Systematic Application of Flow-and-Transport Modeling for Wellfield Design: the Hanford 200-ZP-1 Groundwater Pump-and-Treat Remedy - 10320

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ABSTRACT

During 2007 a Feasibility Study and Proposed Plan were completed that describe the selection of a combined groundwater pump-and-treat, monitored natural attenuation, and flow-path-control remedy for contaminants present in the Hanford 200-ZP-1 groundwater operable unit. In anticipation of the September 2008 signing of the final record of decision, work began on the development of a groundwater flow and contaminant transport model encompassing the 200-ZP-1 OU. The model was developed to support the preparation of the remedial design/remedial action work plan and subsequent design documents; to provide estimates of influent concentrations and mass removal rates for several contaminants of concern, including carbon tetrachloride, technetium-99, and hexavalent chromium; and to assist in the integration of remedial decision making across the Hanford Central Plateau. This paper describes the initial development and application of the flow and transport model through Spring of 2009.

INTRODUCTION

The Feasibility Study (FS) [3] and Proposed Plan (PP) [4] for the 200-ZP-1 Groundwater Operable Unit (OU) describe the use of pump-and-treat (P&T) technology as part of an integrated groundwater remedy. During fiscal year 2008 (FY08), a groundwater flow and contaminant transport (flow-and-transport) model was developed to support remedy design decisions at the 200-ZP-1 OU, since the influence of the proposed P&T remedy was projected to have a larger areal extent than the current interim remedy, and estimates of influent concentrations and contaminant mass removal rates were required to support the design of the aboveground treatment train. This paper describes (1) the flow model construction, calibration, and validation; (2) the methods used to depict the extent of contamination for incorporation in the model; (3) some techniques employed to help represent this complex groundwater system; and (4) the stepwise application of the model in the design of this large-capacity remedy.

MODELING OBJECTIVES

Drilling and construction of the extraction and injection wells that comprise the proposed well field at the 200-ZP-1 OU will occur in a phased manner, and the final remedy itself will be implemented in phases. The planned role of groundwater modeling in support of each phase is described below:

<u>RD/RA Work Plan Design (*described here*)</u>

- Development of initial conditions (i.e., contaminant distributions) for use in predictive simulations of remedy design
- Simulations of groundwater flow and particle paths to identify initial well locations and rates that will accomplish remedial action objectives (RAOs) assuming advective transport

- Simulations of advective/dispersive/reactive transport to provide initial estimates of the concentration versus time for each contaminant of concern (COC) at each recovery well; total system mass recovery versus time; and design basis concentrations for the design of the aboveground treatment train

System Construction, Upgrades, Optimization and Long-Term Operation

- Incorporation of newly-obtained characterization data (e.g., aquifer tests) to help update the model parameters
- Incorporation of newly-obtained sampling data to update the mapped contaminant distributions
- Recalibration of the flow-and-transport model to monitoring data including heads, drawdowns, influent concentrations, and mass recovery rates
- Updating of well locations and rates required to achieve RAOs
- Identification of suitable locations, variables, and data quality objectives (DQOs) for monitoring the performance of the intermediate and final remedies
- Identification of suitable locations, variables, and DQOs for evaluating progress toward the RAOs

Modeling will also be used in support of regular evaluations of remedy performance, such as part of statutory *Comprehensive Environmental Response, Compensation, and Recovery Act of 1980* (CERCLA) 5-year reviews.

