Modeling Review for the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site Richland, Washington

June 18, 2009

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21-1-12218-002

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MODELING REVIEW FOR THE TANK CLOSURE AND WASTE MANAGEMENT ENVIRONMENTAL IMPACT STATEMENT FOR THE HANFORD SITE, RICHLAND, WASHINGTON

This report provides our review of the vadose zone and groundwater flow and transport models developed by the U.S. Department of Energy (DOE) in support of the Tank Closure and Waste Management Environmental Impact Statement for the Hanford site (EIS).

In general, our services have included attendance at meetings as requested with DOE and Washington State Department of Ecology (Ecology) in Richland, Washington, review of documents related to the subsurface movement of contamination at the Hanford site, review of interim model results, and review of the groundwater model related portions of the draft EIS. Our services have been performed under Washington State Department of General Administration Contract No. 32206.

1.0 INTRODUCTION

The purpose of our work is to assist Ecology in the technical evaluation of the computer model developed to support decision making within the EIS process by DOE and it's consultant, SAIC (the modeling team). The technical evaluation is intended to assess the adequacy of the modeling effort to support EIS level decisions, specifically for the evaluation of alternatives for tank closure and waste management at the Hanford site. Our scope of services does not include a review of the alternatives or the modeling results of the comparison of alternatives.

1.1 Objectives

The primary objective of our efforts is to validate the modeling approach for Ecology and to assist Ecology in responding to stakeholder and public comments. Our review is intended to evaluate if the model approach is appropriate for EIS purposes, meets the standard of practice for computer modeling of groundwater flow and contaminant transport, and provides sufficient representation of physical processes that control water movement and contaminant transport in the subsurface.

1.2 Organization

This report does not necessarily correlate directly to the task items identified in the contract statement of work. Instead, the report follows a logical discussion of the modeling process from contaminant sources to discharge at the Columbia River as follows:

- Conceptual models for flow and transport
- Source release models
- Vadose zone transport model
- Groundwater flow model
- Groundwater transport model
- Sensitivity analyses
- Conclusions

Although the order of the report sections is different from the order of tasks in the statement of work, the report covers each of the task items, with the exceptions noted in the following section.

1.3 Deviations from Statement of Work

As indicated above, the report addresses most of the task items described in the statement of work. However, several subtasks could not be completed, specifically those requiring model simulations to evaluate calibration (Task 3), run Visual MODFLOW (Task 4), and conduct additional simulations (Tasks 5 and 6). The primary reason for not performing these subtasks was the reluctance of DOE to allow Ecology access to the model codes. Although the model simulations were not completed, in general, DOE agreed to run simulations at the request of Ecology and, in our opinion, additional model simulations are not essential to perform our review.

1.4 Basis for Review

Our review was based primarily on available documents, meetings with Ecology and the modeling team, presentations by the modeling team, and our experience with computer modeling of water movement and contaminant transport in the subsurface.

The documents reviewed include reports on subsurface conditions and previous modeling efforts at the Hanford site (see Reference section), relevant portions of previous completed EISs for the project, and specific guidance documents related to the current EIS, in particular the Technical Guidance Document (TGD). A number of the documents were recommended and provided to us by Ecology and DOE staff. The Pacific Northwest National Laboratory (PNNL) report describing the System Assessment Capability modeling effort was helpful in providing the basis

for understanding the conceptual model for water movement and contaminant transport at the Hanford site.

Documents specific to this EIS include the report prepared by the MODFLOW Technical Review Group (MTRG) and internal draft EIS dated November 2008. In particular, the internal draft EIS provided our initial opportunity to review the groundwater transport analyses and preliminary simulations of the impact of the proposed Block Rock Reservoir on Hanford groundwater levels and contaminant migration.

We also attended a STOMP modeling short course at Oregon State University in Corvallis, Oregon. STOMP is the computer code proposed by DOE for simulating water and contaminant movement in the vadose zone. Our attendance at this STOMP Short Course provided the opportunity to explore and discuss the structure and use of the STOMP Simulator with the developers of the model from PNNL, including Mark White, Mart Oostrom, and Andy Ward.

