

Modeling Transport in the Down Gradient Portion of the 200-PO-1 Operable Unit at the Hanford Site

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ABSTRACT

Remedial Investigations are underway for the 200-PO-1 Groundwater Operable Unit (OU) at the U.S. Department of Energy's Hanford Site in Washington State. To support the baseline risk assessment and evaluation of remedial alternatives, fate and transport modeling is being conducted to predict the future concentration of contaminants of potential concern in the 200-PO-1 OU. This study focuses on modeling the "down gradient" transport of those contaminants that migrate beyond the 3-D model domain selected for performing detailed "source area" modeling within the 200-PO-1 OU. The down gradient portion is defined as that region of the 200-PO-1 OU that is generally outside the 200 Area (considered "source area") of the Hanford Site.

A 1-D transport model is developed for performing down gradient contaminant fate and transport modeling. The 1-D transport model is deemed adequate based on the inferred transport pathway of tritium in the past and the observation that most of the contaminant mass remains at or near the water table within the unconfined aquifer of the Hanford Formation and the Cold-Creek/Pre-Missoula Gravel unit. The Pipe Pathway feature of the GoldSim software is used to perform the calculations. The Pipe Pathway uses a Laplace transform approach to provide analytical solutions to a broad range of advection-dominated mass transport systems.

Based on the historical concentration distribution data for the extensive tritium plume in this area, three Pipe Pathways are deemed adequate for modeling transport of contaminants. Each of these three Pipe Pathways is discretized into several zones, based on the saturated thickness variation in the unconfined aquifer and the location of monitoring wells used for risk assessment calculation. The mass fluxes of contaminants predicted to exit the source area model domain are used as an input to the down gradient model, while the flow velocities applied are based on the present-day hydraulic gradients and estimation of hydraulic conductivity in the unconfined aquifer. The results of the calculation indicate that the future concentrations of contaminants of potential concern in the down gradient portion of the 200-PO-1 OU declines with time and distance.

INTRODUCTION

Remedial investigation study is currently underway for the 200-PO-1 Groundwater Operable Unit (200-PO-1 OU) at the U.S. Department of Energy's (DOE's) Hanford Site in Washington State. Because of the large areal extent of the OU (Figure 1a), the transport modeling is performed in two parts: (a) by developing a detailed 3-D saturated zone flow and transport model for the "source area," the area that encompasses all of the known contaminant sources in the Central Plateau portion of the Hanford Site, and referred to as the Central Plateau model; and (b) by developing a 1-D semi-analytic model for the "down gradient" portion of the OU to simulate transport from the boundary of the Central Plateau model to the Columbia River. The down gradient portion is shown by the blue-colored area in Figure 1b. Geographically, the down gradient portion of the OU lies outside of the designated 200 Area but falls within the 600 Area and 400 Area of the Hanford site. The focus of this paper is to document the computational basis of the 1-D transport model for the down gradient portion of the affected aquifer and to predict the fate of contaminants. The modeling results are used

to support the baseline risk assessment evaluations by estimating the future concentration of contaminants of potential concern (COPCs) that currently exist in the down gradient portion of 200-PO-1 OU, including the effect of those contaminants that originate in the source area and travel to the boundary of the Central Plateau model domain. The predictive modeling calculation starts at Year 2009 and the simulation is performed for 125 years.

The present-day (calendar year 2008) extent of the tritium, ^{129}I , and nitrate plumes along with the boundary of the Central Plateau model and the down gradient portion of the 200-PO-1 OU is shown in Figure 1b. Although these COPCs are currently present in the down gradient portion of the OU, other COPCs are also simulated as they can migrate out of the Central Plateau model domain in the future. These additional COPCs are ^{99}Tc , ^{90}Sr , uranium, and chlorinated hydrocarbons, such as, tetrachloroethene, trichloroethene, 1,1-dichloroethene, and carbon tetrachloride.