FLOW MODEL DEVELOPMENT AND CALIBRATION

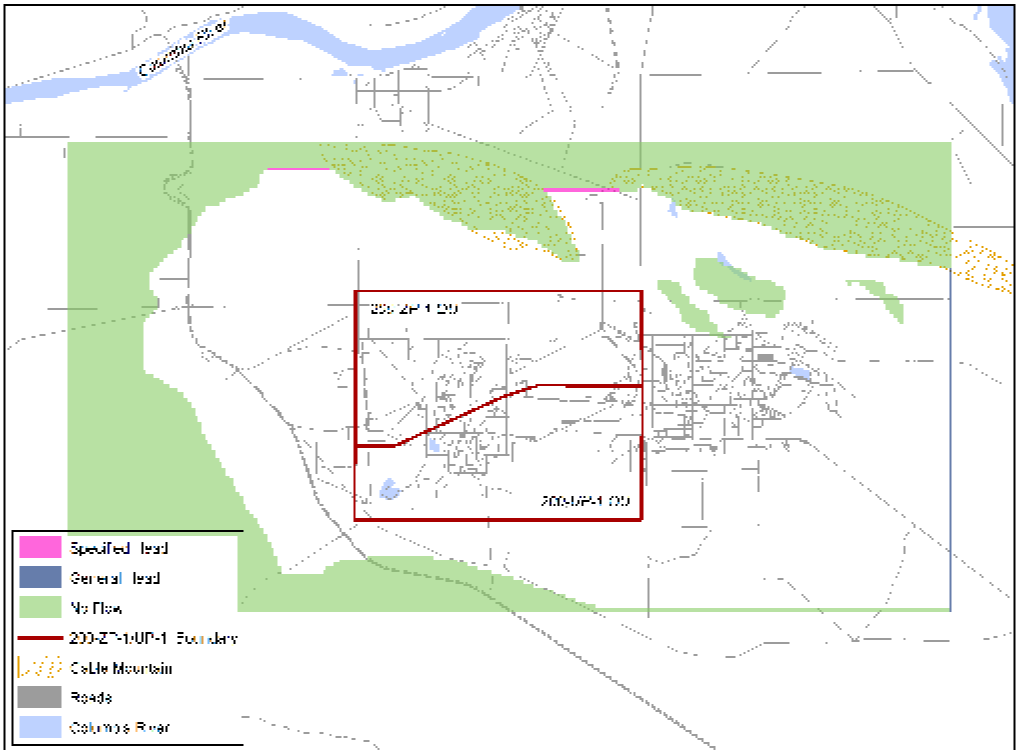
Flow Simulation Code

The flow model is constructed using the U.S. Geological Survey three-dimensional (3D) groundwater flow simulator MODFLOW. The MODFLOW-2000 [7] release of the MODFLOW code was selected because it possesses the necessary simulation capabilities, yet it is relatively simple to use, is public domain software, has been used extensively, and can be executed on a variety of computers and operating systems.

Extents and Boundary Conditions

Due to the expected extent and influence of the final remedy, the model was constructed to simulate an area encompassing the Central Plateau. Figure 1 illustrates the domain and lateral boundary conditions of the flow model, which comprises 134 rows, 256 columns, and 5 layers. All layers are simulated as convertible type. The bottom of the model corresponds with the top of the basalt, which is generally considered a no-flow lower boundary. The eastern and southeastern model boundaries are open, with groundwater flowing toward the Columbia River. Initially, the southern boundary was considered a no-flow boundary, while the eastern boundary was simulated as a general head boundary (GHB) type with the Columbia River stage applied as the boundary head and the conductance computed using the properties of each eastern boundary cell together with the distance to the Columbia River. These boundary specifications have since been revised such that both boundaries are treated as GHBs defined on the basis of two controlling head conditions: the first of these comprising the Columbia River, and the second comprising a relatively static head condition between the Rattlesnake Mountain and Yakima Ridge anticlines.

Figure 1. Domain and Lateral Boundary Conditions of the Flow Model.



Stratigraphy

The model stratigraphy essentially follows the stratigraphy described in *Groundwater Data Package for Hanford Assessments* [11], including the elevation of the top of basalt and the top and bottom elevations of the principal geologic units. Data containing top and bottom elevations of the principal units based on PNNL-14753 [11] were used to define six hydrostratigraphic units that lie within the model domain (Table 1). Some localized revisions were made to the elevation of the top of basalt based on data collected since the publication of PNNL-14753 [11].

Table 1. Stratigraphic Units Represented in the Groundwater Model.

Model Zone	Statigraphic Unit	Description
1	1	Hanford formation gravel, sand and silt (dominated by gravel and sand within the aquifer)
5	5	Ringold gravel Units E and C (BHI-00184); also includes sand facies of the Upper Ringold Unit where it directly overlies the other E and C units
6	6	Fine-grained overbank and paleosol deposits that vertically separate unit B from overlying unit C in the eastern part of the Hanford Site
7	7	Ringold Units B and D (BHI-00184)
8	8	Ringold Lower Mud Unit (BHI-00184)
9	9	Ringold Unit A (BHI-00184), a gravel and sand facies that is dominated by sand in the western part of the Pasco Basin

NOTES:
1. Stratigraphic unit and model zone do not correspond with model layer: a stratigraphic unit or model zone may occur in one or more model layers.
2. BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*.

Recharge

Recharge specified in the flow model comprises (1) net precipitation that reaches the water table; (2) recharge arising from historic wastewater discharge activities; and (3) mountain-front recharge arising from infiltration of snowmelt and run-off from elevated areas, which focuses in the ephemeral Cold Creek and Dry Creek river beds. For the predictive simulations that form the basis of the initial 200-ZP-1 remedy design, the primary source of recharge to groundwater is aerial precipitation, together with recharge in the ephemeral Cold Creek and Dry Creek river beds. However, recharge associated with basalt outcrops may be a significant contributor to groundwater recharge upgradient of the Central Plateau [8, 12]. An electronic version of the recharge package developed previously by PNNL was obtained and spatially distributed to the model grid cells. However, since unique determination of recharge rates within these areas is difficult, sensitivity analyses will be used to evaluate the effect of uncertainties in these parameters on the 200-ZP-1 remedy design.

