sediments was applied, as presented on Figure 3.5. The Area 5106 boundary and treated sediments were specified over the remainder of the model domain.

Transient groundwater flow was simulated over a 40-year period. The tide induced groundwater level fluctuations over the length of the one-dimensional model domain are presented on Figure 4.1.

4.2 DETERMINATION OF AEROBIC ZONE EXTENT

Groundwater conditions within the inland portion of the Slip 1 CDF generally are expected to be anaerobic. However, near the Blair Waterway, the recharge of aerobic seawater will occur inland under high tide conditions and will result in aerobic groundwater conditions for a limited distance inland of the end berm. The compounds of concern considered in the multi-species solute transport simulations biodegrade at different rates under aerobic and anaerobic conditions. For example, the compounds PCE and TCE degrade readily under anaerobic conditions, but more slowly under aerobic conditions. Conversely, the compounds DCE and VC biodegrade more readily under aerobic conditions than under anaerobic conditions. The

variable biodegradation rates for the compounds of concern under aerobic/anaerobic conditions required an estimation of the expected inland extent of the aerobic groundwater conditions, or the aerobic zone.

To estimate the inland aerobic zone extent, a unit relative concentration (i.e., a conservative tracer for dissolved oxygen) was specified at the tidal boundary condition and the inland migration of the relative concentrations was simulated over a 40-year period. A longitudinal dispersivity value of 3.281 feet (1.0 meter) was applied in the solute transport simulations. Simulated relative concentration profiles at several inland distances are presented on Figure 4.2. The inland relative concentrations achieve steady-state conditions in approximately 20 years, and the relative concentrations migrate as far as 120 feet inland. It is recognized that as oxygen is introduced with recharge, it will be utilized by a variety of biological and geochemical reactions. Simulated as a conservative solute, the simulated inland extent of the relative concentrations likely overestimates the extent to which oxygen may migrate inland.

In a study of the Terminal 91 Near Shore Fill located in Puget Sound, Boatman and Hotchkiss (1997[6]) report monitoring data which demonstrate that aerobic groundwater conditions exist up to approximately 60 feet inland from the seaward face of the existing confining berm. This distance corresponds to approximately half of the distance of the inland migration simulated for the conservative relative concentrations. Therefore, based on the data reported by Boatman and Hotchkiss (1997), a 60-foot aerobic zone inland from the seaward face of the end berm was applied in the multi-species solute transport simulations (see Figure 4.2).

4.3 MULTI-SPECIES SOLUTE TRANSPORT SIMULATIONS

Two initial multi-species solute transport simulations (Scenarios 1 and 2) were conducted over a 40-year period. The input parameters applied in the multi-species solute transport simulations are presented in Table 4.1. The applied K_{oc} values reported in Table 4.1 were determined from sediment/porewater analyses presented in the report entitled, "Area 5106 Sediment Characterization Report, Embankment Area Removal Action, Former OCC Tacoma Facility, Tacoma, Washington" (Area 5106 Sediment Characterization) (CRA, 1999[7]). The applied biodegradation rates for each compound of concern under aerobic and anaerobic conditions were determined from literature reported values. Biodegradation rates are influenced by site-specific biological and geochemical conditions, which presently can not be evaluated within the Slip 1 CDF. As a result, conservative estimates of biodegradation rates were applied in the multi-species solute transport simulations. Table 4.1 presents minimum and maximum biodegradation half-life values reported in relevant literature under field-scale, anaerobic, and aerobic conditions.

For Scenario 1, the maximum of the field-scale or anaerobic half-life values was selected for each compound of concern to reflect a minimum amount of anaerobic biodegradation. Within the aerobic zone for Scenario 1, the maximum aerobic half-life values were selected for each compound of concern to reflect a minimum amount of aerobic biodegradation. For Scenario 2, the maximum amount of PCE, TCE, and DCE anaerobic biodegradation is represented by selecting the minimum reported anaerobic half-lives for these compounds, while the minimum amount of VC anaerobic degradation is represented by selecting the

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[6] Boatman, C.D. and D.A. Hotchkiss, 1997, Tidally Influenced Containment Berm Functioning as a Leachate Treatment Cell – Puget Sound, Experience in Confined Disposal of Contaminated Sediments, In Proceedings: International Conference on Contaminated Sediments, Rotterdam, The Netherlands, September 7-11, pp. 897-904.

[7] CRA, 1999, Area 5106 Sediment Characterization Report, Area 5106 Removal Action, Former OCC Tacoma Facility, Tacoma, Washington, April.

maximum reported field-scale half-life for VC. Within the aerobic zone for Scenario 2, the maximum amount of PCE, TCE, and DCE aerobic degradation is represented by selecting the minimum aerobic half-lives for these compounds, while the maximum aerobic half-life was selected for VC to minimize the amount of VC aerobic biodegradation. The selected biodegradation half-life values and resulting biodegradation rates for Scenarios 1 and 2 are presented in Table 4.1. Table 4.1 also presents the stochiometric yield coefficient values and the constant solute concentrations specified over the length of the Area 5106 boundary and treated sediments applied in the multi-species solute transport simulations.

The reaction module 7 for RT3D assumes the sequential biodegradation of PCE to TCE to DCE to VC through reductive dechlorination processes under anaerobic conditions. Under aerobic conditions, RT3D assumes that PCE does not degrade, that TCE degrades via cometabilic processes, and DCE and VC biologically oxidized. Consistent with this approach, an aerobic half-life for PCE is not applied as a model input, the aerobic half-life value for TCE represents cometabolic degradation, and the aerobic half-life values for DCE and VC represent biological oxidation. Scenarios 1 and 2 are considered to conservatively bracket the range of potential biodegradation conditions with the Slip 1 CDF.

The multi-species solute transport simulation results for Scenarios 1 and 2 are presented on Figure 4.3 and 4.4, respectively. Concentration profiles over the 40-year simulation time period for PCE, TCE, DCE, and VC are presented on Figures 4.3 and 4.4. Profiles are presented for the inland edge of the Area 5106 boundary and treated sediments, the seaward edge of the Area 5106 boundary and treated sediments, the inland face of the end berm, the mid-point of the end berm, and the seaward face of the end berm. The simulated concentration profiles at the inland edge of the Area 5106 boundary and treated sediments can be seen to correspond the constant source concentrations specified within the sediments (see Table 4.1). The simulated concentrations decrease with distance toward the seaward face of the end berm. Potential concentrations discharging with groundwater to the Blair Waterway correspond to the concentrations simulated at the seaward face of the end berm. For both Scenarios 1 and 2, the simulated concentration profiles plateau at constant levels for each compound of concern throughout the model domain indicating that steady-state conditions are achieved.

The difference in the biodegradation rates applied in Scenarios 1 and 2 are apparent in the concentration profiles. For Scenario 1, greater PCE, TCE, and DCE concentrations result downgradient from the Area 5106 boundary and treated sediments, reflecting a lesser amount of biodegradation (i.e., greater half-life values, or smaller biodegradation rates) in the anaerobic and aerobic zones. For Scenario 2, greater VC concentrations result downgradient from the Area 5106 boundary and treated sediments, reflecting a greater amount of VC production resulting from a greater amount of PCE, TCE, and DCE biodegradation (i.e., smaller half-life values, or greater biodegradation rates) in the anaerobic and aerobic zones.

The average and peak simulated concentrations discharging with groundwater from the seaward face of the end berm for Scenarios 1 and 2 are presented in Table 4.2. The relevant acute and chronic marine Water Quality Criteria (WQC) for the compounds of concern also are presented in Table 4.2. The simulated peak and average concentrations discharging with groundwater for Scenarios 1 and 2 are significantly less than the acute and chronic WQC.