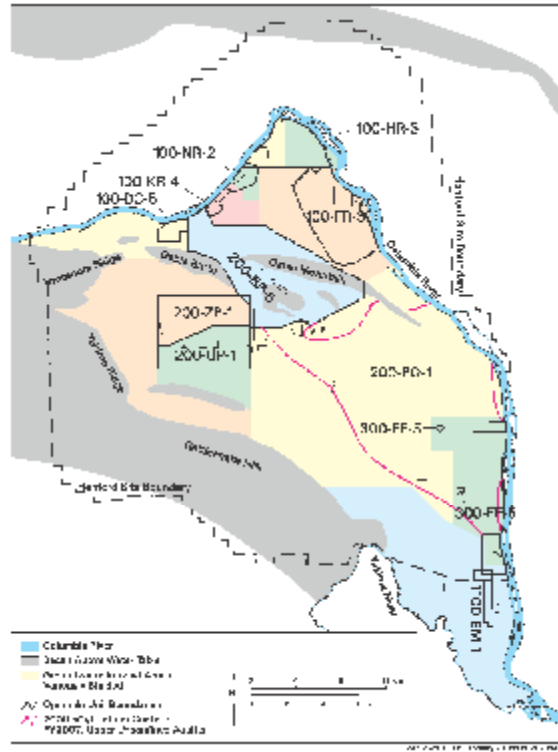
METHODOLOGY

The down gradient contaminant fate and transport modeling for the 200-PO-1 OU is performed by using GoldSim Pro 10.00 (SP2) (GoldSim Technology Group, 2009), a commercial, off-the-shelf computer software package. The Pipe Pathway elements in the GoldSim Contaminant Transport module are used to model transport along pathways that behave as stream tubes or fluid conduits. Pipe Pathways use a Laplace transform approach to provide analytical solutions to a broad range of advective-dominated mass transport systems involving one-dimensional advection, longitudinal dispersion, retardation, decay and ingrowth, and exchanges with immobile storage zones. The geometry of the pathway is defined by specifying length, a cross-sectional area, and a perimeter. Mass enters at one end of a Pipe (or along some specified length of Pipe), advects through with dispersion, sorption, and diffusion within the mobile zone of the Pipe, and then exits at the other end.

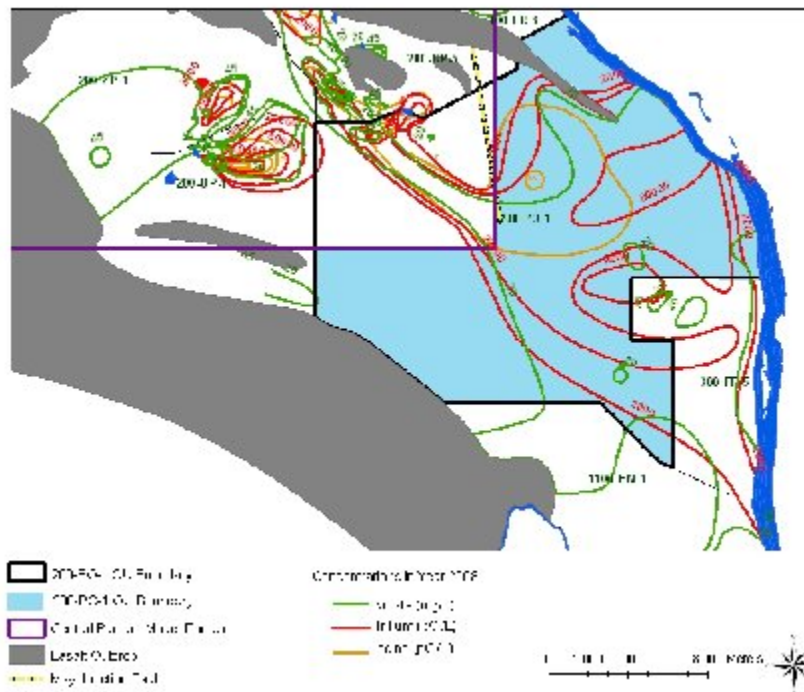
The down gradient portion of the 200-PO-1 OU simulates contaminant transport in the area away from the Hanford Central Plateau. The model domain and discretization is guided by the current spatial extent of the plumes and by the location of wells used in the risk assessment calculations. The mass of COPCs that may exit the Central Plateau model domain to the down gradient region in the future is introduced at the starting location of the Pipe Pathways. It should be noted that the flow and transport modeling for the Central Plateau is performed using MODFLOW-2000 (USGS, 2000) and MT3DMS (SERDP-99-1, 1999) and is described in a separate environmental calculation report.

The basic methodology for this calculation is as follows:

- a. Construct a representative model using Pipe Pathways using site-specific descriptions of the hydrostratigraphy and hydraulic gradients in the down gradient portion of OU. The Pipe Pathways are located near the southeast part of the Central Plateau and originate near the boundary of the Central Plateau model domain of the 200-PO-1 OU. Their location is chosen to capture the mass of contaminants of concern from the Central Plateau model domain and to transport them along the existing hydraulic gradients to the discharge areas near the Columbia River (Figure 2). Three Pipe Pathways are deemed adequate for modeling transport of contaminants in the down gradient portion: one oriented in the



(a)



(b)

Fig. 1. (a) Location of 200-PO-1 OU at Hanford Site, (b) Down gradient model boundary (blue color) along with the extent of plumes in 200-PO-1 OU and nearby area.

northeast direction (designated Transport_NE); one towards east-northeast (designated Transport_E); and one towards the east-southeast (designated Transport_SE).

