# TECHNICAL MEMORANDUM

**TO:** RENE FUENTES (EPA REGION 10)

**FROM:** PETER TOWNSEND (NEWFIELDS, LLC)

**SUBJECT:** EXPLANATION OF EFFECTIVE DISPERSION CALCULATION

**DATE:** 4/20/2007

**CC:** ANNE SUMMERS (PORT OF PORTLAND); SEAN SHALDRAKE (EPA REGION 10)

## INTRODUCTION

This memo provides further explanation on the "effective dispersion" used in the 60% design contaminant transport modeling for Port of Portland's proposed confined disposal facility (CDF) at Terminal 4. The explanation includes a description of the physical process represented by effective dispersion, the rationale for using effective dispersion in the model, its use in previous CDF modeling, and an overview of the approach used to approximate effective dispersion.

## RATIONALE FOR USING EFFECTIVE DISPERSION

Periodic reversals of groundwater flow direction in sediments adjacent to the Willamette River due to tidal and seasonal fluctuations will effectively increase the mechanical mixing of groundwater. "Dispersion" is a general term that describes the degree of mechanical mixing that will naturally occur in groundwater in the sandy berm materials between the contaminated fill and the Willamette River. "Effective dispersion" is a term borrowed from previous CDF modeling analyses used to approximate the dispersive effects in groundwater flows resulting from the time-varying (transient) natural tidal and seasonal fluctuations in the Willamette River.

It is expected that the natural variation of the Willamette River stage will result in river water moving into the berm during high tide periods and water moving out of the berm during low tide periods (see Figure 1). NOAA[1] indicates average tidal fluctuations in the Willamette River near Portland, Oregon are approximately 1.8 ft. Changes in river stage due to seasonal fluctuations will also affect the movement of water into and out of the berm (see Figure 2). The periodic changes in flow direction result in increased travel paths, which increases dispersive effects in groundwater.

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[1] http://co-ops.nos.noaa.gov/tides07/tab2wc1b.html#133

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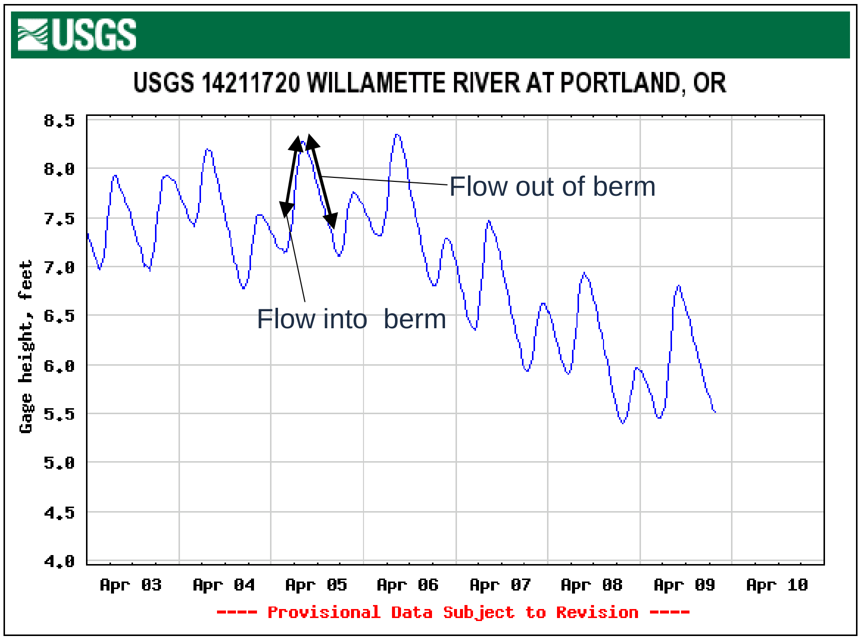


Figure 1. Tidal fluctuations (April 2007) illustrated by Willamette River stream gage near Portland, Oregon.[2]