Two additional multi-species simulations (Scenarios 3 and 4) were conducted to assess the sensitivity of the Scenario 2 results to the applied K_{oc} values. For Scenario 3, the applied K_{oc} values presented in Table 4.1 were multiplied by the factor of $\sqrt{10}$. For Scenario 4, the applied K_{oc} values presented in Table 4.1 were

divided by the factor of $\sqrt{10}$. The simulation results for Scenarios 3 and 4 are presented on Figures 4.5 and 4.6, respectively.

For Scenario 4, the simulated discharge concentrations at the seaward face of the berm are the same as those for Scenario 2. The reduction in the K_{oc} values has the effect of reducing the time required for steady-state conditions to be achieved. Solute migration in groundwater is represented using the well known advection-dispersion equation. Solute adsorption is incorporated into the advection-dispersion equation through the use of a retardation factor. When increased, the retardation factor has the effect of slowing solute migration (both by advective and dispersive processes). When decreased, the retardation factor has the effect of slowing solute migration to a lesser extent. A K_{oc} value reduction results in a retardation factor value decrease, and a K_{oc} value increase results in a retardation factor value increase. Therefore, the reduction in the K_{oc} values has the effect of reducing the time required for solute concentrations to reach the seaward berm face, and steady-state conditions are achieved more rapidly. The magnitudes of the solute concentrations reaching the seaward face of the berm remain unchanged. For Scenario 3, the increased K_{oc} values have the effect of slowing solute migration toward the seaward berm face. Steady-state conditions are not quite achieved for Scenario 3 within the 40-year simulation period, however it is apparent that the simulated concentrations are beginning to plateau at the same steady-state concentrations as Scenario 2. The peak and average simulated discharge concentrations for Scenarios 3 and 4 are presented in Table 4.2. The average simulated discharge concentrations for Scenarios 3 and 4 are the same as those for Scenario 2. The peak simulated discharge concentrations for Scenario 3 are slightly less than those for Scenario 2 since steady-state conditions were not quite achieved over the 40-year simulation period. For Scenario 4, the simulated peak TCE, DCE, and VC discharge conditions essentially are the same as those of Scenario 2.

The average and peak simulated concentrations discharging with groundwater from the seaward face of the end berm for Scenarios 3 and 4 are presented in Table 4.2, and are significantly less than the acute and chronic WQC.

5.0 CONCLUSIONS

The multi-species solute transport simulations presented herein represent a conservative analysis of the potential future groundwater discharge concentrations of contaminants associated with the area 5106 boundary and treated sediments. The simulated contaminant concentrations discharging with groundwater to the Blair Waterway from the Slip 1 CDF are significantly below the relevant acute and chronic WQC. Therefore, the placement of the Area 5106 boundary and treated sediments within the Slip 1 CDF is protective of human health and the environment.

TABLE 4.1
INPUT PARAMETERS FOR MULTI-SPECIES SOLUTE TRANSPORT SIMULATION
PORT OF TACOMA - SLIP 1 CDF
TACOMA, WASHINGTON

Compound of Concern	Organic Carbon Partitioning Coefficient, K_{oc} [1] (L/kg)	Sorption Retardation Factor, R [2] (Dimensionless): End Berm	Existing Peninsula	Sediments
Retardation Parameters				
Tetrachloroethene (PCE)	220	2.63	12.2	9.72
Trichloroethene (TCE)	190	2.41	10.5	8.53
cis-1,2-Dichloroethene (c-DCE)	49	1.28	2.9	2.51
Vinyl chloride (VC)	70	1.52	4.5	3.78

Compound of Concern	Reported Biodegradation Half-Life, $t_{1/2}$ (Years): Field-Scale Conditions [3] Minimum Reported Value	Field-Scale Conditions Maximum Reported Value	Anaerobic Conditions [4] Minimum Reported Value	Anaerobic Conditions Maximum Reported Value	Aerobic Conditions [5] Minimum Reported Value	Aerobic Conditions Maximum Reported Value
Biodegradation Parameters						
Tetrachloroethene (PCE)	2.4	2.79	0.27	4.5	0.5	1
Trichloroethene (TCE)	0.32	4.22	0.27	4.5	0.5	1
cis-1,2-Dichloroethene (c-DCE)	0.79	3.8	0.31	2	0.08	0.5
Vinyl chloride (VC)	0.22	5	0.31	2	0.08	0.5

Compound of Concern	Selected Biodegradation Half-Life: Scenario 1, Anaerobic Zone $t_{1/2}$ (Years)	Scenario 1, Anaerobic Zone λ [8] ($days^{-1}$)	Scenario 1, Aerobic Zone $t_{1/2}$ (Years)	Scenario 1, Aerobic Zone λ ($days^{-1}$)	Scenario 2, Anaerobic Zone $t_{1/2}$ (Years)	Scenario 2, Anaerobic Zone λ ($days^{-1}$)	Scenario 2, Aerobic Zone $t_{1/2}$ (Years)	Scenario 2, Aerobic Zone λ ($days^{-1}$)
Tetrachloroethene (PCE)	4.5	4.220E-04	1	1.899E-03	0.27	7.033E-03	0.5	3.798E-03
Trichloroethene (TCE)	4.5	4.220E-04	1	1.899E-03	0.27	7.033E-03	0.5	3.798E-03
cis-1,2-Dichloroethene (c-DCE)	3.8	5.000E-04	0.5	3.798E-03	0.31	6.126E-03	0.08	2.374E-02
Vinyl chloride (VC)	5	3.798E-04	0.5	3.798E-03	5	3.798E-04	0.5	3.798E-03

TABLE 4.1
INPUT PARAMETERS FOR MULTI-SPECIES SOLUTE TRANSPORT SIMULATION
PORT OF TACOMA - SLIP 1 CDF
TACOMA, WASHINGTON

Compound of Concern	*Constant Source Concentration* [7] *(µg/L)*	*Stochiometric Yield Coefficient* [8] *Value (Dimensionless)*	*Daughter/Parent Compound*
Biodegradation Parameters (Cont'd)			
Tetrachloroethene (PCE)	700	-	-
Trichloroethene (TCE)	830	0.795	TCE/PCE
cis-1,2-Dichloroethene (c-DCE)	48	0.737	c-DCE/TCE
Vinyl chloride (VC)	2,600	0.645	VC/c-DCE

Notes:

(1) Site-specific values calculated from sediment/porewater analyses performed during the Area 5106 Sediment Characterization. The value for c-DCE is based on the value calculated for trans-DCE.

(2) Retardation factor values determined from $R=1+K_{oc}*f_{oc}*\rho_{db}/n$ with the following input parameters:

Input Parameter	*Future End Berm Material* *Value*	*Basis*
Fraction of organic carbon, f_{oc}	0.001	- Conservative value for sand and gravel to be applied in berm construction
Soil dry bulk density, ρ_{bd} (g/mL)	2.6	- Conservative value for sand and gravel to be applied in berm construction
Porosity, n	0.35	- Conservative value for sand and gravel to be applied in berm construction

Input Parameter	*Sediment Material* *Value*	*Basis*
Fraction of organic carbon, f_{oc}	0.0111	- Value from Area 5106 Sediment Characterization
Soil dry bulk density, ρ_{bd} (g/mL)	2.75	- Value from Area 5106 Sediment Characterization
Porosity, n	0.77	- Value from Area 5106 Sediment Characterization

(3) Values correspond to minimum and maximum field scale half-lives reported in "Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Air Force Center for Environmental Excellence, Wiedemeier et al., November 1996".

(4)&(5) Values correspond to aqueous biodegradation half-lives reported as being determined under anaerobic or aerobic conditions in "Handbook of Environmental Degradation Rates, Howard et al., 1991"

(6) First order biodegradation rate determined from $\lambda=\ln(2)/t_{1/2}$.