- b. The representativeness of the model is verified by comparing the construct to the available geologic descriptions, well logs, cross sections, and other appropriate sources of information. The variation in the saturated thickness of the unconfined aquifer and the hydrostratigraphic units (HSUs) present in the down gradient portion is used to determine the adequacy of model discretization. Figure 3 shows the distribution of various HSUs at the water table for the Year 2008.
- c. Appropriate initial conditions are established by introducing the mass COPCs in the Pipe Pathways in a manner such that the groundwater concentrations observed prior to Year 2009 can be reasonably matched at the spatial scale selected for the model discretization. For the predictive calculations a time varying input concentration boundary condition is applied based on the output of the upgradient Central Plateau model. The flow rates are based on the estimation of average hydraulic conductivity and current hydraulic gradients, assuming they would not change appreciably over the simulated time period.

Model Domain

The location of the Pipe Pathways (Figure 2), along with their chosen lengths and widths, are based on the spatial distribution of the current plumes of tritium, ^{129}I , and nitrate in the down gradient region. The location of the Transport_E Pipe Pathway is chosen to capture the highest concentration region within the tritium plume. It is also expected to capture most of the mass that would be exiting the Central Plateau model domain towards the down gradient portion of the OU. The location of the other two Pipe Pathways is chosen to capture the rest of the mass from the Central Plateau model. The starting location of the Pipe Pathways is selected to be approximately 500 m inside the Central Plateau model domain in order to capture the mass of contaminants with minimal impact of the boundary conditions.

The saturated thickness of the unconfined aquifer varies over 30 meters (m) in the down gradient region and is discretized at 10 m interval (three zones) in Pipe Pathways to capture the spatial variability in thickness without unduly increasing the Pipe segments. Each of the three Pipe Pathways are further discretized into six segments, based on the location of observation wells selected in the risk assessment calculations, for which future concentrations may be required. Thus, the concentration history can be obtained from eighteen locations. The Pipe Pathway details are provided in Table 1. Each discretized segment, for the purpose of reference, is numbered from 1 through 6 towards the down gradient direction along with the Pipe Pathway prefix. For example, for the E Pipe Pathway, the Pipe segments are designated, from upgradient to the down gradient direction, as E_1, E_2, E_3, E_4, E_5, and E_6, respectively. The concentrations are calculated for the location at the end of each Pipe segment.

Hydrogeologic Units

The extent and geometry of various HSU in the down gradient portion of 200-PO-1 OU is based on the top and bottom elevation of the HSU at boreholes listed in the Hanford Geologic Contact Depths database. This database provides a controlled dataset that identifies the HSU contacts in various boreholes on the Hanford Site. It updates the existing datasets described by PNNL-14753 (2006). The top and bottom elevation data points taken from the database for a given HSU are interpolated using ordinary kriging to develop the top and bottom surface of the HSU. Similarly, a water table surface is created based on the 2008 water level elevations at monitoring wells. The water table

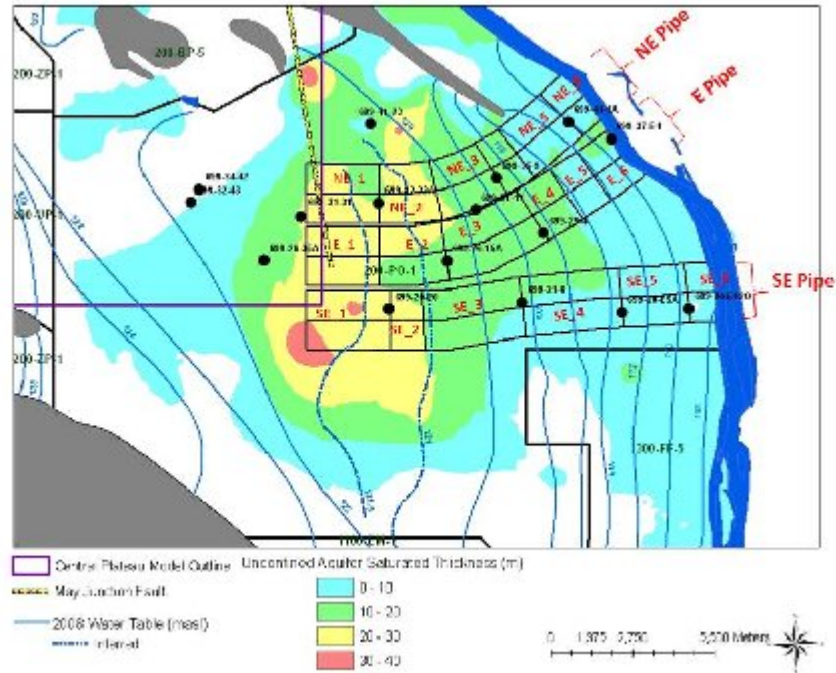


Fig. 2. Spatial discretization of the Pipe Pathways along with the saturated thickness variation in the unconfined aquifer. The six Pipe segments for each Pipe Pathway are shown along with the well locations used in risk assessment calculations.