As noted above, we attended numerous meetings and presentations about the modeling effort. Attachment A provides a list of the meetings and topics discussed.

2.0 REVIEW OF CONCEPTUAL MODELS

Conceptual models provide a basis for developing computer models to simulate a system. In general, the conceptual model describes the physical processes that drive a system, in this case the movement of contaminants from the source, through the vadose zone, and with groundwater to the Columbia River. Although the modeling team did not provide a detailed conceptual model for the EIS, they constructed the computer models based on previous conceptual models for the site and where the previous models did not adequately describe the system, they evaluated and tested their understanding of the system. A discussion of the conceptual basis for the modeling is provided below.

2.1 Source Area Conceptual Model

Conceptually, the source areas have been previously described as part of the cumulative inventory. Our review did not identify specific deviations from the cumulative inventory. The modeling team identified 6 types of sources and developed source release models based on theoretical equations. The specific types of sources potentially include:

- Direct injection (e.g. ponds, trenches, cribs, tank leaks, tank failure, and other spills);
- Solubility-limited waste matrix (e.g. salt cakes from tanks);
- Partitioning-limited convective flow (e.g. contaminated soil);

- Diffusion limited (e.g. grouted tanks, cast stone, and secondary grout waste forms);
- Fractional release rate (e.g. ILAW glass and bulk vitrification glass); and
- Constituent solubility limited (not used).

We reviewed the conceptual models used to develop the equations that provided the basis for the source release models both in meeting with the modeling team and as described in the draft EIS. A key assumption of the modeling team was that the source areas are under homogenous and isotropic conditions. Given the uncertainty associated with source areas, this assumption is appropriate for EIS purposes.

In our opinion, the conceptual models adequately represent the release of contaminants from the identified source types.

2.2 Vadose Zone Conceptual Model

The conceptual model used by the modeling team to develop the vadose zone computer models is similar to the previous models for geology and water movement. However, the previous models assumed that water movement in the vadose zone was primarily downward and could be adequately represented as one-dimensional movement. The modeling team completed a conceptual evaluation of dimensionality by considering simple one-, two-, and three-dimensional simulations of vadose zone water and contaminant movement. They demonstrated that conceptually, three-dimensional models better represent the actual movement of water contaminants in the vadose zone by allowing lateral spreading. As a result, the modeling team developed site specific models of stratigraphy for each source area based on soil types observed in nearby borings to better simulate the three-dimensional nature of flow and transport in the vadose zone.

Previous modeling efforts had not considered the impact of clastic dikes on water and contaminant movement in the vadose zone. The modeling team performed a conceptual evaluation of the clastic dikes by simulating a high permeability vertical slice of soil in the model. The results indicate that clastic dikes may allow for more rapid movement of contaminants to the water table. The analysis suggests that inclusion of clastic dikes is unlikely to have a significant impact on the decision process for the EIS, but would likely be more important for evaluation of specific sites.

Because of the modeling teams plan to use the STOMP code to simulate water and contaminant movement in the vadose zone and MODFLOW to simulate the groundwater flow system, a conceptual evaluation of the impact of a fixed water table as the bottom boundary of the vadose

zone was performed. During the operational period, water table fluctuations were simulated using MODFLOW; however these fluctuations could not be simulated in the STOMP models. The modeling team evaluated the impact of changing the elevation of the lower STOMP boundary (the water table) on contaminant flux from the STOMP model as part of the sensitivity analyses described below.

Several methods are available to describe water movement in the vadose zone. To describe the relationship between pore pressure and moisture content, the modeling team used the Van Genuchten model (Van Genuchten, 1980), which is widely accepted as the standard for vadose zone modeling. The relationship between pore pressure and moisture content is used to estimate the unsaturated hydraulic conductivity of the soil in the vadose zone.

In our opinion, the conceptual models for vadose zone transport adequately represent the movement of water and contaminants from the source areas to the water table.