The correspondence between historic wastewater disposal activities and changes in groundwater levels throughout the 200-ZP-1 OU indicates that disposal at various ponds and drains led to increases in groundwater elevations of over 15 m in some locations. Wastewater disposal constituted a primary driving force in the historic migration – and the current disposition – of contaminants. Water-loss-rate data obtained from several sources for the period from 1944 through 1993 were incorporated into the flow model by defining polygons for each infiltrating body, and calculating the recharge rate in each encompassed cell.

Table 2. Temporal Discretization of the Groundwater Model.

Model	Stress Period(s)	Duration	Description
Historic	1	Approx. 550 years	The initial transient stress period is specified prior to the calibration period to establish an initial pre-development groundwater condition.
Historic	2 to 63	62 years	The 62 transient annual stress periods span the calibration period from 1944 through 2005.
Historic	64	5 years	This stress period simulates current conditions under the assumption that predictive simulations of the 200-ZP-1 remedy should commence no earlier than 2010.
Predictive (future)	1	3 years	Phase I; current interim remedial measure, operating at approximately 350 gpm total extraction/injection rate.
Predictive (future)	2	3 years	Phase II of final 200-ZP-1 pump-and-treat remedy operating at 1,000 gpm.
Predictive (future)	3	54 years	Phase III of final 200-ZP-1 pump-and-treat remedy operating at 2,000 gpm.

Gpm = gallons per minute

Flow Model Calibration

The flow model comprises two distinct periods: the first representing historic conditions from pre-development through to the current time; and the second representing predictive (future) conditions from about the current time through the phased implementation of the final 200-ZP-1 remedy. For historic conditions, the transient flow model simulates 64 stress periods; for predictive (future) conditions, the transient flow model simulates 3 stress periods. Details are provided in Table 2.

The flow model was calibrated to groundwater elevations recorded at monitoring wells throughout the 200-ZP-1 OU, which document changes in groundwater elevations in response to infiltration of discharged wastewater as described above. Calibration of the model parameters using these widespread water level changes focused on hydrographs (i.e., comparisons of modeled and observed heads) together with hydraulic gradients – calculated using the three-point method [1] to ensure that the model reproduced flow directions and rates throughout the period that contaminants were released and during their subsequent migration within the aquifer. Parameters estimated through the calibration process include specific yield, hydraulic conductivity in the principal water-bearing units, the net recharge accrued from precipitation, and the conductance terms of the general head boundaries.

Calibration focused on obtaining correspondence between simulated and measured changes in groundwater elevations; hydraulic gradients; and contoured and simulated depictions of groundwater elevations. Manual and automated parameter estimation techniques [5] were used during the calibration however formal statistical methods were not used to assess the calibration results at this stage. Rather, the calibration was interpreted qualitatively by reviewing maps and hydrographs illustrating measured and simulated quantities, and comparing estimated parameter values with independent sources of information such as aquifer tests and previous publications. Calculations performed at the end of the calibration suggest that the total aquifer transmissivity (i.e., above the basalt) near the 200-ZP-1 OU ranges from about 300 to 900 m^2/day. These values are comparable with values reported from aquifer test analyses and other modeling efforts.

CONTAMINANT TRANSPORT MODELING

The future migration of alternate depictions of the extent of contamination was simulated under a variety of remedy configurations, employing a range of transport properties for those contaminants that exhibit the largest extents and may dictate the time required to achieve cleanup goals. These results also laid the foundation for calculating design basis concentrations for the above-ground treatment train.

Transport Simulation Code

MODPATH [15] was used to conduct preliminary particle tracking simulations to approximate general groundwater flow directions and rates, and the advective transport of contaminants. Following this, MT3DMS (Modular 3-D Transport Multi-Species) [17], a 3D, multi-species transport model for the simulation of advection, dispersion, and chemical reactions, was used to evaluate the approximate directions and rates of migration of the COCs and the approximate time-varying influent concentration of these COCs at the extraction wells.

Predictive Simulations

Contaminant transport modeling considered the migration of COCs mapped as being present at the current time within the saturated aquifer. As such, the simulations assume that there are no continuing sources of contaminants to groundwater, and also that the dissolved and sorbed contaminants are in equilibrium. Although the predictive (future) model simulates the migration and fate of the COCs for 54 years following implementation of the final full-scale remedy (Table 2), calculations of mass recovery are made using model outputs at t = 28 years from the present day. This corresponds with 25 years from the implementation of Phase I of the remedy, in accordance with the record of decision.