(7) Based on peak concentration obtained from the column leach tests (CLTs) conducted on the boundary sediments as reported in "Column Leach Test Evaluation Report, Area 5106 Removal Action, Former OCC Tacoma Facility, Tacoma, Washington" (CRA, April 1999). The c-DCE concentration is taken to be the maximum trans-1,2-Dichloroethene (t-DCE) concentration obtained from the CLTs.

(8) Stochiometric yield coefficient equal to the gram-molar mass ratio of the daughter product to the parent compound.

TABLE 4.2

COMPARISON OF SIMULATED DISCHARGE CONCENTRATIONS TO SURFACE WATER QUALITY CRITERIA
PORT OF TACOMA - SLIP 1 CDF
TACOMA, WASHINGTON

Compound of Concern	*Acute Marine Water Quality Criteria* (µg/L)	*Simulated Peak Concentrations Discharging with Groundwater at the Seaward Berm Face*			
		Scenario 1 [1] (µg/L)	*Scenario 2* [2] (µg/L)	*Scenario 3* [3] (µg/L)	*Scenario 4* [4] (µg/L)
Tetrachloroethene (PCE)	10,200	9.0	0.6	0.5	0.6
Trichloroethene (TCE)	2,000	11.4	1.4	1.3	1.5
cis-1,1-Dichloroethene (DCE)	224,000	2.2	0.8	0.7	0.9
Vinyl Chloride (VC)	nc	31.0	37.3	31.1	38.9

Compound of Concern	*Chronic Marine Water Quality Criteria* (µg/L)	*Simulated Average Concentrations Discharging with Groundwater at the Seaward Berm Face*			
		Scenario 1 [1] (µg/L)	*Scenario 2* [2] (µg/L)	*Scenario 3* [3] (µg/L)	*Scenario 4* [4] (µg/L)
Tetrachloroethene (PCE)	450	6.1	0.4	0.4	0.4
Trichloroethene (TCE)	nc	7.3	1.0	1.0	1.0
cis-1,1-Dichloroethene (DCE)	nc	1.4	0.6	0.6	0.6
Vinyl Chloride (VC)	525 [5]	19.5	23.5	23.5	23.5

Notes:

(1) Simulated discharge concentrations at seaward face of Slip 1 CDF future end berm (Model Cell 2) for Scenario 1 are presented on Figure 4.3.

(2) Simulated discharge concentrations at seaward face of Slip 1 CDF future end berm (Model Cell 2) for Scenario 2 are presented on Figure 4.4.

(3) Simulated discharge concentrations at seaward face of Slip 1 CDF future end berm (Model Cell 2) for Scenario 3 are presented on Figure 4.5.

(4) Simulated discharge concentrations at seaward face of Slip 1 CDF future end berm (Model Cell 2) for Scenario 4 are presented on Figure 4.6.

(5) Estimated based on human health criteria.

nc No criteria.

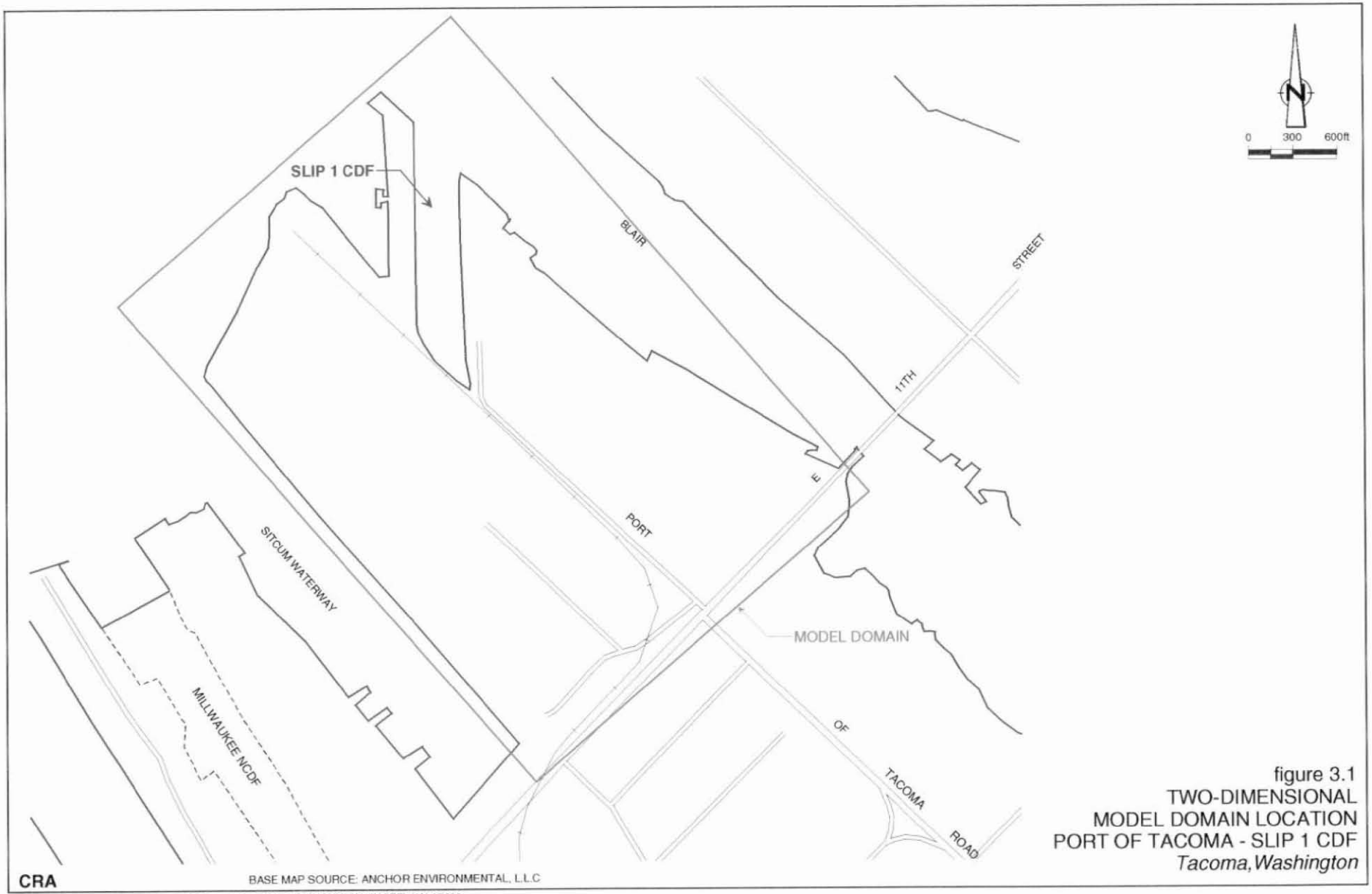


figure 3.1
TWO-DIMENSIONAL
MODEL DOMAIN LOCATION
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT'D\SRF\MODDOMAIN.SRF) JAN 4/2000