2.3 Groundwater Flow Conceptual Model

The modeling team used the previously completed groundwater modeling work and the TGD as the basis for the groundwater flow conceptual model, with the exceptions discussed below. The exceptions were incorporated into the conceptual model with concurrence from the MTRG. The modeling team did not provide a written conceptual model and instead noted deviations from the previous modeling work.

The TGD states that two cases for groundwater flow should be evaluated; the base case with flow primarily to the east and the alternative case with flow primarily to the north. Currently, groundwater flow is primarily to the east; however, during the operational period, as a result of additional recharge to the water table from source areas, a rise in the water table allowed for the potential for flow to the north through Gable Gap. Conceptually, the rate of groundwater flow through Gable Gap is likely controlled by either the elevation of the basalt bedrock surface or the hydraulic conductivity of the shallower basalt, which may have been weathered resulting in an increase in the hydraulic conductivity relative to the majority of the basalt (DOE, 2007). There is some uncertainty in the elevation of bedrock in Gable Gap, and the modeling team completed a statistical evaluation using kriging techniques to contour the bedrock surface in this area and determine the most likely elevation for the easterly flow condition and most likely lower limit of the bedrock surface for the northerly flow condition.

The modeling team assumed the basalt bedrock underlying the unconfined aquifer has a low permeability and behaves as a no-flow boundary. Although they acknowledged that this may not

be completely accurate, they performed model simulations to validate the assumption by allowing some flow through the bedrock based on hydraulic parameters values described by others. The simulations indicated that the rate of groundwater flow from bedrock into the overlying, unconfined aquifer would have negligible impact on the modeling results, with the MTRG concurring with the results. In our opinion, the assumption of a no-flow boundary for the basalt bedrock is appropriate for EIS purposes.

The primary source of recharge to the water table had been assumed to be water discharge to the ground surface during the operational period of Hanford and an average recharge from precipitation of 3.5 millimeters per year as stated in the TGD. However, several sources of potential recharge exist along the mountain front at the western boundary of the site, including springs and subsurface flow. The modeling team incorporated these features based on field evidence and water level data.

The modeling team assumed that the Columbia and Yakima River stages are constant. Given the long period of simulation for the EIS (10,000 years), this is a reasonable assumption as both rivers have upstream hydraulic controls.

Conceptually, the modeling team assumed each stratigraphic unit identified at the Hanford site would have a constant set of hydraulic parameters in the model. For example, the Ringold Mud would have a single horizontal hydraulic conductivity value, a single ratio of horizontal to vertical hydraulic conductivity, a single porosity value, and a single storage coefficient value. In our opinion, this is not valid as field and laboratory data indicate that most stratigraphic units have hydraulic parameters values that range over orders-of-magnitude. This assumption needs to be acknowledged and tested. As discussed below in the section on calibration of the groundwater flow model, this assumption may pose challenges for the modeling process. In addition, it is our opinion that decision making processes for specific sites during tank closure (i.e., localized models) will require a more detailed evaluation of the hydraulic parameter variability within specific stratigraphic units.

2.4 Transport in Groundwater Conceptual Model

The conceptual approach for transport of contaminants in groundwater was to input the contaminant fluxes at the water table developed from the vadose zone modeling onto the calibrated groundwater flow field. The contaminants would then move advectively with groundwater, spreading in response to hydrodynamic dispersion, and, in the case of

radionucleotides, decay over time. The movement of some contaminants would be slowed by chemical bonding to soil particles as a function of the contaminant distribution coefficient.

In general, this conceptual model is appropriate for the purposes of the EIS with the exception of a couple of contaminants. In particular, the implemented model of contaminant movement in groundwater does not sufficiently represent the movement of dense, non-aqueous phase liquids (DNAPLs), such as carbon tetrachloride. Because DNAPLs are denser than water, these contaminants tend to migrate downward through the water column. Although some of the contaminant may become dissolved in groundwater and then migrate as described by the conceptual model for other contaminants, the majority of the mass of these contaminants has been shown to remain as a NAPL.

Based on our understanding of the distribution of carbon tetrachloride from conversations with Ecology staff, it is likely that the release of carbon tetrachloride occurred as a DNAPL and migrated downward through the water column to the basalt bedrock surface. Therefore, the conceptual model used for groundwater transport does not adequately represent the movement of carbon tetrachloride.