Mapping of Contaminants of Concern

Current depictions of the distribution of the COCs in 3D were prepared using two interpolation techniques to accommodate uncertainty in the extent of contamination:

- An ordinary kriging method that produces a single depiction of the likely extent of a COC. This method was used to prepare initial conditions for all simulated COCs.
- A multi-Gaussian (stochastic) method that produces multiple realizations of the likely extent of a COC, each consistent with spatial statistics developed for that COC. This method was used to prepare initial conditions for the most widespread COCs - carbon tetrachloride, technetium-99, and nitrate.

Multi-Gaussian mapping of carbon tetrachloride and technetium-99 was completed by PNNL [13, 14], using robust non-parametric methods of data processing during the interpolation [16]. Five hundred (500) stochastic realizations were constructed on a regular grid using the Geostatistical Software Library (GSLIB) protocols [2]. From these realizations, PNNL provided several realizations for use in remedy simulations. However, the expected average (E-type estimate) of the 500 realizations was, in each case, considered primary for the modeling effort. These fine-resolution regular 3D grids were interpolated to the model grid using a locally weighted average approach that preserves mass.

Common data sets were used to prepare these depictions of the extent of contamination. Within the convex hull of the data domain, depictions prepared using the ordinary kriging method are considered to be a “best estimate” of the contaminant distribution, leading to a corresponding “best estimate” of the likely influent concentration at each extraction well. The contaminant depictions prepared using the stochastic multi-Gaussian method represent alternate “potential” contaminant distributions, leading to corresponding “potential” influent concentrations.

Transport Properties for Contaminants of Concern

Transport simulations were completed for carbon tetrachloride, technetium-99, iodine-129, nitrate, TCE, chromium, tritium, and uranium (note: uranium is not a COC). Simulated transport terms include advection, dispersion, and simple reactions. All transport terms were solved implicitly. Parameters defined for the transport of carbon tetrachloride are primarily based on values provided in the FS [3]. The parameters defined for the remaining contaminants are based on values provided in the FS and in the *Hanford Contaminant Distribution Coefficient Database and Users Guide* [10] and in the *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW PA)* [9].

The following parameters applied to all transport simulations and all contaminants, with the exception of sensitivity analyses completed for carbon tetrachloride:

- Dispersivity:
    - Longitudinal = 50 m
    - Transverse = 10 m
    - Vertical assumed zero
- Bulk density = 1.72 kg/L
- Mobile porosity = 0.18

Instantaneous, reversible sorption was simulated for two COCs - carbon tetrachloride and iodine-129. A distribution coefficient (K_d) of 0.200 L/kg and corresponding retardation rate (R) of 2.911 were used for iodine-129. The radioactive decay of radionuclides was not simulated in this initial series of model runs.

Since carbon tetrachloride is the primary COC at the 200-ZP-1 OU and the initial simulations focused on a well configuration designed to achieve the RAOs for carbon tetrachloride, simulations of carbon tetrachloride were completed using the following parameter sets to illustrate the potential impact of transport parameter uncertainty on remedy performance (note: bulk density = 1.72 kg/L for all parameter sets):

- Base case parameter set: K_d = 0.0110 L/kg
  Mobile porosity = 0.180
  R = 1.105
- Alternate parameter set #1: K_d = 0.0110 L/kg
  Mobile porosity = 0.130
  R = 1.146
- Alternate parameter set #2: K_d = 0.060 L/kg
  Mobile porosity = 0.180
  R = 1.573

These three parameter sets were used together with two alternate initial conditions for carbon tetrachloride, resulting in six simulations of the likely fate of carbon tetrachloride under the assumed extraction and injection well configuration.

REMEDY SIMULATIONS

The 200-ZP-1 FS [3] and PP [4] describe simple, comparative evaluations of alternate remedy well configurations on the basis of semi-analytical groundwater flow modeling and particle-tracking calculations. Those analyses were used to identify first-order estimates of the number, locations and rates of extraction and injection wells required to meet the RAOs. These calculations provided a starting point for the more sophisticated flow-and-transport simulations described here.

Procedures

A series of flow-and-transport simulations were completed to identify approximate rates and locations for extraction and injection wells to maximize carbon tetrachloride mass recovery. Simulations focused on well configurations that would recover groundwater contaminated above 100 µg/L carbon tetrachloride while providing hydraulic containment to prevent further eastward migration of contaminants. A concentration of 100 µg/L was selected based on calculations performed as part of the FS [3] and based on analyses presented by PNNL [13, 14], which suggest that about 95% of the mass of carbon tetrachloride lies above a concentration of about 100 µg/L. After these simulations were completed, additional simulations were completed to calculate likely influent concentrations for the remaining COCs.