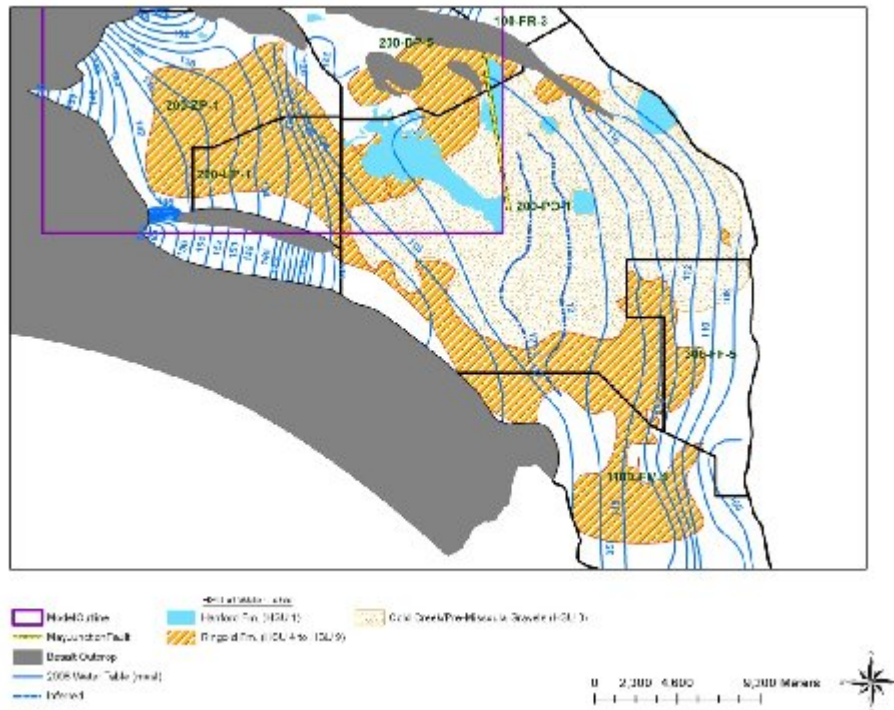


Fig. 3. HSU at the 2008 water table surface

Table 1. Pipe Pathway Property Details

Transport_NE Pipe	Zone 1		Zone 2		Zone 3	
Length of NE Pipe (m)	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
	2457	1876	2012	976	1988	961
Width (m)	2000		2000		2000	
Average Depth (m)	25		15		5	
Hydraulic Gradient	2.5e-4					

Transport_E Pipe	Zone 1	Zone 2			Zone 3	
Length of E Pipe (m)	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
	2983	1661	3194	1339	1102	1102
Width (m)	2000	2000			2000	
Average Depth (m)	25	15			5	
Hydraulic Gradient	2.5e-4					

Transport_SE Pipe	Zone 1		Zone 2	Zone 3		
Length of SE Pipe (m)	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
	2793	1133	3367	3336	2235	898
Width (m)	2000		2000	2000		
Average Depth (m)	25		15	5		
Hydraulic Gradient	2.5e-4					

surface is compared to the top surface of HSU 1 (Hanford Fm), HSU 3 (Cold Creek/Pre-Missoula Gravel unit), HSU 4 (Upper Ringold unit), and HSU 5 (Ringold E, predominantly) to determine the HSU at the water table and to determine the saturated thickness of the unconfined aquifer above Ringold Formation (HSU 4 through HSU 8).

The HSU at the water table is predominantly the Cold Creek/Pre-Missoula Gravel unit (HSU 3) in the down gradient portion of 200-PO-1 OU (Figure 3). This unit is underlain by a relatively thick (>10 m) semi-confining Upper Ringold unit (HSU 4) for most of the modeled area. Since all of the COPCs are highly mobile and occur at relatively low concentrations, they are likely to be constrained within the unconfined aquifer. Because of this, the Pipe Pathways are modeled to represent the unconfined aquifer (primarily the Cold Creek/Pre-Missoula Gravel unit). Since the hydraulic gradients in the down gradient portion of the OU have remained relatively unchanged over the past decade, the current water table surface represents near steady-state conditions.