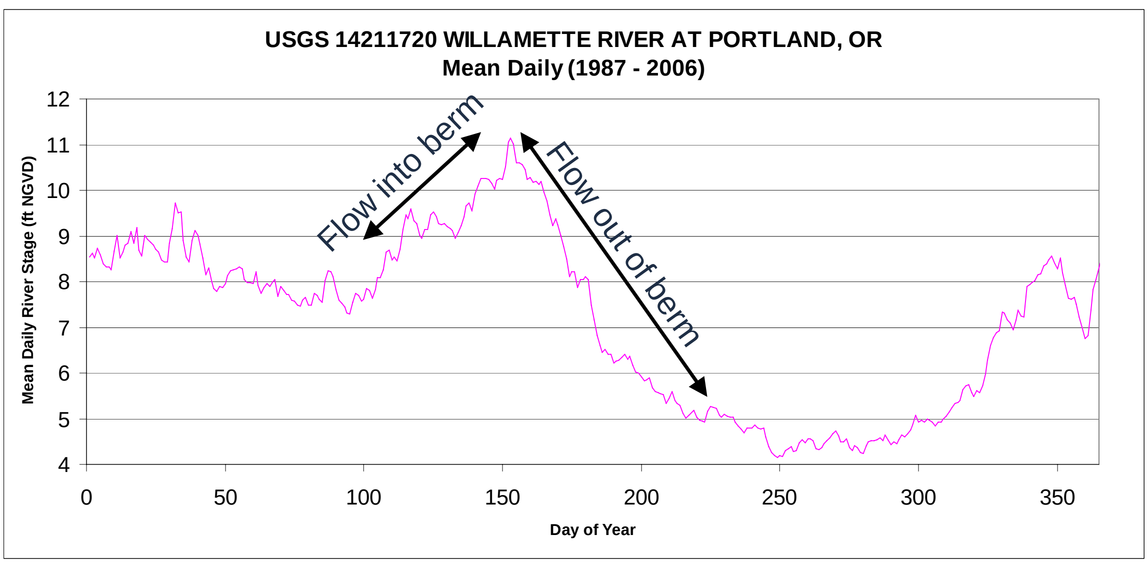


Figure 2. Mean daily river stage in the Willamette River near Portland Oregon.[3]

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[2] http://waterdata.usgs.gov/nwis/uv?14211720

[3] http://waterdata.usgs.gov/nwis/uv?14211720. Mean Daily statistics (Calculation Period 1987-10-01 through 2006-09-30) corrected for 1.55 ft gage datum.

The naturally occurring mixing effect due to river fluctuations is an important process to consider in the assessment of contaminant transport from the CDF. In the contaminant transport analysis for the 60% design, the affect of the transient river stage is approximated using "effective dispersion." The rationale for using effective dispersion is related to the simulation time-frame required to illustrate contaminant breakthrough curves for the contaminants of concern (COCs) in the long-term simulations.

For example, in the 60% design, 1000-year simulations times are performed for long-term model predictions. Representing the transient river stage in a transient flow model requires approximately 1,460,000 stress periods. Use of such an extreme number of stress periods in the flow model, transport predictions, and all subsequent sensitivity analyses is not practical. The stress periods are calculated as follows:

- 365 (mean daily stage periods per year) x 4 (twice-daily tidal periods) * 1000 (years).

The required simulation time frame for model runs, however, is dependant on the adsorption characteristics ($K_d$) assumed in the model (i.e., larger adsorption requires longer transport times to calculate or simulate past the moment of breakthrough). In addressing EPA comments on the 60% design, more conservative (smaller) $K_d$ values will be used in updated model predictions. Shorter simulation times to observe contaminate breakthrough curves are expected. Because of this, decreased simulation time-frames may make the use of a transient flow field in contaminant transport analyses more practical. Whether this is indeed the case, the appropriate approach will be reassessed based on revised model input.

## PREVIOUS CDF MODELING

This section below provides an overview of modeling analyses performed for three recent CDFs in the Puget Sound area. Specifically, the use of "dispersion" in these analyses is discussed.