3.0 COMPUTER SIMULATIONS OF FLOW AND TRANSPORT

This section describes our review of the computer models used to simulate the movement of contaminants in the subsurface from the source areas. When applicable, we reviewed construction of the models, model input parameters, model calibration, model simulation runs, and model output. Contaminants to be evaluated are described in the TGD and Cumulative Impact Inventory.

3.1 Release Models

The computer models developed by the modeling team to simulate the release of contaminants to the subsurface are simple models based on accepted equations representing flux, solubility, diffusion, or a combination of the above from the identified source types. Input parameters were based upon information provided in the Cumulative Impact Inventory and on expected values from field and laboratory testing at the Hanford site.

Although no systematic process of calibration or sensitivity analysis was completed for the release models, the computer models do not represent a major source of error when compared to uncertainty associated with model inputs, such as concentrations of contaminants in the sources or flux from sources including ponds, cribs, and trenches. The Cumulative Impact Inventory

provides some information for the approximately 380 source areas evaluated at the Hanford site, however many of the source areas are not historically well documented and input data may be based on recent sampling, historical photos and drawings, and assumed typical operation of disposal areas.

Output contaminant flux from the release models was used as input to the vadose zone model.

In our opinion, the release models are consistent with the standard of practice for computer modeling, sufficiently represent the known physical processes governing contaminant movement in the subsurface, and are sufficient for the purpose of the EIS.

3.2 Vadose Zone Model

To simulate the movement of water and contaminants from the sources areas, through the vadose zone, and to the water table, the modeling team used the STOMP code developed by PNNL. The STOMP code is licensed and available only through PNNL, and it not a commonly used or well known computer program. Based on the information provided in the short course we attended and in discussions with developers of the code, the STOMP code is in a constant state of verification through both laboratory and field experiments performed at PNNL. In our opinion, the STOMP code has been well-verified to simulate the physical processes controlling the movement of water and contaminants in the subsurface, and is an appropriate code for modeling the transport of water and contaminants through the vadose zone and estimating contaminant fluxes to the water table in support of the EIS at the Hanford Site.

The modeling team constructed approximate soil profiles for each of the source areas using all validated boring logs in the vicinity of the source area. Depending on if there was a sufficient number of borings associated with a particular source area, multiple profiles were developed to provide a three-dimensional model of soil stratigraphy. In some cases, only one boring log was available and the three-dimensional model of soil stratigraphy was based solely the boring log. A total of approximately 5,000 profiles were developed and used to generate about 150 STOMP models, which incorporated the 380 individual source areas (that is, some of the STOMP models contained multiple source areas). A computer code was developed to then convert the three-dimensional models of soil stratigraphy to input files for STOMP models. We reviewed several of the profiles, three-dimensional models of soil stratigraphy, and input files to STOMP to verify the soil stratigraphy was properly coded into STOMP. This three-dimensional approach to vadose zone modeling is, in our opinion, significantly better than previous attempts to simulate the vadose zone by allowing for lateral movement of water and contaminants along layers of

lower permeability soil. Previous models simulated vadose zone transport primarily as one-dimensional downward movement and did not allow horizontal spreading of water and contaminants.

The STOMP grid for all models was vertically subdivided into 43 layers, each 2 meters thick. The horizontal size of the grids was variable based on type of source area, with source areas contributing more recharge, such as ponds, having a larger grid to allow for more lateral spreading of water. The grid size was evaluated as part of the sensitivity analyses, described in a later section.

Initial input parameters were selected based on field, laboratory, and literature values, and the results of the calibrated groundwater flow model described below. The model was initialized to pre-Hanford conditions by allowing the model to approach steady-state conditions based on the average recharge from precipitation of 3.5 millimeters per year as stated in the TGD.

Once the models were constructed, the modeling team attempted to calibrate the models where sufficient information was available to characterize the water and contaminant distribution in the vadose zone. A key component to the calibration was to maintain consistency in the values of hydraulic conductivity between the vadose zone models and the calibrated groundwater flow model (discussed in the following section).