Model Parameters

1. Hydraulic conductivity used in the model is based on the pump-test data for the wells screened in unconfined aquifer (Hanford or Cold-Creek/Pre-Missoula Gravel units). Around twenty such pump-test based measurements are available in the down gradient portion of the 200-PO-1 OU, as presented in PNNL-13641(2001, Figure 4-19). Of these, only thirteen wells are located within the spatial extent of the Pipe Pathways, where the water table is in the Cold-Creek/Pre-Missoula Gravel unit. Based on the reported transmissivity from the pump-test analyses, the hydraulic conductivity is calculated by dividing the transmissivity by the current estimate of saturated thickness of the unconfined aquifer (Dupuit assumption). The hydraulic conductivity values vary from about 5 m/day to 450 m/day. The data is fitted to a log-normal distribution that has a geometric mean of 61.98 m/day and standard deviation of 7.36 m/day. The distribution is truncated at 5 m/day and 450 m/day, leading to an adjusted mean of 97.16 m/day. The first segment of the Northeast and East Pipe Pathways (namely, Transport_E and Transport_NE) is given the adjusted mean hydraulic conductivity, while the first segment of the third Pipe Pathway (Transport_SE) is given a hydraulic conductivity of 120 m/day based on the pump-test data from well 699-20-20 that is located near the middle of the pipe segment. The volumetric discharge calculated for the first segment of the Pipe Pathway is maintained through the other segments of the Pipe Pathway to conserve the mass of water in a stream tube.
2. The longitudinal dispersivity for each Pipe segment is based on initially assuming the value to be one-tenth of the length of the Pipe segment. But it is modified by attempting to match the actual measurements of tritium concentrations in wells located along the flow path in the down gradient region. The reason for choosing tritium is that it is considered a conservative tracer (non-sorbing), and long-term measurements exist along these wells for a period extending over 20 years that allows for estimation of longitudinal dispersivity.

An initial attempt was made to calculate the longitudinal dispersivity from the tritium concentrations observed at selected wells located approximately along a flow path within the 200-PO-1 OU. The observed concentrations at the wells are plotted as breakthrough curves following the radioactive decay correction and by normalizing the concentration to the maximum observed value for that well. By assuming a constant source concentration upgradient, the breakthrough curve at the observation point (well) is assumed to follow a normal distribution. Based on the methodology given in Domenico & Schwartz (1990, Section 18.2), the variance of the distribution can be calculated using the graphical method

and the expected (mean) longitudinal dispersivity is determined. The longitudinal dispersivity calculated using this method ranged from 120 meters (for a transport distance of 2740 m) to 1450 m (for a transport distance of 4060 m). Because of the large variation in longitudinal dispersivity compared to the transport distance, it was deemed that longitudinal dispersivity values cannot be extrapolated to pipe segments where observation wells with long-term tritium records are not available. Thus, the approach was simplified to initially assume the longitudinal dispersivity at one-tenth of the length of transport distance.

The other transport relevant parameters such as K_d , decay rate, effective porosity, and bulk density are taken from laboratory measurements and other modeling studies. These are summarized in Table 2. Both the effective porosity and bulk density values selected are representative of the sandy gravel sediment from the Hanford Formation and are selected due to the lack of information specific to the Cold Creek/Pre-Missoula Gravel unit in the down gradient portion of the 200-PO-1 OU. A single representative value is deemed adequate because of the averaging of the rock volumes over large transport distances.

Sorption of ^{129}I to the matrix of the unconfined aquifer is considered based on the observation that ^{129}I plume has moved little over the last ten years. To match the observed concentrations, a spatially varying K_d is applied that ranges from 0 ml/g to 0.35 ml/g.

Contaminant Initial and Boundary Conditions

The initial conditions in the Pipe Pathways represent the current distribution of contaminant concentration. This is accomplished by mass loading of contaminants in the Pipe Pathways at desired concentrations and running the model until required concentration conditions are established. The initial conditions in the Pipe Pathways are established by introducing the mass of contaminants and flow rates in such a manner that the concentration profile for years prior to Year 2009 (starting time for predictive calculations) approximate the observed concentrations at the monitoring wells located in the Pipe Pathways and follow the general concentration trends, as observed in the wells. Because the discharge history of water from the operations period and its effect on changing the hydraulic gradients in the area of the Pipe Pathways is poorly understood, the flow rates that are assigned to match the past concentration profiles of the down gradient wells are somewhat arbitrary. Nevertheless, care is taken that the concentration at the starting locations, when convolved with the flow rates, lead to a reasonable agreement with the downstream concentrations for the history matching exercise and for setting up the initial conditions for the start of predictive modeling. History matching is attempted for tritium, nitrate, and ^{129}I by comparing the concentration at selected Pipe segments (that correspond with the location of monitoring wells) with the historical concentration record available for the monitoring wells. The selection of wells for upstream boundary concentrations is based on their relative location from the Pipe Pathways and the time duration of the concentration dataset available for a given analyte.