For the predictive transport simulations, recovery and injection wells were assumed to intercept the entire saturated thickness of the aquifer. While this is unrealistic in terms of practical implementation, it is expected that given the vertical distribution of carbon tetrachloride several of the recovery wells in particular will be constructed with relatively long (>30 m) screened intervals. As a result, the simulated mass recovery at each well may be relatively accurate, regardless of screen length, under the assumption that most mobile mass resides within transmissive units that a shorter well screen would be designed to intercept. However, the simulated influent concentrations may be under-estimated and should be reviewed accordingly. Further simulations are being conducted using as-built well designs with open-screened intervals focused on the vertical extent of the COCs as sufficient data become available to accomplish this goal.

Results

Figure 2 depicts the configuration of extraction and injection wells simulated for the two phases of the expanded remedy implementation, identified following the simulation of several alternate configurations. The proposed remedy well configuration comprises:

- Current conditions: Fourteen extraction wells and five injection wells, and a total extraction/injection rate of about 352 gpm (*not illustrated in Figure 2*)
- Phase I of New Implementation: Fourteen extraction wells and six injection wells, and a total extraction/ injection rate of about 1,000 gpm
- Phase II of New Implementation: Twenty extraction wells and 16 injection wells, and a total extraction/injection rate of about 2,000 gpm

Figure 3 depicts the predicted cumulative mass recovery of carbon tetrachloride over time calculated for all six cases that were simulated (three parameter sets, and two sets of initial conditions). Figure 3 suggests that the rates and timing of mass recovery may vary significantly over time, depending on the actual transport parameters that apply and the actual conditions that are encountered when the remedy is implemented.

Figure 2. Configuration of Extraction and Injection Wells.

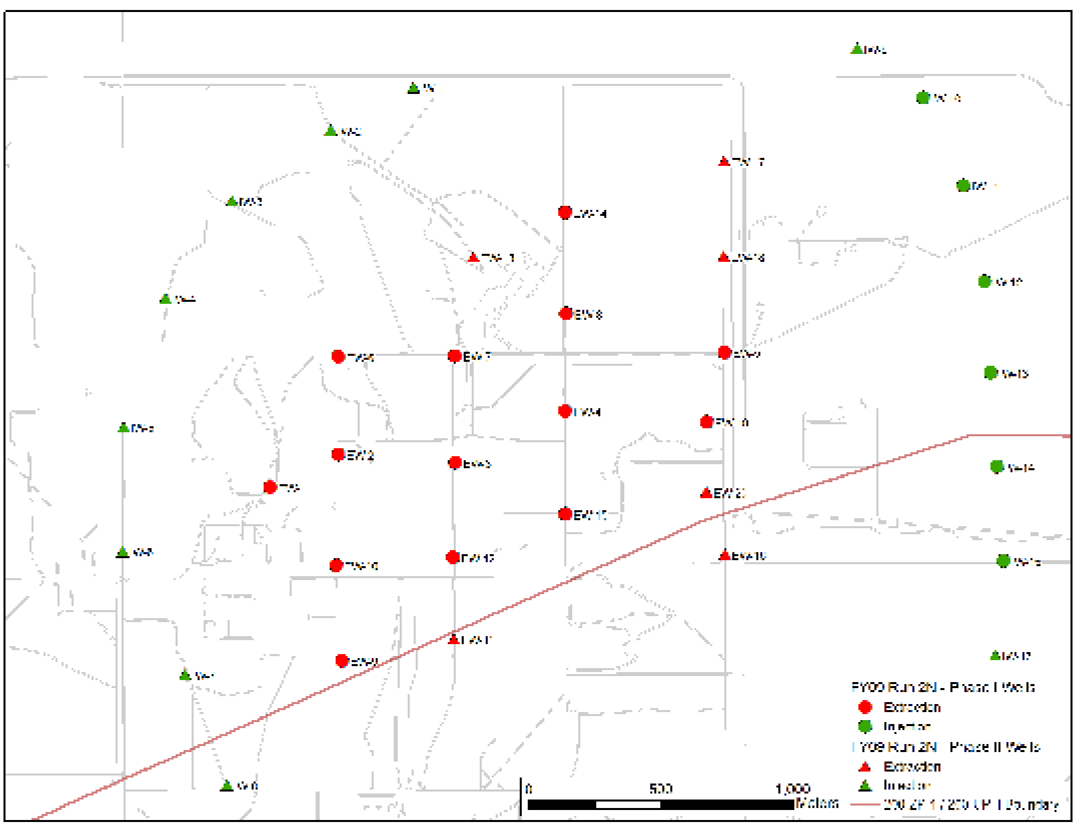


Figure 3. Cumulative Carbon Tetrachloride Mass Recovery
(Extracted and Treated): All Six Simulated Cases.