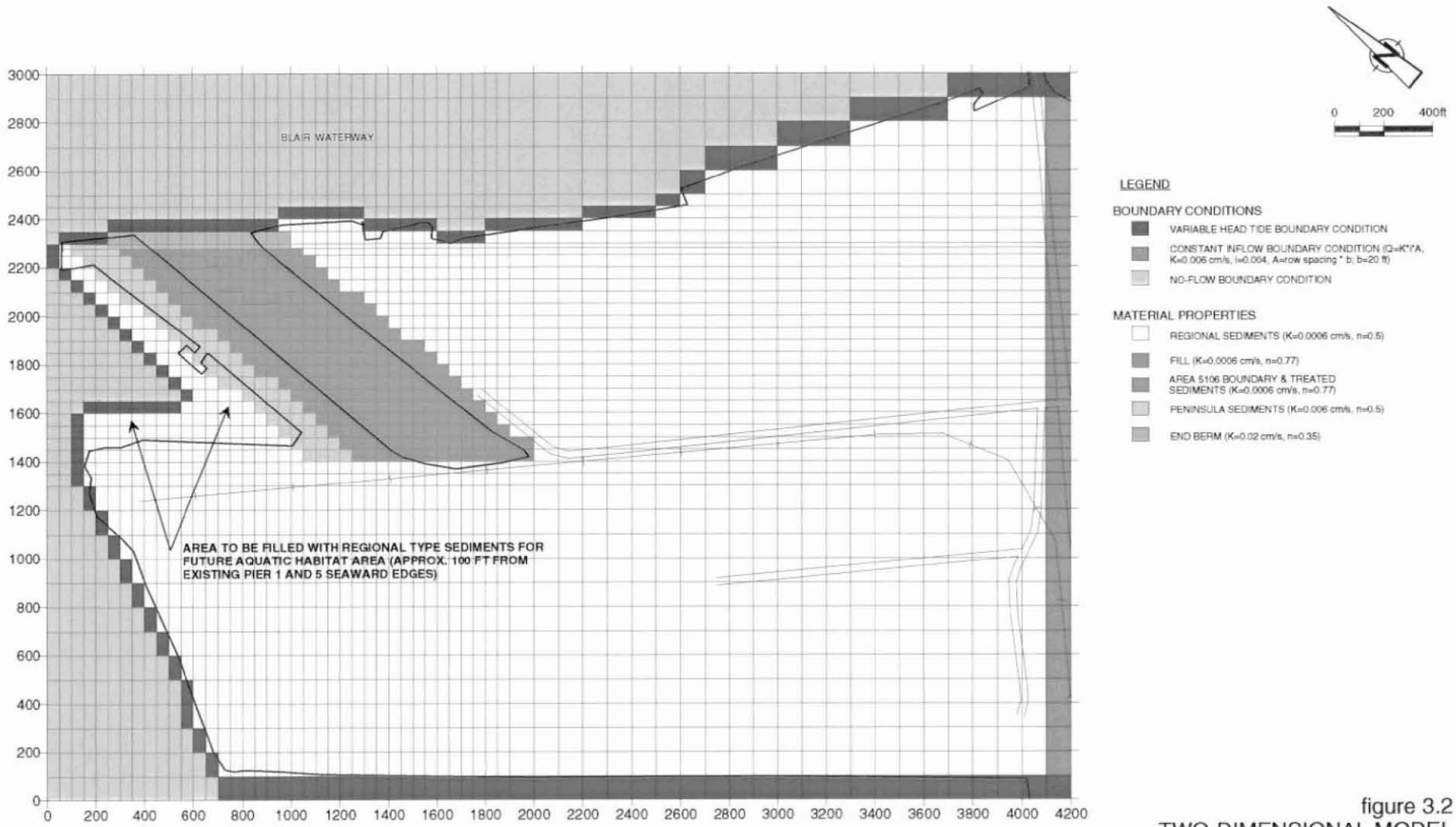


figure 3.2
TWO-DIMENSIONAL MODEL
FINITE-DIFFERENCE GRID, BOUNDARY CONDITIONS, AND MATERIAL PROPERTIES
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\2D\MODELDOMAIN2DA.SRF) JAN 4/2000

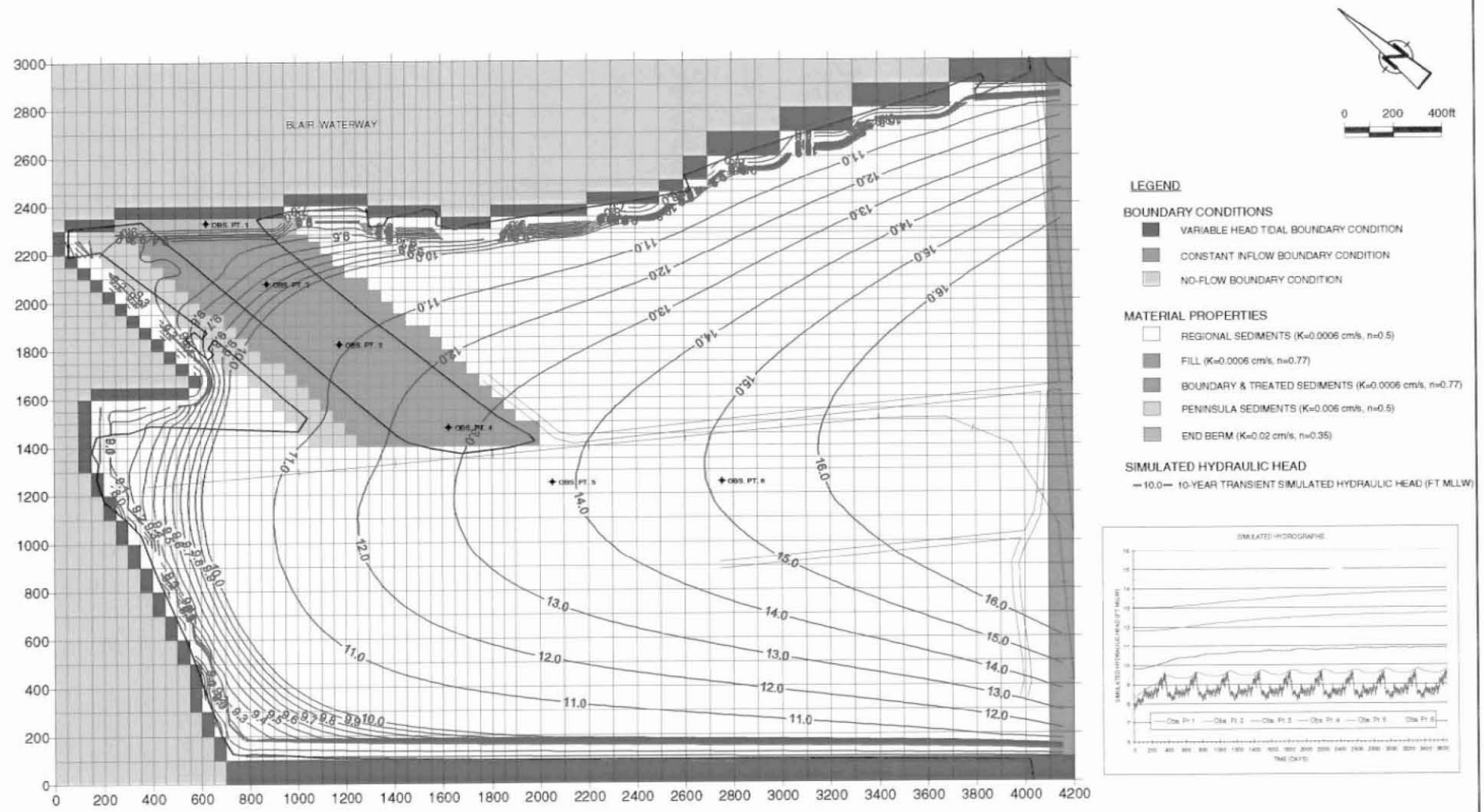


figure 3.3
SIMULATED HYDRAULIC HEAD DISTRIBUTION AFTER 10 YEARS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\2D\2DAYR10.SRF) JAN 4/2000