For the predictive modeling, the volumetric discharge of water applied to each of the three Pipe Pathways is calculated based on the estimation of average hydraulic gradient, hydraulic conductivity, and cross-sectional area in the discretized region for the most upgradient Pipe segment. The same volumetric discharge is applied to the down gradient Pipe segments for the given Pipe Pathway even when the saturated thickness varies from one Pipe segment to the next, resulting in varying groundwater velocities. The volumetric discharge is held constant in order to preserve the stream tube geometry as the flow lines in the down gradient portion of the OU are observed to remain parallel, representing a nearly undisturbed water table condition with horizontal flow (Dupuit assumption).

For the predictive modeling, the input mass flux of contaminants at the boundary of the Pipe Pathways will be provided by the output of the Central Plateau model. For this, at each timestep, the average concentration of contaminants from the Central Plateau model domain grid nodes that correspond to the width of each of the three Pipe Pathways is calculated and applied as a boundary condition. In the vertical direction, the concentrations from only those grid blocks are averaged that correspond to the HSU 1 or HSU 3. The input from Central Plateau model starts at Year 2009 and lasts throughout the simulated time.

CALCULATIONS

The transport calculation is performed by running the GoldSim model file called 200_PO_1_Far_Field_Transport_Model.gsm in a deterministic mode. The contaminant transport module is run with one-year timesteps throughout the simulated time frame using the high solution precision setting in GoldSim. The radioactive decay (and any ingrowth) of the contaminant mass is automatically calculated by GoldSim. The total simulation time is 172 years with the simulation start time equivalent to the beginning of Year 1962. The first 47 years of simulation (from Year 1962 to the end of Year 2008) is used for the purpose of loading the mass in the Pipe Pathways for setting up the initial conditions. The next 125 years of simulation is the predictive part that starts at the beginning of Year 2009 and ends in Year 2133. A single run simulates the transport of all ten COPCs modeled, which are tritium, ^{129}I , ^{99}Tc , ^{90}Sr , uranium, nitrate, tetrachloroethene, trichloroethene, 1,1-dichloroethene, and carbon tetrachloride.

For the predictive part of the simulation, the input concentration of COPCs at the upstream boundary of the Pipe Pathways is based on the simulated output of the MT3DMS calculations performed by the Central Plateau model. The grid blocks in the Central Plateau model that correspond to the spatial location of each of the three Pipe Pathways are identified and the concentrations computed by the corresponding block-centered nodes are averaged for each of the three Pipe Pathways. The selected grid blocks are located 500 m inside the Central Plateau model boundary to reduce the effects of the boundary condition. In the vertical direction, only the grid blocks represented by HSU 1 (Hanford Formation) and HSU 3 (Cold Creek/Pre-Missoula gravel unit) are selected, because they represent the most transmissive part of the unconfined aquifer simulated in the down gradient transport model, where most of the contaminants are expected to be transported through along the hydraulic gradient. A total of 22 grid blocks are considered for the Northeast Pipe Pathway (Transport_NE), 33 grid blocks for the East Pipe Pathway (Transport_E), and 27 grid blocks for the Southeast Pipe Pathway (Transport_SE). All grid blocks for the East and Northeast Pipe Pathway are located along the N-S line, while all but two grid blocks for the Southeast Pipe Pathway are located along the E-W line (the remaining two grid blocks are located along the N-S line). The average concentration time history for each COPC applied at the upstream boundary is post-processed so that the starting time of 0 years as reported by MT3DMS is changed to 47 years for use in the down gradient model (the start of predictive calculations). Other timesteps are translated similarly.

RESULTS AND CONCLUSIONS

Based on the transport simulation in the Pipe Pathways, the future concentrations of selected COPCs are presented in Figure 4. The predicted concentration time history of tritium, ^{129}I , ^{99}Tc , uranium, and nitrate are shown for the Pipe segments in the East Pipe Pathway (Transport_E) that correspond to the location of monitoring wells (shown in Figure 2). The East Pipe Pathway is chosen as it transports the majority of the mass for these contaminants. The concentration of ^{90}Sr is not presented, as the input boundary concentration is practically zero ($< 10^{-12}$ pCi/L). For the

chlorinated hydrocarbons, the future concentrations are shown for only tetrachloroethene as the transport behavior is qualitatively the same for other chlorinated hydrocarbons. Note that for the tetrachloroethene, the calculation results are presented for the Southeast Pipe Pathway (Transport_SE), as the boundary concentrations applied is greater than that for the East Pipe Pathway by about an order of magnitude.