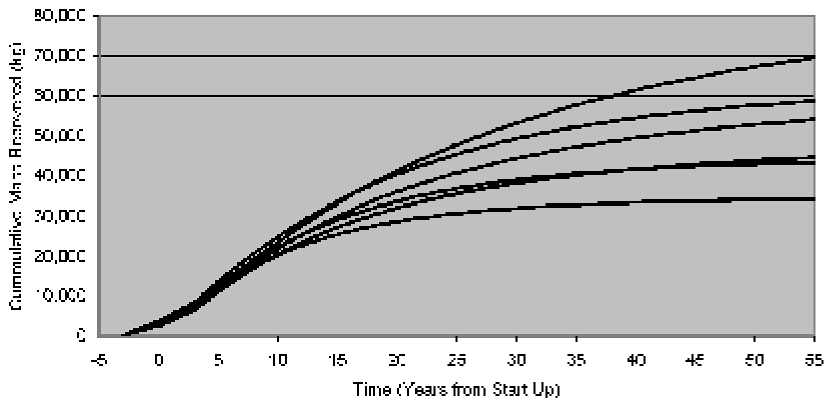


Figure 4. Percent of Dissolved Carbon Tetrachloride Mass Recovered
(Extracted and Treated): Maximum and Minimum Calculated.

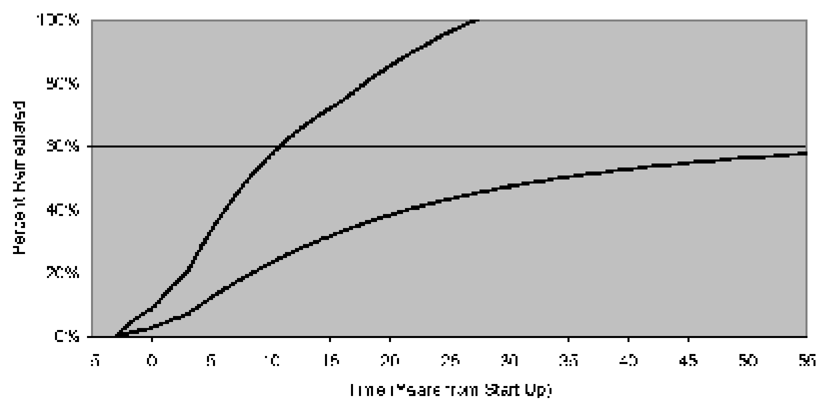
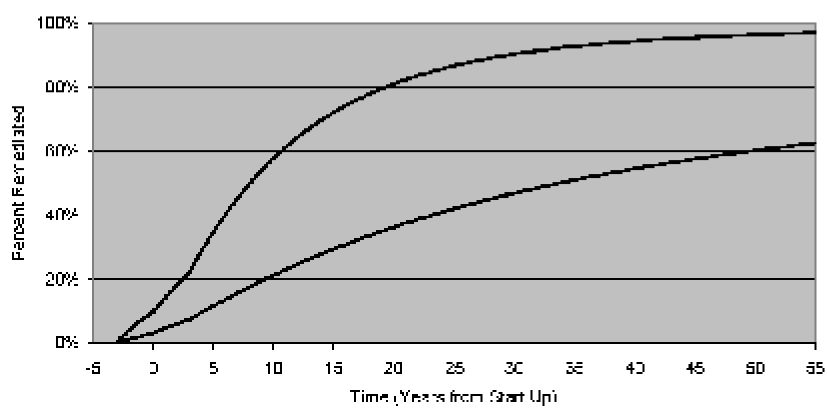


Figure 5. Percent of Total Carbon Tetrachloride Mass Remediated
(Recovered + Decayed): Maximum and Minimum Calculated.



Figures 4 and 5 illustrate the likely impact of this potential uncertainty in terms of the potential for recovering 95% of the initial mass of carbon tetrachloride. Figure 4 depicts the maximum and minimum percentages of the initial dissolved mass of carbon tetrachloride that is recovered (i.e., extracted and treated) by the remedy over time, calculated using the results of all six simulated cases. Figure 4 suggests that under suitable conditions, it is possible that the remedy could recover a mass of carbon tetrachloride equivalent to over 95% of the corresponding initial (i.e., current) estimate of the dissolved mass. Figure 5 depicts the maximum and minimum percentages of the initial total (i.e., dissolved and sorbed) carbon tetrachloride mass that is remediated (i.e., extracted and treated by the remedy, and that decays) over time, calculated using the results of all six simulated cases. Figure 5 suggests that under suitable conditions, it is possible that the remedy could recover a mass of carbon tetrachloride equivalent to over 95% of the corresponding initial (i.e., current) estimate of the dissolved mass of carbon tetrachloride.