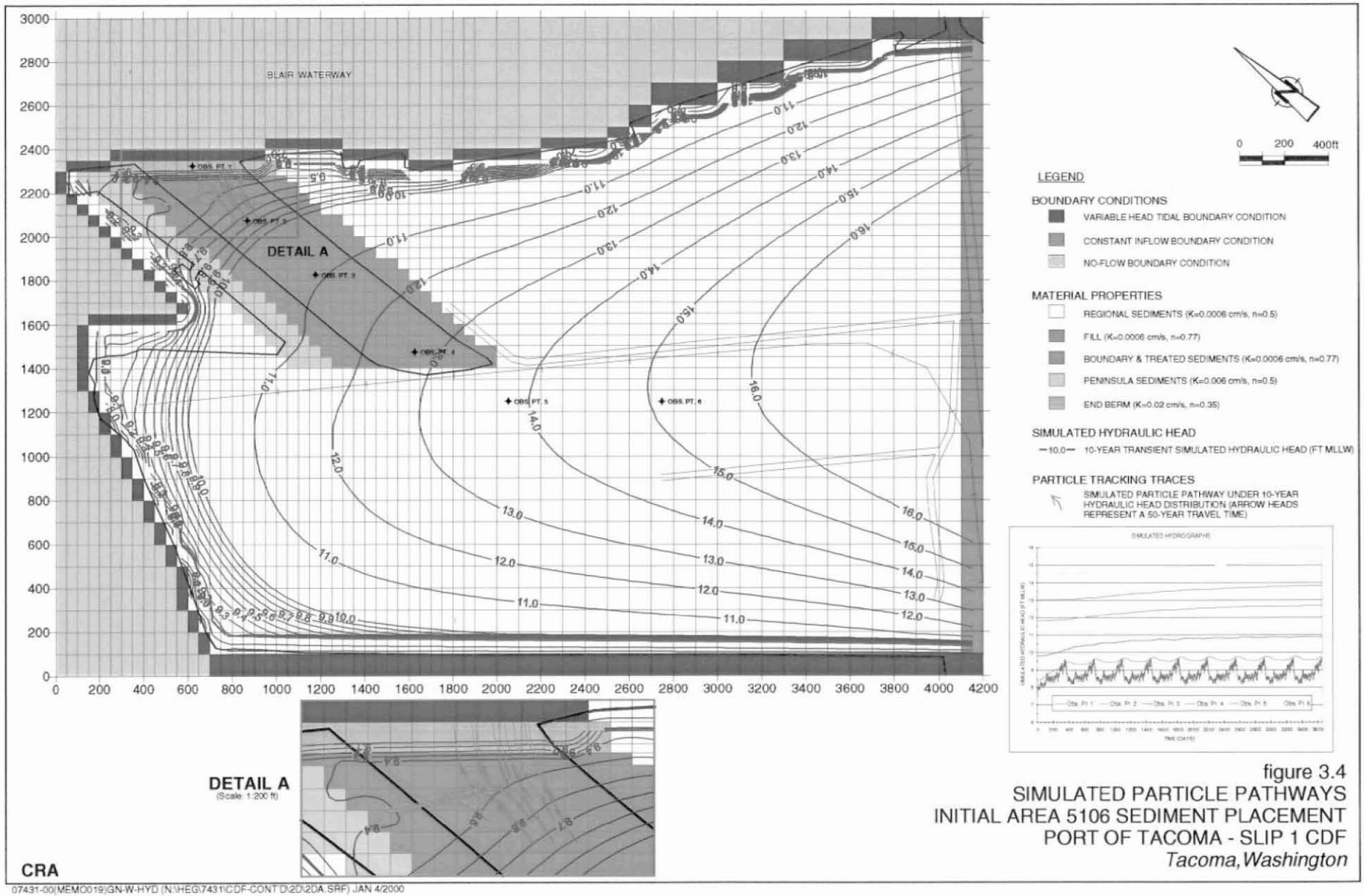


figure 3.4
SIMULATED PARTICLE PATHWAYS
INITIAL AREA 5106 SEDIMENT PLACEMENT
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\2D\2DA.SRF) JAN 4/2000

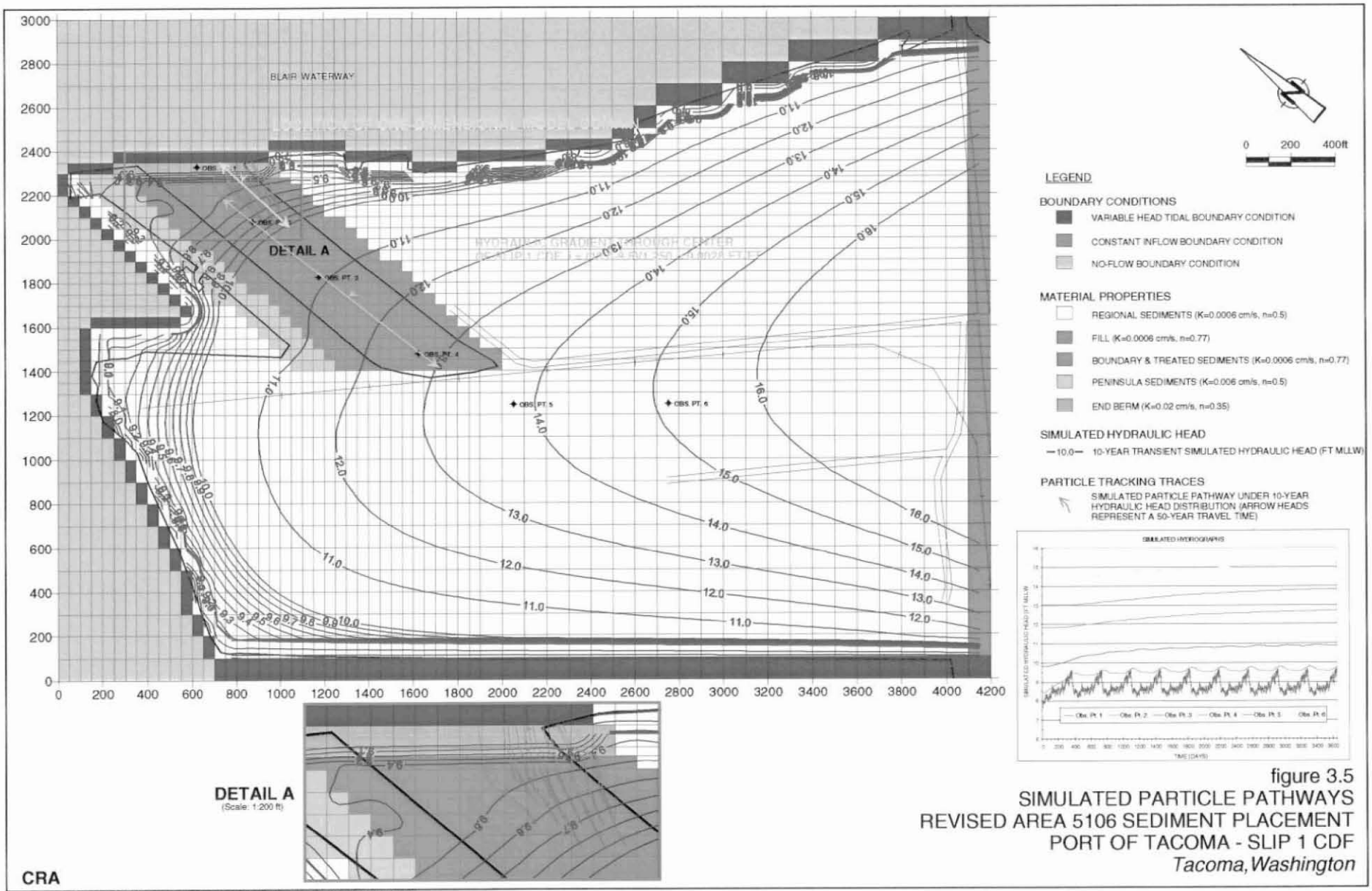
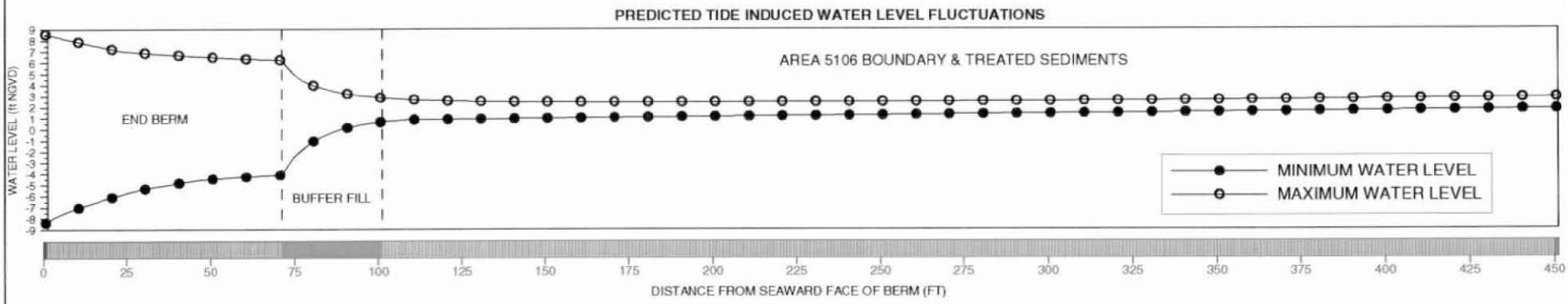
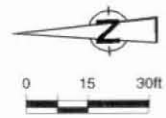