For tritium, ^{129}I , and nitrate, the upstream boundary concentrations applied are lower than the existing concentrations in the Pipe Pathways resulting from the past releases (Figure 4). Therefore, the mass introduced at the boundary does not greatly affect the future concentration in the Pipe Pathways. Nevertheless, the concentrations decrease with time and distance. The tritium concentration in the various Pipe Pathways decline rapidly due to short half-life of tritium (12.3 years). The tritium concentration in the down gradient Pipe Pathways (E_5 and E_6) remains higher than the upstream Pipe Pathways throughout the simulated time. In contrast, ^{129}I concentration in the E_2 Pipe Pathway starts high but declines rapidly due to lower K_d value (0.02 ml/g) implemented compared to the Pipe Pathways immediately upgradient and down gradient, where the K_d value is chosen to be 0.35 ml/g. As mentioned earlier, spatially varying K_d value for ^{129}I is employed based on the concentration history matching exercise undertaken to establish the initial conditions in the Pipe Pathways. At later times, the concentration in E_2 Pipe Pathway is controlled by the concentration in the upstream E_1 Pipe Pathway. The ^{129}I concentration in the down gradient Pipe Pathway increases over time indicating slow down gradient movement of the plume. Because of long half-life compared to the simulation duration, the radioactive decay has negligible effect on ^{129}I concentration. The nitrate concentration in various Pipe Pathways also decline gradually over time as limited mass is added from the upstream boundary. The gradual decline results from movement of currently residing mass in the down gradient portion of the 200-PO-1 OU out of the various Pipe Pathways. No retardation is modeled for nitrate.

For ^{99}Tc and uranium, the upstream boundary concentration in the Pipe Pathway is the only source of contaminants as these contaminants are not known to currently exist in the down gradient portion of the 200-PO-1 OU. Since no retardation is modeled for ^{99}Tc , the delay in peak concentration in the down gradient Pipe Pathways are due to travel time and the reduction in peak concentration is due to dilution and dispersion. In comparison, the breakthrough curves for uranium concentration are considerably delayed due to retardation ($K_d = 0.4$ ml/g), leading to negligibly small breakthrough fraction past E_1 Pipe Pathway.

The concentration breakthrough curves for tetrachloroethene shows affect of limited retardation ($K_d = 0.075$ ml/g) in the Pipe Pathways. The breakthrough times appear to be faster than that for ^{99}Tc , which is unretarded. This is due to different flow velocities in the South East Pipe Pathway (for which tetrachloroethene results are shown) compared to the previous results that are shown for the East Pipe Pathway (such as ^{99}Tc). The concentration of tetrachloroethene decreases with distance due to dilution and dispersion. Similar behavior is observed for other chlorinated hydrocarbons, however, the concentration of carbon tetrachloride shows a larger decline due to a comparatively higher degradation rate.

The results of the down gradient transport model demonstrate that the peak concentration of COPCs that presently exist in the down gradient region of the 200-PO-1 OU generally decline with distance and time. For the COPCs that do not presently exist in the down gradient region but are injected at the upstream boundary, the peak concentrations in the down gradient region remain lower than that at the boundary suggesting decreasing risk.