**St. Paul Waterway, Tacoma**. Modeling analyses performed for the St. Paul Waterway CDF are similar to those described in the Terminal 4 60% design. Simulation time-frames of transport predictions for St. Paul ranged from 450 to 2000 years. Representation of the mechanical mixing resulting from the transient tidal affects is stated as being "computationally inefficient." To address this issue, transport simulations were performed using an effective dispersion coupled with a steady-state flow field. To calculate the effective dispersion, transient simulations were performed using the transient tidal boundary condition coupled with a conservative (non-attenuating and non-reactive) source. Transient simulations were run for 2500 days (equals approximately 7 years). Concentrations from the transient case simulations were recorded. Those resulting concentrations were then used to calibrate dispersivity using a long-term steady-state flow field model. The resulting dispersivity term estimated from this procedure was then used for long-term predictions with cross-section models along critical flow paths using a steady state flow-field.

**Terminal 91, Seattle**. Boatman and Hotchkiss[4] (1997) describe modeling performed for the Terminal 91 CDF. A transient flow model was used to simulate the mechanical mixing resulting from tidal fluctuations at Terminal 91. Maximum tidal velocities were used to estimate a tidal dispersion coefficient based on dispersivities measured for similar materials. One-dimensional

[4] Boatman, C. and D. Hotchkiss, 1997. Tidally influenced Containment Berm functioning as a Leachate Treatment Cell – Puget Sound Experience in Confined Disposal of Contaminated Sediments. Proceedings of the International Conference on Contaminated Sediments, Rotterdam, The Netherlands. September.

transport simulations along critical flow paths were then performed using the estimated dispersion coefficient.

**Blair Slip 1, Tacoma**. Blair Slip 1 modeling analyses used a two-dimensional, single layer, transient flow model to estimate a Tidal Dispersion Factor (TDF). The "TDF" should not be confused with the terms dispersion and dispersivity used in the St. Paul, Terminal 91, and Terminal 4 analyses. The TDF is equivalent to EPA's Dilution and Attenuation Factor[5]. In the Blair modeling analysis, the TDF only considers the mechanical mixing of groundwater as a result of tidal fluctuations. In other words, attenuation is not considered or included in the estimated TDF. To estimate the TDF, simulations were performed using the transient tidal boundary condition coupled with a conservative (non-attenuating and non-reactive) source, assuming a concentration of 1. The range of predicted concentrations at the receptor point were recorded. The resulting TDFs ranged from 26 to 52 (i.e., dilution factor resulting from naturally occurring mechanical mixing with ambient groundwater). For most COPCs (except for volatile organic compounds, described below), the TDF results demonstrated the CDF was protective of human health and the environment. Additionally, one-dimensional transport simulations were then performed to simulate sequential biodegradation of PCE to TCE to DCE to VC under aerobic and anaerobic conditions along the critical groundwater flow path.

### APPROXIMATING EFFECTIVE DISPERSION

This section describes the process for approximating the T4-specific "effective dispersion." As discussed above, it is recognized that periodic reversals of groundwater flow direction in the sandy berm materials adjacent to the Willamette River is an important process to consider in contaminant transport evaluations. However, large simulation time-frames made a transient flow field impractical in the 60% design's transport analysis. Thus, the use of effective dispersion with a steady-state flow field was a more practical alternative to predictions made with a transient flow field.

To approximate effective dispersion, a transport simulation is performed using a transient flow field. The mean daily stage statistic (Figure 2) with the superimposed daily average tidal variation is representative of the full tidal stage variation of an average flow year of the Willamette River. This resulting transient hydraulic head boundary condition is shown in Figure 3. The time-series shown in Figure 3 is repeated in the transient hydraulic head boundary for additional years necessary to achieve peak concentration at the berm-river interface.

To approximate how actual dispersion is impacted by these daily tide fluctuations and seasonal variations, a conservative (non-attenuating and non-reactive) contaminant source is assumed in the sediment fill area at concentration of 1. Dispersivity is set to a small value in the entire model (2.0 ft). The transient model is then run until peak concentrations at the berm-river interface are observed. The resulting peak concentration in groundwater is recorded.