figure 3.5
SIMULATED PARTICLE PATHWAYS
REVISED AREA 5106 SEDIMENT PLACEMENT
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\2D\2DA-2.SRF) JAN 4/2000





LEGEND

BOUNDARY CONDITIONS

- VARIABLE HEAD TIDAL BOUNDARY CONDITION
- CONSTANT INFLOW BOUNDARY CONDITION (DETERMINED USING K=0.0006 cm/s & i=0.0028 FROM 2-D MODEL)

MATERIAL PROPERTIES

- END BERM (K=0.02 cm/s, n=0.35)
- FILL (K=0.0006 cm/s, n=0.77)
- AREA 5106 BOUNDARY & TREATED SEDIMENTS (K=0.0006 cm/s, n=0.77)

figure 4.1
ONE-DIMENSIONAL MODEL
FINITE-DIFFERENCE GRID, BOUNDARY CONDITIONS, AND MATERIAL PROPERTIES
WITH PREDICTED TIDE INDUCED GROUNDWATER LEVEL FLUCTUATIONS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT'D\BERM.SRF) JAN 4/2000

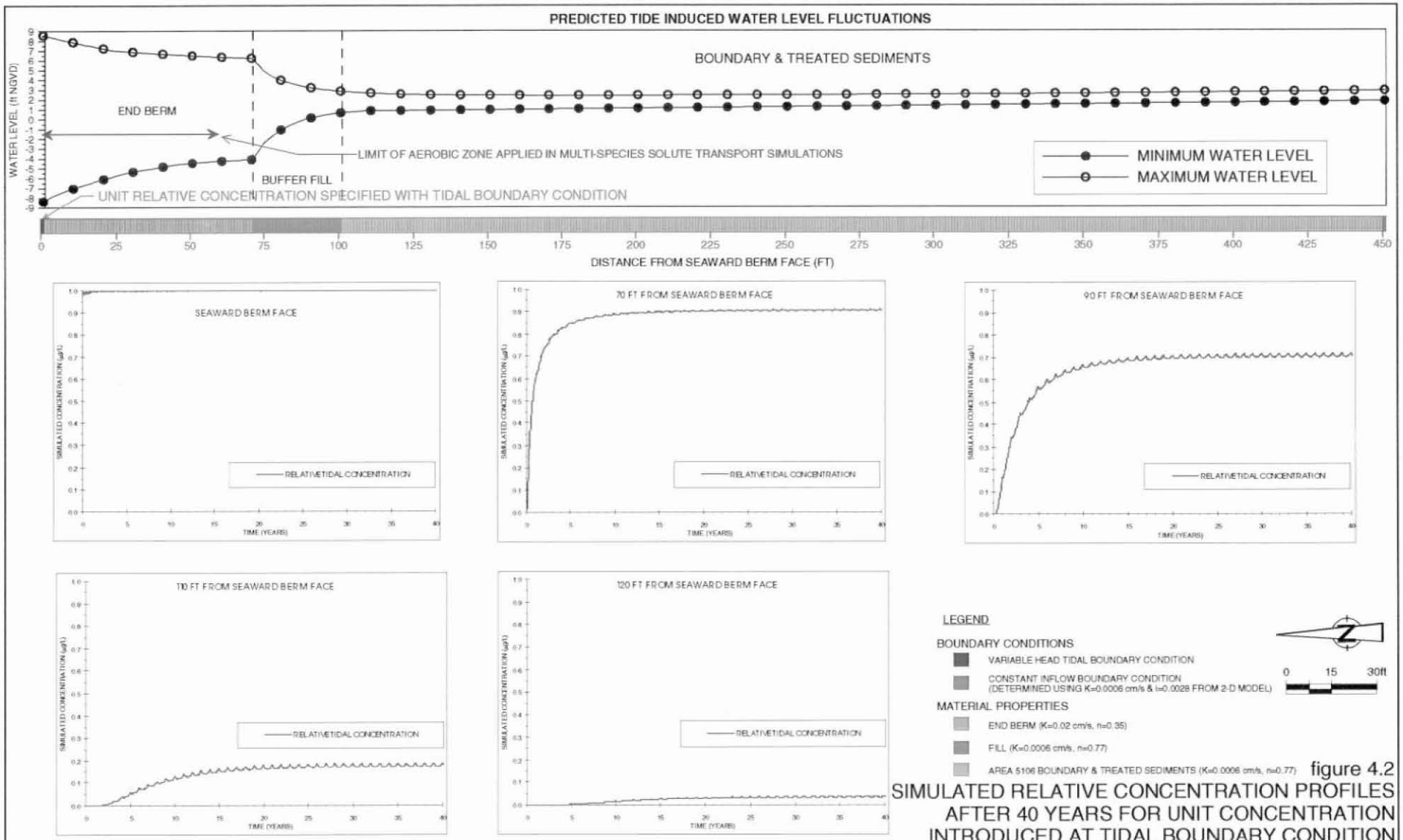


figure 4.2

SIMULATED RELATIVE CONCENTRATION PROFILES AFTER 40 YEARS FOR UNIT CONCENTRATION INTRODUCED AT TIDAL BOUNDARY CONDITION

PORT OF TACOMA - SLIP 1 CDF

Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\AEROBIC.SRF) JAN 4/2000

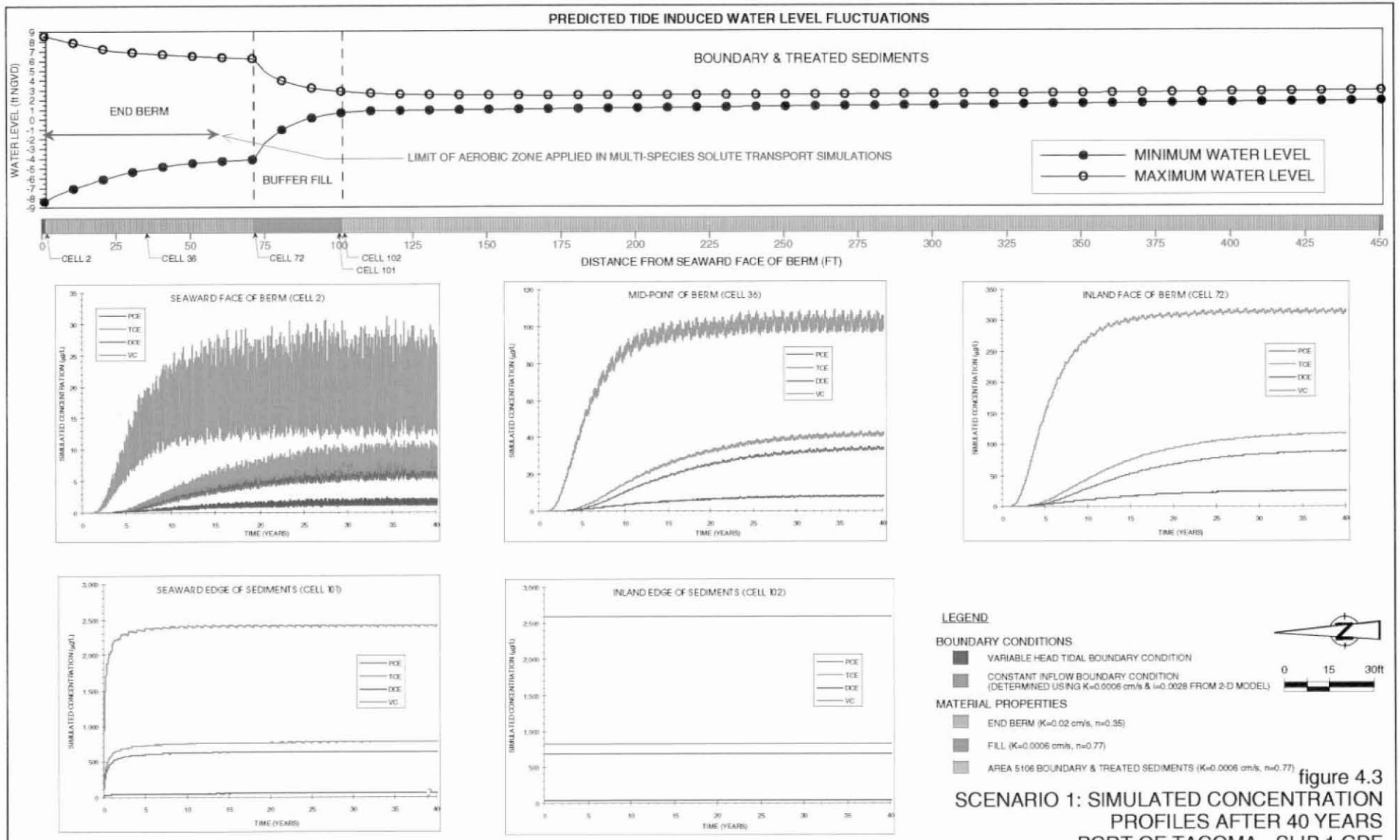


figure 4.3
SCENARIO 1: SIMULATED CONCENTRATION PROFILES AFTER 40 YEARS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT'D\SCEN1.SRF) JAN 4/2000

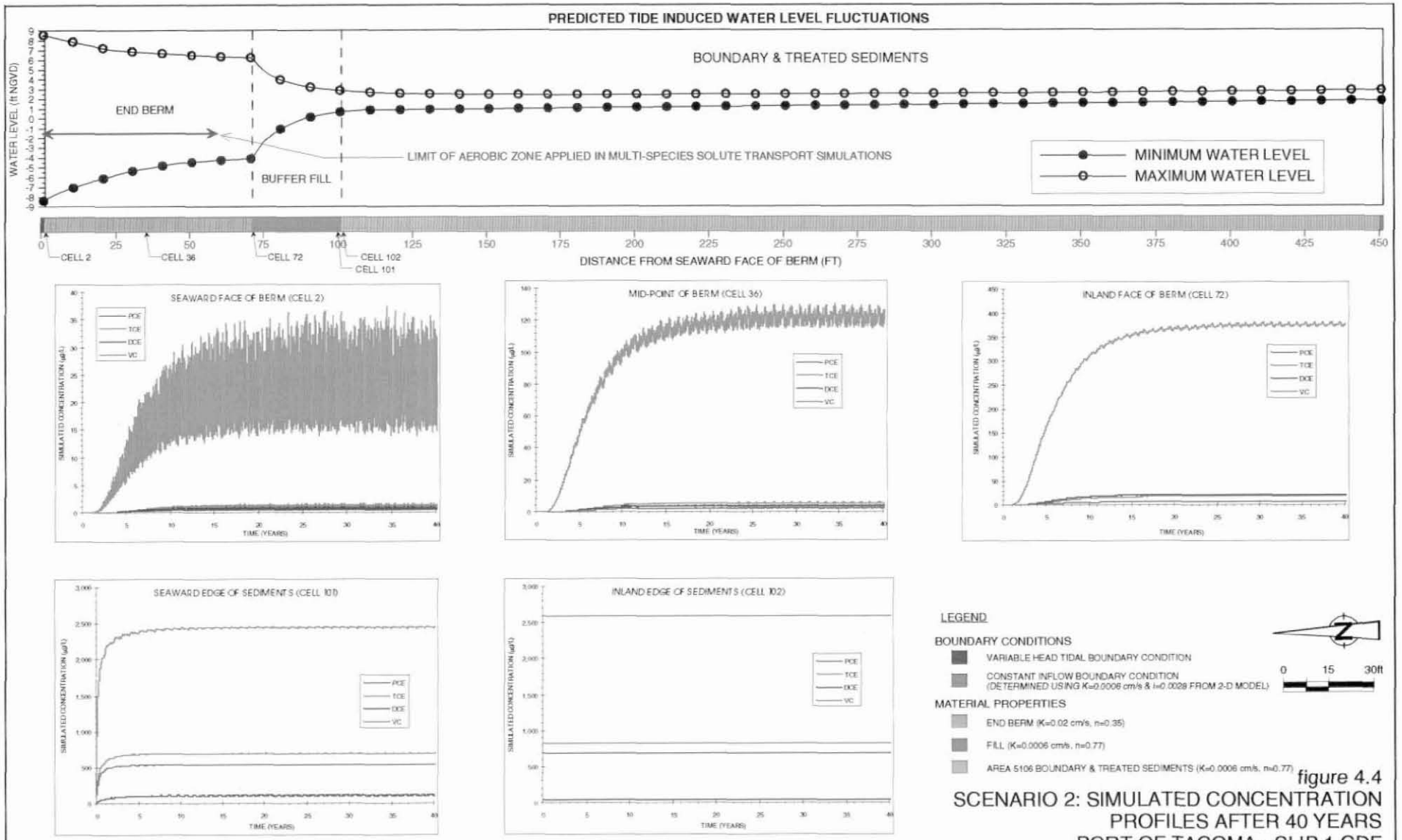


figure 4.4

SCENARIO 2: SIMULATED CONCENTRATION PROFILES AFTER 40 YEARS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT'D\SCEN2.SRF) JAN 4/2000