Table 3. Tabulation of Extraction Wells by Approximate Cumulative Carbon Tetrachloride Mass Recovery

	Ordinary Kriging Initial Conditions		**Multi-Gaussian Initial Conditions**		**Average Rank**
	Mass (kg)	**Rank**	**Mass (kg)**	**Rank**	
EW-1	870	18	1,189	19	18.5
EW-2	1,529	11	1,832	11	11
EW-3	1,953	7	2,356	4	5.5
EW-4	2,730	1	2,934	1	1
EW-5	2,072	6	2,211	7	6.5
EW-6	1,110	15	1,302	16	15.5
EW-7	1,554	10	1,941	10	10
EW-8	2,387	3	2,669	3	3
EW-9	886	17	891	20	18.5
EW-10	1,383	13	1,452	14	13.5
EW-11	807	20	1,200	18	19
EW-12	2,103	5	2,048	8	6.5
EW-13	808	19	1,314	15	17
EW-14	1,239	14	1,767	12	13
EW-15	1,904	8	2,225	6	7
EW-16	1,409	12	2,017	9	10.5
EW-17	1,057	16	1,206	17	16.5
EW-18	1,814	9	1,549	13	11
EW-19	2,643	2	2,771	2	2
EW-20	2,158	4	2,255	5	4.5

Table 3 summarizes the results of the modeling in terms of the cumulative recovery of carbon tetrachloride at each extraction well. Similar tables were produced for each COC. Table 3 also ranks the recovery wells in terms of their predicted cumulative mass recovery after 25 years of operation at the final proposed extraction and injection rates. Table 3 illustrates that some extraction wells are predicted to recover considerably more mass than other wells. This information was used to help prioritize the order of installation and operation of the extraction wells to accelerate progress toward the RAOs.

ASSUMPTIONS UNDERLYING THE MODELING ANALYSIS

Project reports that present the simulation results also discuss assumptions that underlie the modeling analyses. The list of assumptions is not all-inclusive, but provides directions for analyses and actions to refine and update the estimates presented therein. These assumptions are broadly categorized as follows:

Contaminant Distribution: The simulations evaluate the current mapped extent of contaminants in groundwater and sorbed on aquifer materials: there are assumed to be no continuing sources of contaminants.

Aquifer Properties: Although all principal water-bearing units documented in PNNL-14753 [11] that lie within the model domain are explicitly simulated, the representation of the hydrostratigraphy in the model is relatively simplistic. For example, homogeneity is assumed within each water-bearing unit. The dual domain approach for simulating solute transport in heterogeneous media [6] is being evaluated for its suitability in future applications of the transport model.

Recharge: The original flow model incorporated anthropogenic sources of infiltration within the 200 West Area, plus B Pond and Gable Mountain Pond (the most substantial historic sources of water within the 200 East Area) in addition to net recharge from precipitation. Other historic sources of water were not included. The model has since been revised to incorporate spatially-variable net recharge from aerial precipitation; historic wastewater discharges in 200 East; and, mountain front recharge via the ephemeral Dry Creek and Cold Creek river beds.

Well Screen Intervals: The recovery wells are considered to be fully penetrating from the water table to the top of the basalt. This assumption is not a limitation of the model, but was made to obtain reasonable first-order estimates of mass recovery rates. Mass recovery estimates may be relatively insensitive to this assumption, however, the model may under-estimate influent concentrations. Final screened intervals will be determined based upon depth-discrete groundwater samples collected during drilling and site characterization, and the results of modeling analyses using methods similar to those described here but explicitly considering alternate discrete vertical screened intervals.

Boundary Conditions: The original flow model considered the southeastern boundary as a no-flow boundary, forcing flow to be parallel to this boundary. The model has since been revised to treat this boundary – and the eastern boundary – as a GHB that is defined on the basis of two controlling head conditions: (1) the Columbia River, and (2) a relatively static head condition between the Rattlesnake Mountain and Yakima Ridge anticlines.

Finally, although limited sensitivity analyses of the predicted remedy performance have been performed with respect to the distributions of carbon tetrachloride and technetium-99, and the transport parameters for carbon tetrachloride, additional sensitivity analyses are underway to guide the identification of flow-and-transport model parameters and improve model predictions.

DISCUSSION

A flow-and-transport model has been used to simulate the approximate fate of COCs listed in the 200-ZP-1 OU ROD. For the principal COC, carbon tetrachloride, six simulations were made to consider the effect of alternate depictions of the extent of contamination and of alternate transport parameters on the likely effectiveness of the P&T component of the proposed remedy. This approach was taken acknowledging that there is uncertainty about the actual conditions that will be encountered in the field as the remedy is implemented. For two further COCs (nitrate and technetium-99), two simulations were made to consider the potential effects of alternate depictions of the extent of contamination on likely remedy performance.