Initially, the STOMP models were calibrated to water content profiles (generated from neutron logs) from 140 locations within the 200 and 600 areas. All 140 were done simultaneously using a regression analysis. Because the modeling team was trying to maintain consistency with the groundwater flow model, the primary calibration parameters were the Van Genuchten parameters. The Van Genuchten parameters includes porosity, residual saturation, and two correlation function parameters (alpha and n), which define the shape of the pore pressure versus moisture content curve for a particular soil. In general, the model could be calibrated to the data using Van Genuchten parameters values consistent with laboratory estimates.

The challenge with this approach is that the calibration data represents "dry" conditions, that is, post-operational Hanford conditions. The modeling team attempted to simulate "wet" operational conditions and the results were not as good as the "dry" conditions, with excessive flux at the water table. Instead they attempted to calibrate to the shape and order-of-magnitude concentration at the water table over time at 4 different areas. To do this they performed a Monte Carlo simulation which included millions of realizations Several thousand realizations were selected for final evaluation for STOMP model runs that had a reasonable set of parameters

(no contradictions between parameter values), which led to a set of 87 realizations that met their screening criteria. Finally, they attempted to simulate the concentration in a well some distance from the source area. The modeling team qualitatively selected the best result for the four different areas and applied the values uniformly across all of the STOMP models. With this approach, the movement of water and contaminants in the vadose zone in primarily a function of the soil stratigraphy.

In our opinion, the approach the modeling team used to evaluate hydraulic parameters for the vadose zone is acceptable for the purposes of the EIS. Given the lack of vadose zone data from the operational period during which a higher flux of water was occurring, a more detailed evaluation of hydraulic parameters is not warranted. The focus on soil stratigraphy as the controlling factor in the movement of water and contaminants in the vadose zone is consistent with the conceptual model.

3.3 Groundwater Flow Model

The groundwater flow model was constructed using the MODFLOW code as part of the Visual MODFLOW computer program. MODFLOW was originally developed by the U.S. Geological Survey (USGS) and is the most widely used groundwater flow program in the world. The MODFLOW code has been well tested and verified, and is the standard of practice for the industry.

The modeling team began construction of the groundwater flow model for Hanford by using all of the validated boring logs for the site and developing a three-dimensional model of soil stratigraphy. This information was then encoded onto the numerical grid. The model grid was selected by dividing the model domain into a set of 200-meter by 200-meter cells in the horizontal direction and 41 layers in the vertical direction. Each layer was of a uniform thickness ranging from 1 meter up to 40 meters. The thickness of the layers decreased in the elevation range of the water table and the elevation of Gable Gap to provide a more detailed analysis and increased away from these elevations. The uniform thick layers were horizontal, that is, the top and bottom elevation of each layer was constant throughout the model domain.

For each model layer, the stratigraphy was then "painted" onto each layer. The model layers do not correlate directly with specific stratigraphic units. Within each model layer, different soil types may be present depending on where the variable elevation of each stratigraphic unit is located relative to the top and bottom elevation of the model layer.

The model domain was bounded by the Columbia River to the north and east, upland mountains to the west and most of the south, and with a small portion of the Yakima River on the eastern edge of the southern border. The mountains were generally simulated as no-flow boundaries, that is, there is no water movement into or out of the model along these boundaries, with exceptions of several areas of mountain front springs as described in the conceptual model. The rivers were simulated using the MODFLOW River Package. This package uses a head-dependent, flux boundary to allow water to flow in and out of the model based on the difference in aquifer hydraulic head and river stage, and the hydraulic conductivity of the river bottom. For groundwater flow model, the modeling team did not allow the river stage to vary in time.

The groundwater flow model was bounded at the base by basalt bedrock, which was encoded by contouring the top of bedrock elevation from the boring logs. As described in the conceptual model, there is some uncertainty in the elevation of bedrock through Gable Gap and two elevations selected were selected through statistical evaluation to represent the base case and alternative case. The bedrock surface is a no-flow boundary, with the exception of an area through Gable Gap where a thin layer of bedrock is allowed to have low permeability. This is purely a numerical convenience to allow the computer program to run more efficiently and is not intended to represent reality.