Then, to finalize the calibration process, the model is run again using a steady-state flow field with the same conservative contaminant source. A long-term average river stage [6] (7.4 ft) is assumed to be representative for the steady-state flow field. Dispersivity for the berm materials is adjusted in the steady-state flow field case until peak concentrations match the transient case, that way effectively implementing the estimated dispersion into the model as it was simulated using a transient flow field.

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[5] The DAF is the ratio of source concentration to the predicted concentration in ground water at the receptor. http://www.epa.gov/superfund/resources/soil/index.htm

[6] http://waterdata.usgs.gov/nwis/uv?14211720

The procedure resulted in dispersivity values consistent with ranges provided in the literature and EPA guidance [7].

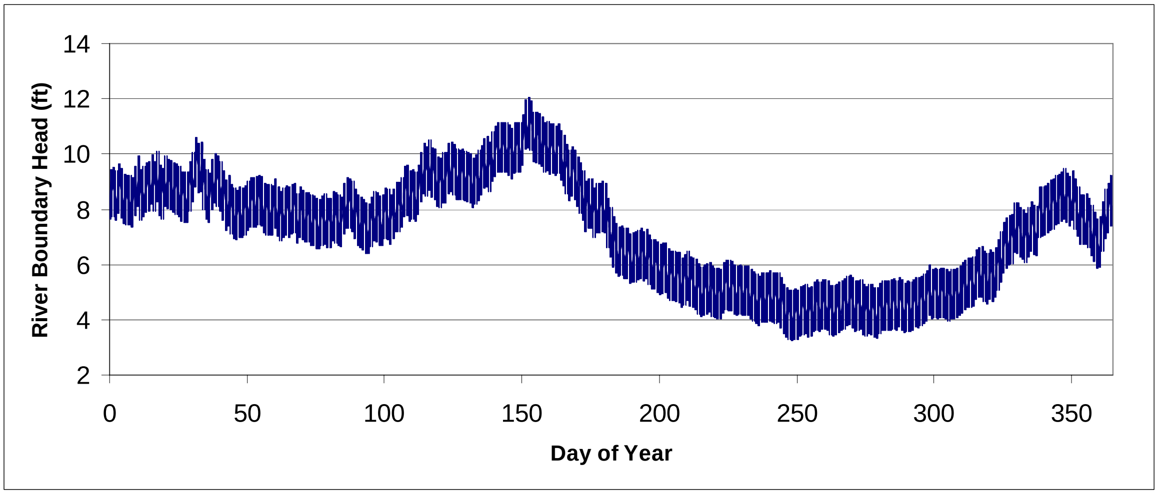


Figure 3. Transient hydraulic head boundary condition representing the Willamette River.

## CONCLUSIONS

Dispersion in the sandy berm material adjacent to the Willamette River is caused by periodic reversals of groundwater flow direction. Reversal in groundwater flow direction is the result of tidal and seasonal river stage fluctuations. The natural fluctuation in river stage effectively increases the mechanical mixing of ambient groundwater with dredged material leachate water.

It is understood that representing the mixing effect resulting from river fluctuations is an important process to consider in the assessment of contaminant transport from the CDF. However, large simulation time-frames inhibited the practical use of a transient flow model in the 60% design contaminant transport analysis. The use of dispersion with a steady-state flow field was an appropriate and effective alternative to approximate the effects of mechanical mixing in groundwater.

The approach used in the 60% design for Terminal 4 for estimating mechanical dispersion was similar to the St. Paul CDF modeling approach. Terminal 91 also estimated dispersion using a transient flow model and was applied in a one-dimensional transport analysis. Modeling for Blair Slip 1 focused predominately on transient flow modeling. Estimated dispersivity values used in contaminant transport analyses for Terminal 4 60% design were within literature ranges and EPA guidance.

It should be stressed that berm design changes (e.g., size of training dikes) and other model input assumptions (e.g., hydraulic conductivity, $K_d$, etc.) will change the result of the described modeling analysis. As such, a revised modeling analysis will be performed following agreement of flow model and transport model input assumptions. Finally, as discussed in conversations regarding modeling documentation, more illustrations and description will be provided to more clearly describe model assumptions and results of analyses.

[7] http://www.epa.gov/athens/learn2model/part-two/onsite/longdisp.htm