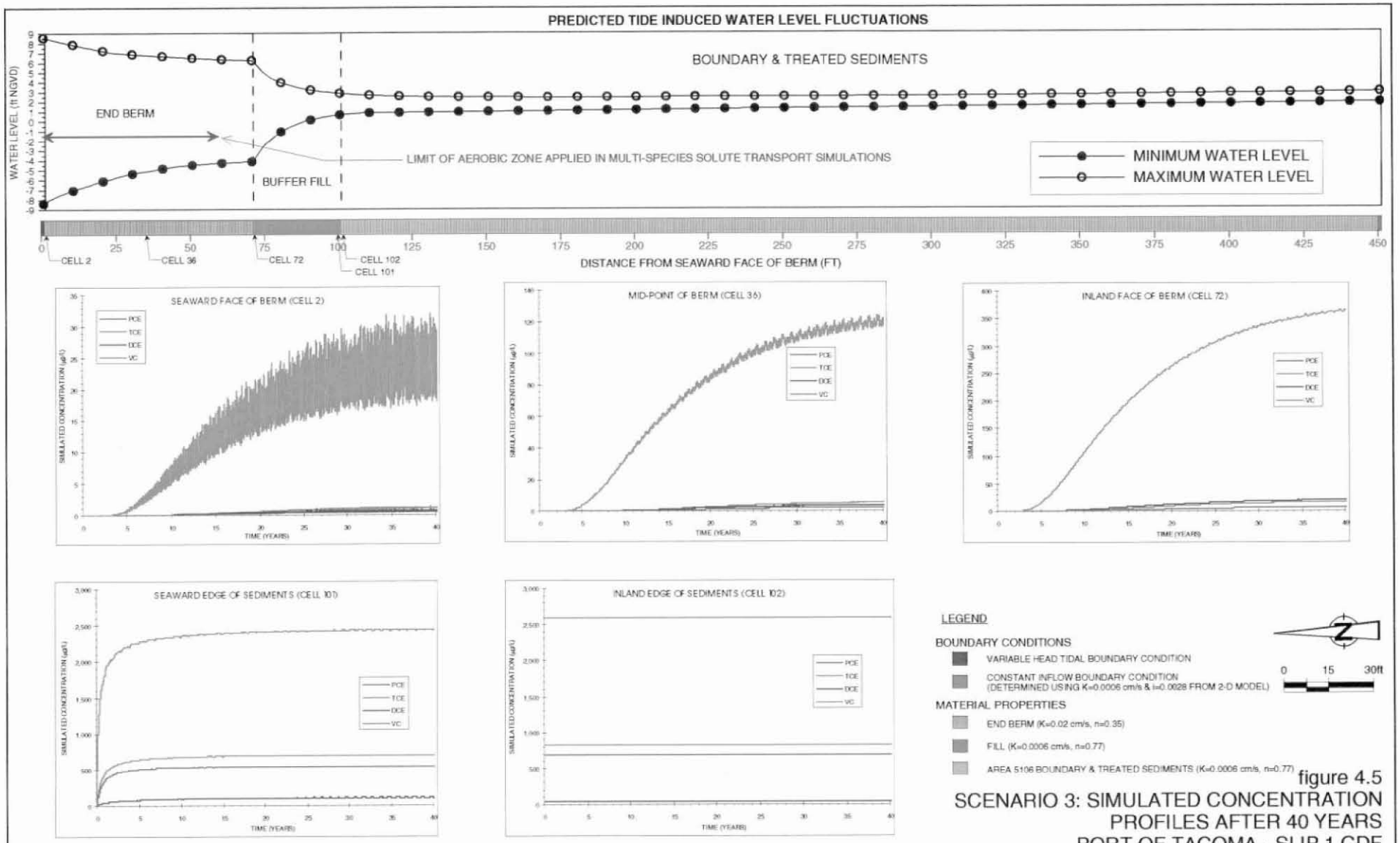


figure 4.5

SCENARIO 3: SIMULATED CONCENTRATION PROFILES AFTER 40 YEARS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT'D\SCEN3.SRF) JAN 4/99

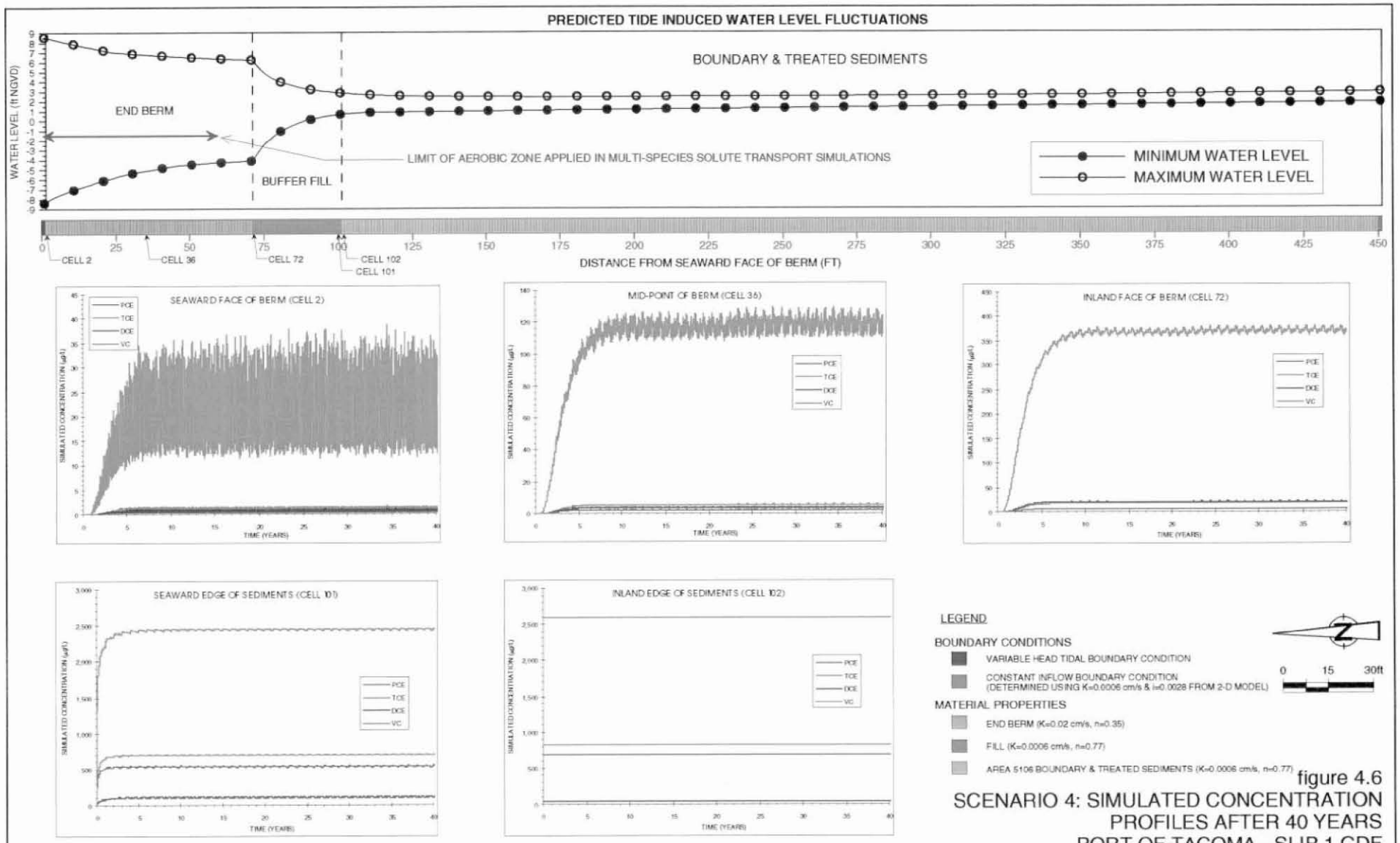


figure 4.6

SCENARIO 4: SIMULATED CONCENTRATION PROFILES AFTER 40 YEARS
PORT OF TACOMA - SLIP 1 CDF
Tacoma, Washington

CRA

07431-00(MEMO019)GN-W-HYD (N:\HEG\7431\CDF-CONT D\SCEN4.SRF) JAN 4/2000