The modeling team simulated the operational period of the Hanford site by including a series of recharge boundaries to represent ponds, ditches, cribs, and other features that may have contributed water to the subsurface. The flux from each feature was estimated based on historical information provided in the cumulative database. Where sufficient information was available, the recharge features had a flux that varied over time.

A numerical model needs to have starting point, in this case the elevation of the water table. The modeling team assumed that changes in the elevation of the water table over time are a function of the influx of water during the Hanford operational period. In order to simulate the change in water table elevation, the modeling team estimated the pre-Hanford water table by running the model over a long period time with only natural recharge (3.5 millimeters per year as stated in the TGD) until the model approached steady-state conditions. Given the lack of water table elevation data for the pre-Hanford period, in our opinion, this approach is appropriate to estimate the starting water table elevation.

Once the model was constructed, the modeling team began model calibration by evaluating all of the water table elevation data available for the Hanford site from the beginning of the operational period. The water level data was divided into four distinct sets of mostly randomly selected data

(as an example, if two wells were located in the same model grid cell, they were placed in different data sets); three of the data sets were used for calibration and the fourth set was used to verify the calibration results.

The initial calibration was performed using a parameter estimation program called PEST. The PEST program uses a statistical comparison between the measured water levels and modeled water levels to estimate model parameters. The user selects model parameters, such as hydraulic conductivity, and assigns a possible range of values for the parameter. The PEST program then adjusts the model parameters to improve the statistical comparison between measured and modeled data. This iterative process continues until a statistical criterion, assigned by the modeling team, is met. For the PEST calibration, the modeling team selected the hydraulic conductivity of each stratigraphic unit, the hydraulic conductivity of the river bottom, the ratio of horizontal to vertical hydraulic conductivity, and the flux of the mountain recharge boundaries to vary during the PEST calibration. The range of parameter variability was based on field and laboratory data.

In general, groundwater flow equations result in non-unique solutions, that is there are more than one set of parameters that may have the same results when solving the equations. To better understand if the Hanford groundwater flow problem is non-unique and to reduce potential bias in the set of observed hydraulic head data, the modeling team divided the calibration effort into three independent groups, each with one of the three water level data sets generated for calibration. Each calibration group used PEST to achieve calibration to their water level data set. An iterative calibration process continued until the three PEST calibration groups each generated a calibrated model with similar parameter values and similar statistical results. The three calibrated models were then tested against the fourth water level data set to verify that the similar parameter values would generate similar results. The results of the PEST calibration indicated that multiple sets of aquifer parameters could be developed that would meet the statistical criteria for calibration, that is, a unique solution could not be developed using the PEST calibration methodology.

The modeling team moved to a Monte Carlo approach and evaluated groundwater flow directions in addition to the hydraulic head distribution. The Monte Carlo calibration approach involved developing approximately 5,000 realizations of hydraulic parameters by randomly selecting a value from a range of possible values for each parameter for both the base case and alternative case. The result of each model run was then compared to contours of the Hanford groundwater flow field over time and hydrographs at specific locations. For a select set of realizations that met statistical criteria for residual mean square and correlation coefficients, the

modeling team performed particle tracking to compare model results with tritium plumes. Based on the results of the particle tracking, the modeling team qualitatively selected two realizations to represent the calibrated groundwater flow field for the base case (predominately easterly flow) and the alternative case (predominately northerly flow). The base case calibrated flow field had residual mean square of 2.118 meters and a correlation coefficient of 0.979.

In our opinion, the base case groundwater flow field adequately simulates the Hanford groundwater flow field, and the base and alternative case flow fields are sufficient for the purpose of the EIS and for comparison of site wide alternatives.