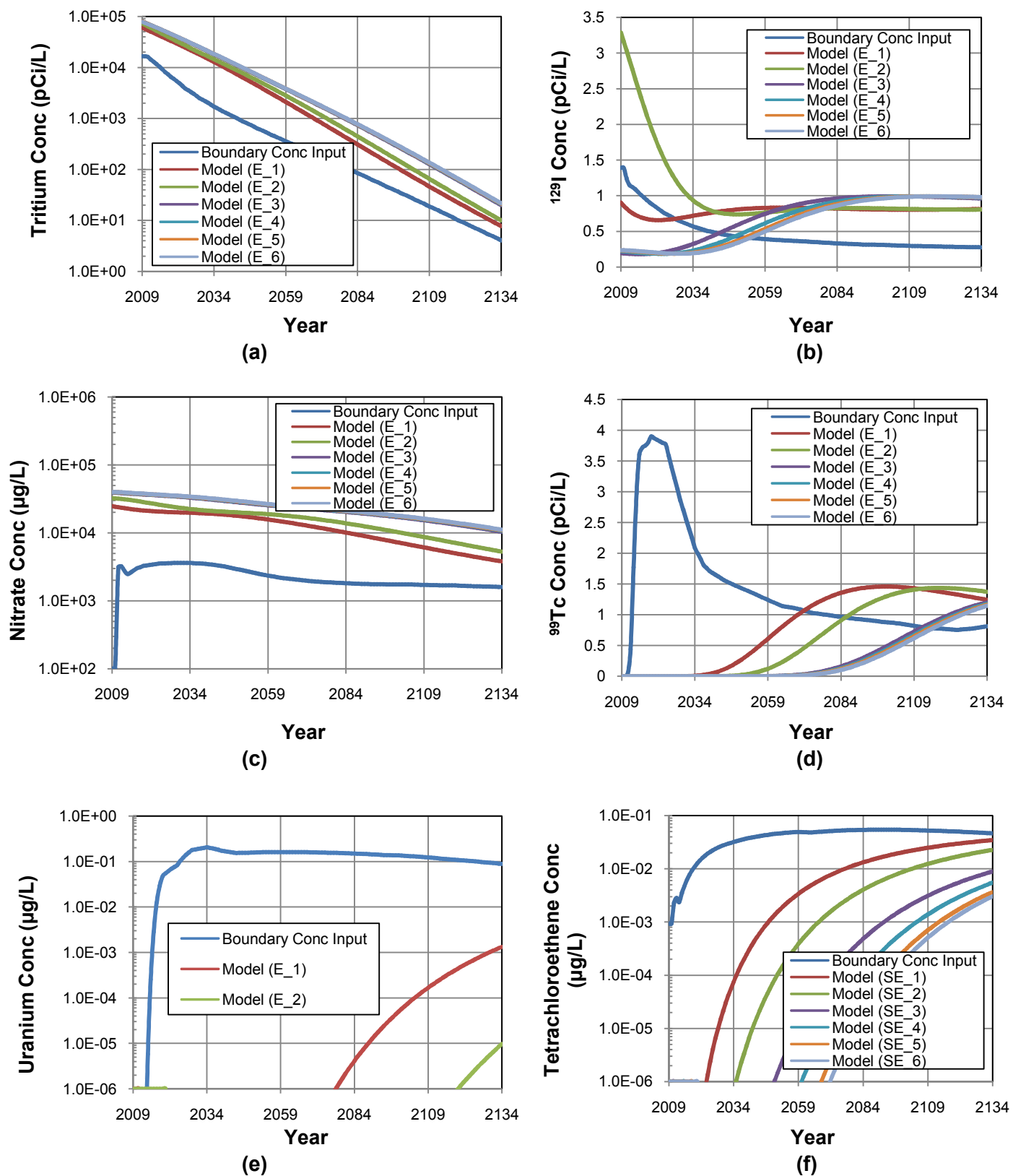


Fig. 4 (a-f). Predicted concentration time history of selected COPCs in the future in the down gradient portion of 200-PO-1 OU. The concentration time history for tritium, ^{129}I , ^{99}Tc , uranium, and nitrate are shown for the East Pipe Pathway (Transport_E), while the concentration time history for tetrachloroethene is shown for the Southeast Pipe Pathway (Transport_SE).

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Table 2. Transport Parameter Values for the Central Plateau Model and the Down gradient (200-PO-1) Model

Final COPCs	Kd (ml/g)	Half-Life (yr)	Half-Life (day)	First Order Decay Rate (1/day)	Reference for Kd	Reference for Degradation Rate
Chromium	0.00E+00			No Decay	(same as for Cr 6+)	
Hexavalent Chromium	0.00E+00			No Decay	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
Nitrate	0.00E+00			No Decay	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
Strontium	1.20E+01	2.88E+01	1.05E+04	6.59E-05	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
Uranium	4.00E-01	4.47E+09	1.63E+12	4.25E-13	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
¹²⁹ I	1.00E-01	1.57E+07	5.73E+09	1.21E-10	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
⁹⁹ Tc	0.00E+00	2.11E+05	7.71E+07	8.99E-09	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
Tritium	0.00E+00	1.23E+01	4.50E+03	1.54E-04	PNNL-18564, Table 6.9, Sandy Gravel sediment type	
Carbon Tetrachloride	3.00E-03	4.13E+01	1.51E+04	4.60E-05	PNNL-16100 (Rev 1), 200-UP-1 sediments, Phase 2 (Table 5.5)	PNNL-13560, Table 18, Most Probable Value
Chloroform	8.40E-03	1.73E+03	6.3E+05	1.10E-06	PNNL-13560, Table 16, Equation 2	PNNL-13560, Table 18, Most Probable Value
Tetrachloroethene (PCE)	7.49E-02			No Decay	Based on empirical calculation <input type="checkbox"/>	No Hanford relevant reference
Trichloroethene (TCE)	2.50E-02			No Decay	Based on empirical calculation <input type="checkbox"/>	No Hanford relevant reference
1,1-Dichloroethene (DCE)	0.00E+00			No Decay	No information	No Hanford relevant reference

Table 2. Transport Parameter Values for the Central Plateau Model and the Down gradient (200-PO-1) Model (continued)

Property	HSU1*	HSU 3*	HSU 5**	Reference
Effective Porosity	0.227	0.227	0.267	PNNL-18564, Table 6.4, Site Wide
Bulk Density (g/cm ³)	1.93	1.93	1.90	PNNL-18564, Table 6.2, Site Wide

□ The empirical calculation is based on PNNL-13560 (Equations 1 & 2, p. C.16), assuming $f_{oc} = 0.00027$, solubility of PCE of 150 mg/L, and solubility of TCE of 1100 mg/L.

* Value based on Hanford Formation sandy gravel sediment class

** Value based on Ringold Formation sandy gravel. Applied to other HSUs in the Ringold Formation