The simulations suggest that under suitable conditions, the remedy could recover a mass of carbon tetrachloride equivalent to or exceeding 95% of the corresponding initial (i.e., current) estimate of the dissolved mass of carbon tetrachloride, thus demonstrating that the RAO can potentially be achieved. The simulations also suggest that the further that conditions encountered in the field differ from these suitable conditions, the less likely the RAO can be achieved within the proposed timeframe using the proposed well configuration.

The use of the alternate parameter sets and alternate initial conditions also predicts different system-wide (i.e., combined) mass recovery rates, which can present difficulties for designing a cost-effective treatment system for the extracted water. These simulations suggest that significant variables that might affect both the mass recovery rates and the attainment of RAOs are likely to be the following:

- Initial distribution of contaminants
- Spatially varying aquifer properties (principally hydraulic conductivity)
- K_d and retardation rate for certain contaminants

Although not explicitly considered in these simulations, the presence of continuing sources of contaminants would also significantly impact the attainment of RAOs.

The simulations suggest that characterization, sampling, and monitoring efforts should focus on improving the understanding of the variables listed above, which will in turn help improve model predictions of likely remedy performance. Information obtained through each implementation phase will therefore inform the implementation of subsequent phases. For example, the following data are currently being collected and evaluated to refine model predictions, optimize implementation of the later phases, and re-evaluate the likelihood of attaining the RAOs:

- As-built well capacities and performance
- Sample data enabling updated depictions of the extents of contamination
- Aquifer properties obtained through pumping tests and other methods
- Transport parameters for key COCs, primarily carbon tetrachloride
- Mass recovery rates for all COCs, enabling a correspondence between this source of information on contaminant extents to be combined with point sample data.

Current and planned characterization and monitoring programs will collect information to enable conditions in the field to be identified as early as possible, so that the likelihood of attaining the RAOs can be assessed early in the implementation. For example: stratigraphic data will be collated, and/or aquifer testing performed, at each newly installed well to refine understanding of the transmissive and storage properties of the aquifer; comprehensive sampling will help refine the contaminant distributions; and as-built well capacities will identify whether the well spacing is likely to be suitable for attaining the RAOs.

Despite the variety of methods available for estimating K_d, it is difficult to obtain an estimate of K_d that is applicable at the site scale throughout the longevity of the site. Estimates for this parameter may ultimately be obtained indirectly through model calibration, by refining the understanding of aquifer properties and the contaminant distribution, and by comparing the model-predicted mass recovery with the measured mass recovery. Given the time required for a groundwater system to stabilize following implementation of a large pump-and-treat remedy (and for monitoring data to elucidate patterns and trends enabling inference of the remedy performance), information regarding the large-scale K_d and/or the presence of any continuing sources may require several years to obtain.

If an improved understanding of any of these variables deviates substantially from the assumptions made during the design, subsequent implementation phases may require revision. For example - if the model predictions are based on assumptions that are contradicted by new data, it may become evident that the remedy may be either over-designed (i.e., too many wells may be planned than are required to meet the RAOs), or under-designed (i.e., too few wells may be planned than are required to meet the RAOs). Hence, the design, evaluation, and optimization of groundwater remedies should be viewed as a long-term project in which the system design and operation is modified in response to improved understanding of the site (NRC 1994). The methods and tools used to assist in this understanding develop over time and with increasing knowledge. Hence, while modeling provides approximate predictions of groundwater flow, the migration of contaminants, and the potential effectiveness of a proposed remedy, assumptions underlying any modeling assessment must be communicated and evaluated, and where possible actions taken to mitigate their impact on decision-making.

PROJECT STATUS

The model is being used by S.S. Papadopulos and Associates, Inc (SSP&A), Intera, Inc., and CH2M HILL Plateau Remediation Company (CHPRC) in support of remedial decision making at the 200-ZP-1 OU and adjacent groundwater OUs. At present, the model is being used to help evaluate contaminant migration directions and rates within both 200 West and 200 East. During FY10 the western portion of the model will be reviewed and updated on the basis of continuous stratigraphic data, vertical interval sampling, and other information obtained during drilling and installation of the new remedy extraction and injection wells, in addition to planned large-scale aquifer tests. The eastern portion of the model will be reviewed and updated on the basis of stratigraphic data compilation and calibration efforts presently in progress by Intera, Inc related to remedial investigation/feasibility study (RI/FS) activities at the 200-PO-1 OU. Further development and application of the model represents a continuing collaborative effort between these and other groups at the Hanford site.

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