3.4 Groundwater Transport Model

The modeling team's initial approach for the groundwater transport modeling was to use a companion code (MT3D) to the groundwater flow code. However, MT3D uses the same grid as the groundwater flow code, which resulted in a challenge to accurately input the contaminant flux from the vadose zone when the areal distribution of the source areas does not match the regular grid of the groundwater flow model. In addition, it is our understanding that there challenges in modifying MT3D to accept input concentration fluxes from STOMP. Instead the modeling team selected a grid independent groundwater transport code to modify for EIS purposes and developed a data management code to input the results of the STOMP models into the transport code.

The modeling team developed a transport code (Blue Dot X) to evaluate contaminant movement in groundwater below the water table. The code is a modification of the USGS code, RAND3D, which is based on random-walk techniques (Prickett, Naymik, and Lonnquist, 1981) to evaluate contaminant movement within a groundwater flow field. RAND3D is also a grid independent code. The random-walk technique is well established and widely used before the development of more recent techniques.

The primary modifications to the RAND3D code were for data management and incorporation of the Gelhar (1983) description of hydrodynamic dispersion. Gelhar noted that hydrodynamic dispersion is scale dependent, which is the impact of hydrodynamic dispersion is greater as the flow length increases. As a result, the dispersivity value used in the equation for hydrodynamic dispersion is calculated based on the scale of the problem. The data management modifications were done to more readily allow the input of concentration fluxes from the vadose modeling using the STOMP code.

The Blue Dot X code was verified by a series of 24 tests against both analytical solutions and other accepted numerical codes, including MT3D, the companion transport code to MODFLOW.

The groundwater transport code was not calibrated to contaminant distribution; however, the accuracy of the groundwater transport model was evaluated qualitatively to assess if the overall modeling approach was adequate to meet the needs of the EIS. Model results were compared to contour plots of groundwater concentration for historic and current chemical data. Because of the limitations in the data set for various contaminants, the comparison could only be completed for the site tritium plumes and the technetium plume in associated with the BY cribs. The qualitative approach compared the general order-of-magnitude concentrations, areal extent, and shape of the plumes.

In our opinion, groundwater transport calibration is not a necessary step as part of the modeling process, because the transport modeling is simply a matter of overlaying contaminant fluxes from the vadose zone onto the calibrated groundwater flow field. As such, comparison of the model-predicted results to the actual contaminant plumes represents a verification of both the groundwater flow and vadose zone models. As indicated above, it is our opinion that both the groundwater flow and vadose zone models were sufficiently calibrated to meet the requirements of the EIS and evaluation of groundwater plumes is mostly a function of the inputs from the source areas for both models. Therefore, the uncertainty represented in the source inputs is propagated through the models to the groundwater transport results.

Given the uncertainty in the source area water and contaminant fluxes, it is our opinion that the qualitative evaluation of the contaminant plumes is sufficient given the model's ability to simulate the general concentration, size, and shape of the plumes, and verifies that the source area model fluxes, the vadose zone transport, the groundwater flow regime, and the groundwater transport processes are sufficiently and accurately represented in the models.

4.0 SENSITIVITY ANALYSES

4.1 Vadose Zone Model

Given the high degree of uncertainty and sparseness of data for vadose zone parameters, the modeling team performed extensive sensitivity analyses on most of the water flow and transport parameters, including the van Genuchten parameters, dispersivity, depth to water table, recharge from source areas, moisture content, permeability, and geologic structures (presence of clastic dikes, soil layering, and tilt of layers). For all of the parameters, with the exception of

permeability, the sensitivity analyses were performed by evaluating low, average, and high values of the parameters within the range of expected values.

The models exhibited a relatively high sensitivity to the Van Genuchten parameters (all four), longitudinal dispersivity, moisture content, and recharge. For these parameters, changes to the values resulted in either high changes in contaminant flux at the water table or high changes in travel time.

The models were not particularly sensitive to the depth to the water table in terms of the contaminant flux at the water table.

Changes to the geologic structure showed variable sensitivity, with increased sensitive to soil layering as the contrast in permeability of the soil increased. For example, the modeling team compared hypothetical vadose consisting of a series high permeability sand and gravel layers. By adding a thin layer of low permeability silt, the model exhibited a significant change in contaminant travel time, peak contaminant concentration at the water table, and area of the contaminant plume because of lateral spreading.

The sensitivity to permeability was evaluated as part of the calibration process, whereby thousands of realizations were evaluated as part of Monte Carlo simulation. In general, the models were not particularly sensitive to a specific permeability value for a soil type, but more for an increased contrast between the permeability of two soils. These results indicate the importance of incorporating site specific stratigraphy during evaluation of vadose zone transport at specific sites.

4.2 Groundwater Flow Model

For the groundwater flow model, sensitivity analyses were completed for grid spacing, river conductance, and saturated hydraulic conductivity.

The base grid has a 200-meter by 200-meter spacing. To evaluate the model sensitivity to grid spacing, the modeling team reduced the grid spacing to 100-meter by 100-meter spacing in the vicinity of Gable Gap. Gable Gap was selected because the modeling team noted during early calibration attempts that this portion of the groundwater flow model was very sensitive to changes in aquifer parameters and boundary conditions. The analysis indicated that in the vicinity of Gable Gap, the model does not show significant sensitivity.

The model sensitivity to river conductance and hydraulic conductivity was evaluated during both the PEST calibration and the Monte Carlo simulations. The modeling team noted that the model was highly sensitive to low river conductance and the hydraulic conductivity of the Hanford gravels. For the Monte Carlo simulation, the modeling team plotted the results of all realizations versus the highest probability result for each material type to show the variability of results over the range of the parameter space. The results indicate a high sensitivity to the Hanford gravels.

The results of the sensitivity analyses indicate that the groundwater flow model is highly sensitive to the hydraulic conductivity of the Hanford gravels. In our opinion, site specific testing of Hanford gravels should be completed and the groundwater flow field revised for evaluation of closure processes for individual sites.

4.3 Groundwater Transport Model

Because the groundwater flow field was already defined, the only sensitivity analysis performed with respect to the groundwater transport model was for dispersivity. The Gelhar scale-dependent relationship for dispersion was used to calculate a dispersivity of 500 meters for the transport analyses. The sensitivity analysis evaluated a range of dispersivity values from 50 to 50,000 meters. The analysis indicated that the model in not particularly sensitive to dispersivity because of the large-scale of the problem.

5.0 CONCLUSIONS

Our review of fate and transport modeling performed in support of the EIS included review of previous completed modeling and site conceptual models, numerous meetings and presentations with the DOE modeling team and Ecology, and a review of the internal draft EIS. We reviewed the conceptual and computer models starting with release of contaminants from the source areas, migration of water and contaminants through the vadose zone to the water table, development of a time variant groundwater flow field from the beginning of the Hanford operational period to present, and the movement of the contaminants within the groundwater flow field toward the Columbia River.

In our opinion, the fate and transport modeling completed for the EIS meets the standard of practice for the industry, adequately represents the known physical processes that control water and contaminant movement in the subsurface, and meets the requirements for decision processes for the EIS for evaluation of alternatives.

However, in our opinion, the fate and transport models do not contain sufficient detail to evaluate closure processes for individual sites. In our opinion, additional detail and incorporation of this detail into all aspects of the models will be necessary to adequately simulate the movement of water and contaminants for individual sites.

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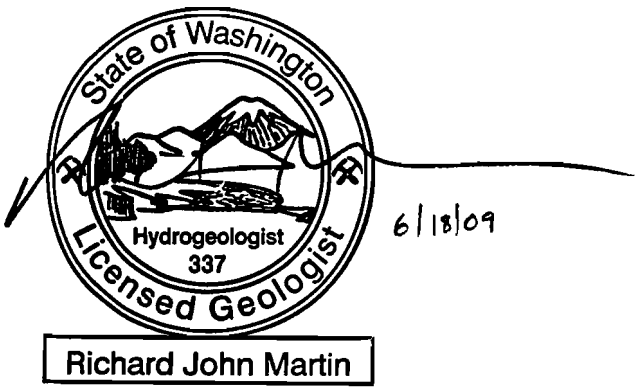

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RJM:SWG/rjm

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APPENDIX

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors which were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland