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Vadose Zone Transport Modeling to Calculate Strontium-90 Flux to Groundwater and Preliminary Remediation Goal in Support of the 100-N Remedial Investigation/Feasibility Study

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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company
P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
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By Lee Ann Snyder at 11:15 am, Aug 18, 2014

Release Approval Date

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ENVIRONMENTAL CALCULATION COVER PAGE

Part 1: Completed by the Responsible Manager

Project: 100-N RI/FS **Date:** 04/15/2014

Calculation Title & Description: Vadose Zone Transport Modeling to Calculate Strontium-90 Flux to Groundwater and Preliminary Remediation Goal in Support of the 100-N Remedial Investigation/Feasibility Study

Preparer: N Hasan	**Basis of Qualification:** Education & experience. Software user qualification checked 5/7/14 WEN - confirmed that N. Hasan has an approved STOMP installation available, and have completed software-training requirements.
Checker: H Rashid	**Basis of Qualification:** Education & experience
Senior Reviewer: WE Nichols	**Basis of Qualification:** Education & experience

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APPLICABLE IF CALCULATION IS A RISK ASSESSMENT OR USES AN ENVIRONMENTAL MODEL

WE NICHOLS, ACTING FOR AH ALY — 21 JULY 2014

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ENVIRONMENTAL CALCULATION COVER PAGE (CONTINUED)

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SIGNATURE		DATE

Environmental Calculation File

Vadose Zone Transport Modeling to Calculate Strontium-90 Flux to Groundwater and Preliminary Remediation Goal in Support of the 100-N Remedial Investigation/Feasibility Study

Contents

1 Purpose **1**

2 Background **2**

2.1 Hydrogeologic Setting 2

2.2 Nature and Extent of Contamination 5

3 Methodology **10**

3.1 Extension of the Model Grid 10

3.2 Modification of the Boundary Conditions 10

3.3 Calculation of Strontium-90 Fluxes 10

3.4 Calculation of Soil Screening level and Preliminary Remediation Goal Values for Strontium-90 12

4 Assumptions and Inputs **14**

4.1 Model Discretization 15

4.2 Hydraulic and Transport Parameters 16

4.3 Boundary Conditions 22

4.3.1 Lower Boundary 22

4.3.2 Upper Boundary (Recharge) 22

4.3.3 Lateral Boundaries 23

4.4 Initial Conditions 23

4.5 Calibration 23

5 Software Applications **29**

5.1 Approved Software 29

5.1.1 Description 30

5.1.2 Software Installation and Checkout 30

5.1.3 Statement of Valid Software Application 31

6 Calculation **31**

6.1 Calculation of Strontium-90 Flux from Vadose Zone to Groundwater 31

6.2 Calculation of Strontium-90 Soil Screening Level and Preliminary Remediation Goal Values 32

7 Results/Conclusions **35**

8 References **36**

Attachment

A. **Software Installation and Checkout Form for STOMP Build 4 on GREEN Server** i

Figures

Figure 1. Hanford Site and Location of the 100-N Area 1
Figure 2. Topographic Map of the 100-N Area Showing the Location of the Geologic Cross-Section and 2-D Numerical Model Section (both A-A') 3
Figure 3. Geologic Cross-Section (A-A') from under the Columbia River through Well N-85 to Well N-67 4
Figure 4. 100-N Area Strontium-90 Concentrations in the Unconfined Aquifer in 1995 6
Figure 5. Average Strontium-90 Concentrations in 100-N Area, Upper Portion of Unconfined Aquifer in 2010 7
Figure 6. (a) Original Model Domain (b) Extended Model Domain 11
Figure 7. Location of the Surfaces used for Strontium-90 Flux Calculation 12
Figure 8. Strontrium-90 Source Distribution for PRG Calculation 14
Figure 9. Two-Dimensional Finite Difference Grid Used in the Bank Storage Simulation (Cross-Section A-A') 16
Figure 10. Transient, Constant-head Boundary Condition Applied at the Right Boundary (green line) and on the River Bottom (blue line) 24
Figure 11. Correlation between Water Levels and Sr-90 Concentration Levels at Wells N-67, N-2, N-3 and N-8 25
Figure 12. Strontium-90 Concentration Levels on Soils in Nearby Boreholes 26
Figure 13. Initial Conditions for Strontium-90 Interpolated onto the STOMP Model Grid 27
Figure 14. Comparison between Original Model and the Modified Model (Well N-8s) 28
Figure 15. Comparison between Original Model and the Modified Model (Well N-3) 28
Figure 16. Comparison between Original Model and the Modified Model (Well N-2) 29
Figure 17. Variation of Average Sorbed Concentration with Time 33
Figure 18. Variation of Integrated Flux with Time 33
Figure 19. Variation of Integrated Flux Normalized to Sorbed Concentration with Time 34
Figure 20. Variation of Normalized Integrated Flux with Time 34
Figure 21. Breakthrough Curve for Strontrium-90 35

Tables

Table 1. Model Assumptions 15
Table 2. Mualem-van Genuchten Hydraulic Parameters for Sandy Gravels in the 100-N Area Vadose Zone 19
Table 3. Source-area-specific Aquifer Horizontal Saturated Hydraulic Conductivity Data 20
Table 4. Hydraulic and Transport Parameters used in the Model 21
Table 5. Recharge Rates for Soil Types by Period 22

Terms

1D	one dimensional
CHPRC	CH2M HILL Plateau Remediation Company
CPK	peak groundwater concentration
C_s	average sorbed concentration
DWS	drinking water standard
ECF	environmental calculation file
HEIS	Hanford Environmental Information System (environmental database)
HISI	Hanford Information System Inventory
HSU	hydrostratigraphic unit
IF	integrated flux
IF_{norm}	normalized integrated flux
LWDF	liquid waste disposal facility
PNNL	Pacific Northwest National Laboratory
PRB	permeable reactive barrier
PRG	preliminary remediation goal
PRZ	periodically rewetted zone
RETC	RETention Curve (software for quantifying the hydraulic functions of unsaturated soils)
RI/FS	Remedial Investigation/Feasibility Study
RUM	Ringold upper mud
S_a	surface area
STOMP	subsurface transport over multiple phases (modeling software)
V_z	average velocity in the vertical direction
WQS	water quality standard

1 Purpose

This environmental calculation file (ECF) documents an environmental fate and transport simulation model used for CH2M HILL Plateau Remediation Company's (CHPRC's) work in support of remedial activities at the 100-N Area of the Hanford Site (Figure 1). The objective of this ECF is to calculate strontium-90 flux entering to the groundwater from the vadose zone and also to calculate the soil screening level (SSL) and preliminary remediation goal (PRG) value for strontium-90. The calculated vadose zone flux entering the groundwater will be used as vadose zone strontium-90 source in the subsequent groundwater strontium-90 transport model. PRG for strontium-90 represents the strontium-90 activity that can remain in the vadose zone without causing an exceedance of groundwater regulatory standard for strontium-90. For the calculation of strontium-90 flux, SSL and PRG , a previously developed two-dimensional coupled vadose zone/saturated zone model (HydroGeoLogic [1999], *Groundwater – River Interaction at the 100-N Area*; HydroGeoLogic [2004], *Strontium-90 Transport in the Near River Environment at the 100-N Area*) was adopted as the basis for simulation of fate and transport of strontium-90 at the 100-N Area. Model development beyond that in the adopted model is documented in this ECF and in the model package report (SGW-52559, *Model Package Report: Coupled Vadose Zone and Groundwater Flow and Strontium 90 Transport Model for the 100-N Area of the Hanford Site: 100N-VZGW-Sr90 Model Version 3.0*).

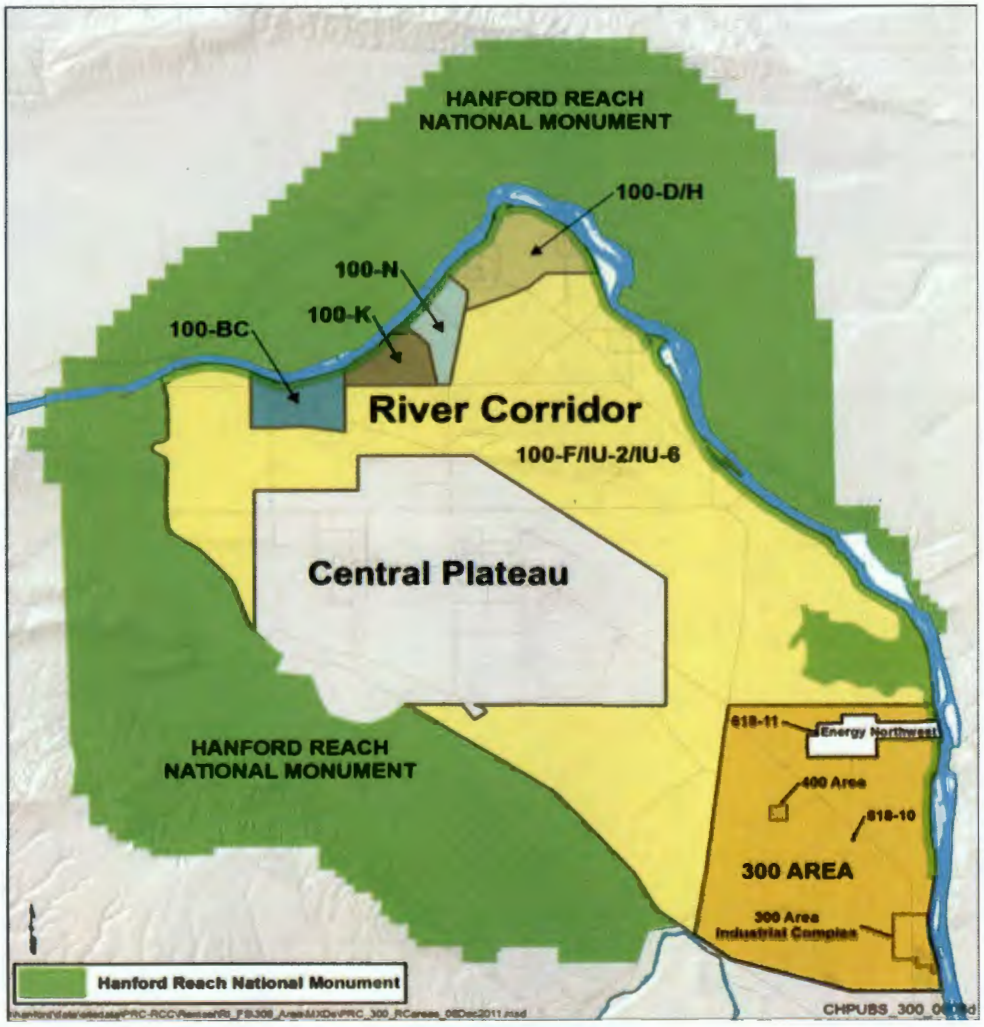


Figure 1. Hanford Site and Location of the 100-N Area

2 Background

A brief description of 100-N Area is described in this section for the convenience of the reader.

2.1 Hydrogeologic Setting

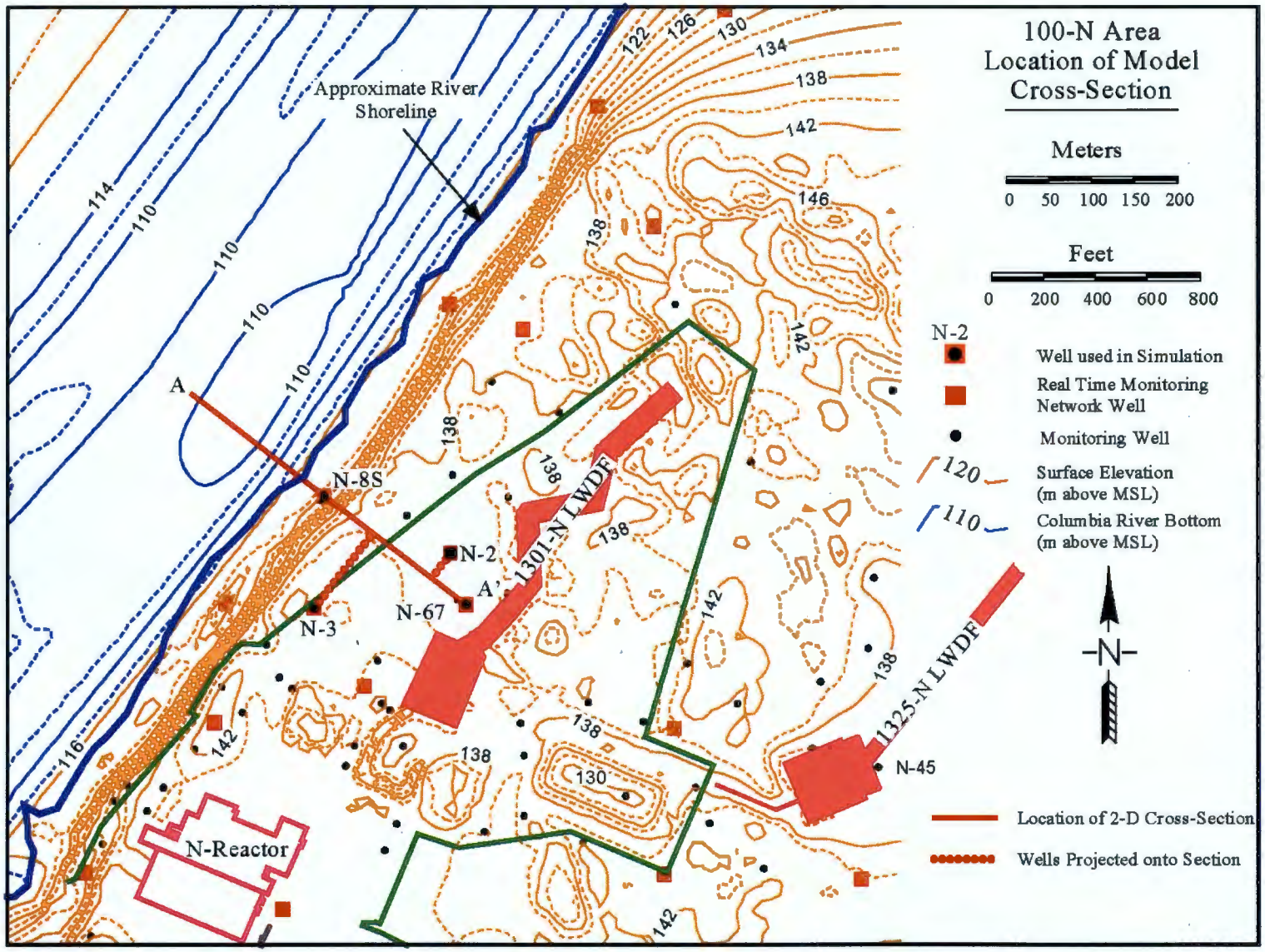
The uppermost stratigraphic unit of significance in the 100-N Area is the Hanford formation. In the 100-N area, this unit consists of uncemented, clast-supported pebble, cobble, and boulder gravel with minor sand and silt interbeds. The matrix in the gravel is composed mostly of coarse-grained sand, and an open-framework texture is common. For most of the 100-N Area, the Hanford formation extends from ground surface to just above the water table. However, channels of Hanford gravels extending below the water table have been reported. Drilling during the characterization phase of the vertical barrier test revealed that Hanford gravel channels are close to the Columbia River (BHI-0185, *Technical Evaluation of the N-Springs Barrier Wall*).

An erosional unconformity separates the Hanford formation from the underlying Ringold Formation. The uppermost Ringold strata at 100-N is Unit E, consisting of variably cemented pebble to cobble gravel with a fine- to coarse- grained sand matrix. Sand and silt interbeds also may be present. Unit E forms the unconfined aquifer in the 100-N Area. The base of the aquifer is situated at the contact between Ringold Unit E and underlying, much less transmissive, silty strata referred to locally as the Ringold Upper Mud (RUM).

Figure 2 is a topographic map of the 100-N Area showing the location of the geologic cross-section A–A' (Figure 3). This cross section shows the relationships between the geologic units underlying the 100-N Area, groundwater, and the Columbia River channel. Water table elevation data are from the Hanford Environmental Information System (HEIS).

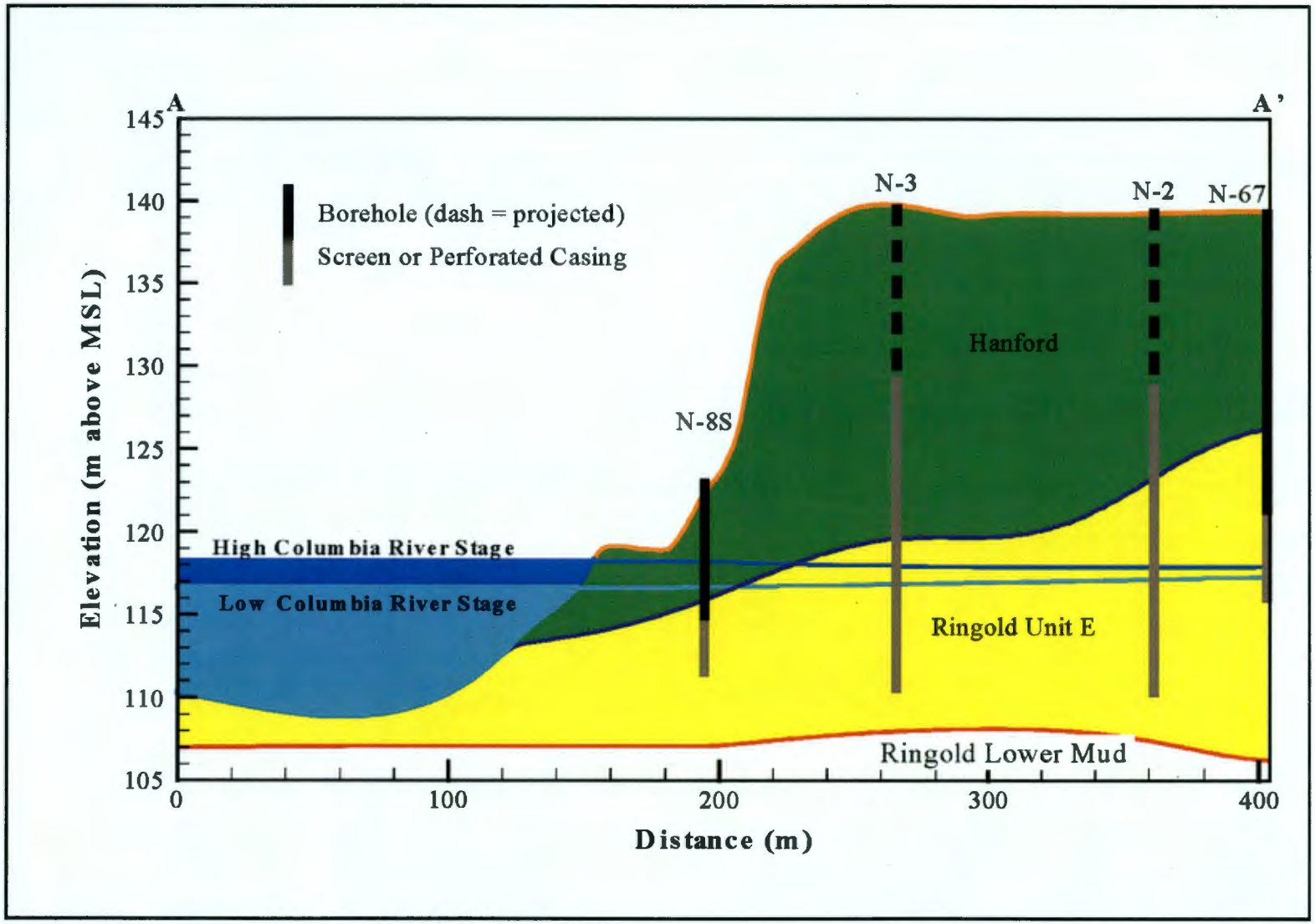
River channel bathymetry data are from an unpublished Corps of Engineers survey conducted in 1986. The bottom half of this cross-section corresponds to the two-dimensional cross-section used in the numerical model. Fluctuating river stage influences water level and water quality measurements in monitoring locations along the shoreline. During periods of rising river stage, a pressure pulse moves inland, raising water levels in monitoring wells located hundreds of meters inland from the Columbia River. Fluctuating water levels may also help to remobilize contamination held in the intermittently saturated sediments immediately above the water table. During high river stage, river water moves into the bank and mixes with groundwater. During low river stage, this "bank storage" water drains back into the river and may be observed as springs along the riverbank. The zone of mixing is restricted to within tens of meters of the shoreline.

A groundwater mound, approximately 6-m high, was created as a result of the large volumes of discharged liquid waste disposed to the 1301-N and 1325-N facilities during operations at 100-N Area. The disposal of the liquid waste not only raised the water table into more transmissive Hanford and Ringold sediments, but also created steeper hydraulic gradients, which increased the groundwater flow rate towards the river. While N-Reactor was operating, riverbank seepage was more pronounced than it is today.



Source: HydroGeoLogic, Inc. (1999)

Figure 2. Topographic Map of the 100-N Area Showing the Location of the Geologic Cross-Section and 2-D Numerical Model Section (both A-A')



Source: HydroGeoLogic, Inc. (1999)

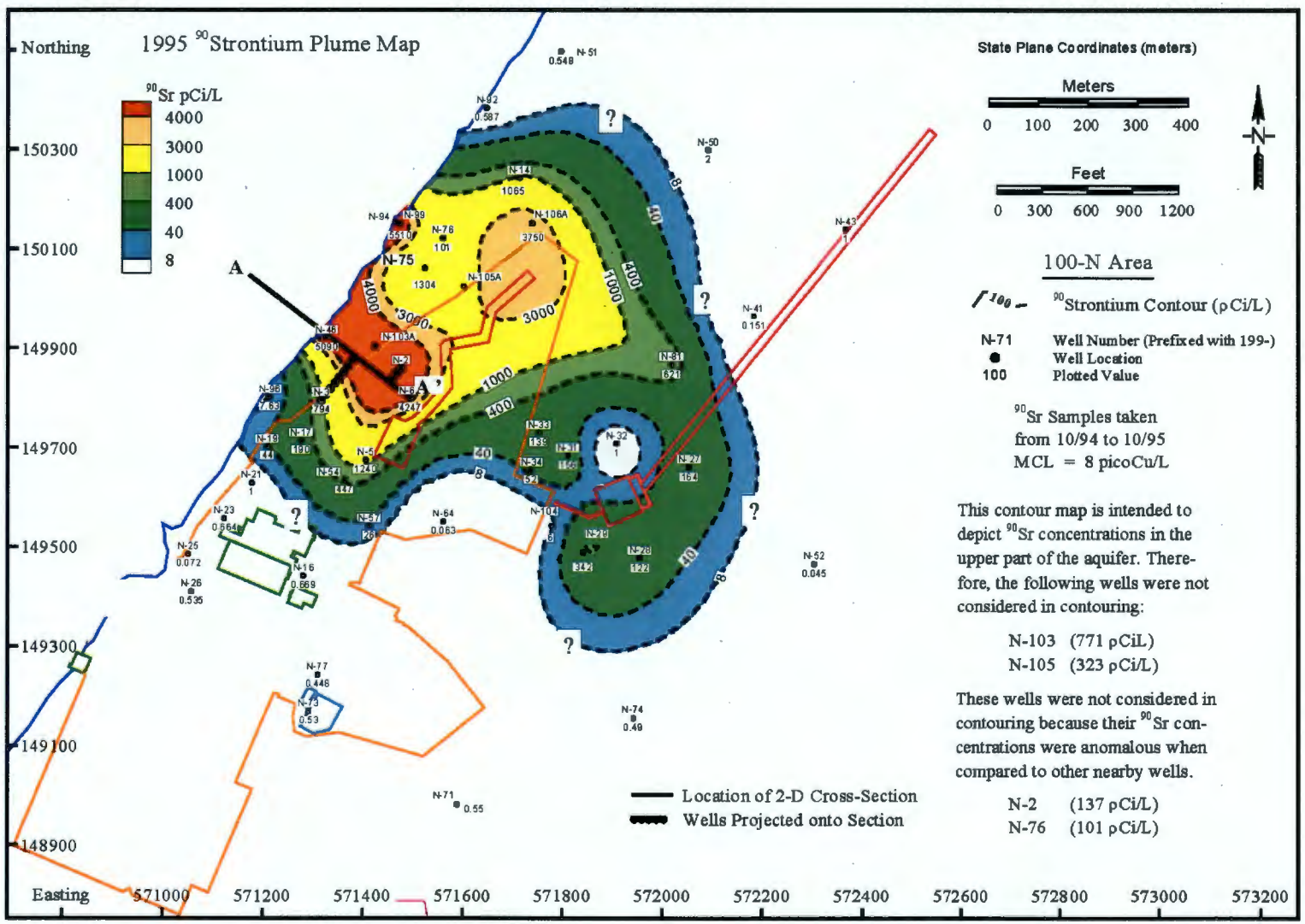
Figure 3. Geologic Cross-Section (A-A') from under the Columbia River through Well N-85 to Well N-67

2.2 Nature and Extent of Contamination

The full nature and extent of strontium-90 contamination at the 100-N Area will be developed and reported in Chapter 4 of the Remedial Investigation/Feasibility Study (RI/FS) report for the 100-N Area. The nature and extent discussion presented here is a high-level summarization to support model development and reflects both the information available when the original model was developed as well as updated information used to revise the model for current use. As noted in DOE/RL-2011-01, *Hanford Site Groundwater Monitoring Report for 2010*, strontium-90 is the principal contaminant of concern in the 100-N Area and the plume has not changed significantly since 1996.

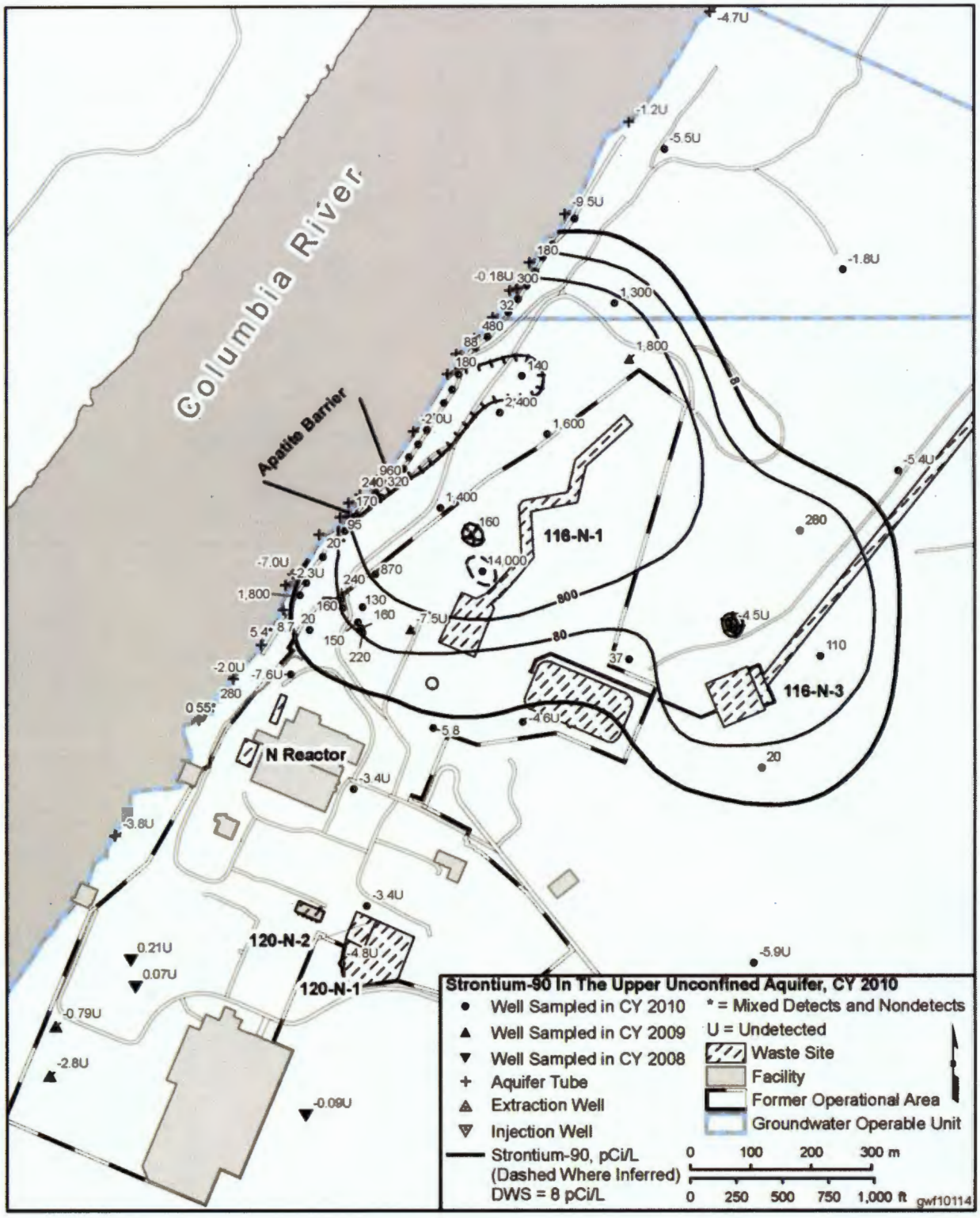
At the time the original model was developed, the highest concentration of strontium-90 in groundwater was located on the river side of the 1301-N facility and midway along its length. A second but smaller plume was centered on the 1325-N facility. Figure 4 shows these relationships for year 1995, while a more recent depiction of the strontium-90 contamination is provided in Figure 5; strontium-90 is being transported by groundwater to the river, but at a much slower rate than the actual groundwater flow rate owing to the sorption characteristics of this contaminant.

The movement of strontium-90 is retarded (slower) relative to subsurface water flow because it is adsorbed onto the sediments. From characterization data obtained from 12 new boreholes at the 100-N Area, bulk distribution coefficient (K_d) of strontium-90 was measured for the 100-N soils in over 80 separate tests (PNL-10899, *Strontium-90 Adsorption and Desorption Properties and Sediment Characterization at the 100-N Area*). It was found that the K_d for strontium-90 varied from 15 to 40 mL/g depending on the rock type's particle size distribution. It was recommended that a K_d value of 15 mL/g to be used for the coarse grained sediments of the Hanford formation and Ringold gravel Unit E. Using 15 mL/g for K_d, 2.0 g/cm^3 for the soil bulk density, and a porosity of 0.28 yielded a relative velocity for strontium-90 to groundwater of approximately 1:100.



Source: HydroGeoLogic, Inc. (1999)

Figure 4. 100-N Area Strontium-90 Concentrations in the Unconfined Aquifer in 1995



Source: DOE/RL-2011-01, Figure 6-4

Figure 5. Average Strontium-90 Concentrations in 100-N Area, Upper Portion of Unconfined Aquifer in 2010

DOE/RL-2011-01 reports the most recently published information on strontium-90 contamination in the 100-N Area. Selected pertinent information relevant to model development reported in DOE/RL-2011-01 is noted here:

- The majority of the strontium-90 remaining in the unsaturated and saturated zones in the 100-N Area is present in the vadose zone above the aquifer. Far more strontium-90 is contained within the unsaturated zone than in the groundwater. Strontium-90 has a much greater affinity for sediment than for water (i.e., a high distribution coefficient), so its rate of transport in groundwater to the Columbia River is considerably slower than the actual groundwater flow rate. The relative velocity of strontium-90 to groundwater is ~1 to 100.

- Strontium-90 is generally distributed in a layer around the current water table, mostly in the upper portion of the Ringold Formation unit 5. This layer is thickest around the liquid waste disposal facilities (LWDFs) (up to 12.2 meters) and thins toward the Columbia River (1.5 to 6.1 meters). Strontium-90 concentrations in soil from wells/borings near the LWDFs show a decreasing trend with distance and depth from the LWDFs. The majority of strontium-90 contamination within the LWDFs was retained within the facilities (nearer the head end and immediately below the base).

- The LWDFs were interim remediated in 2005 and 2006, and contaminated concrete and soil were removed to a depth of 4.6 meters. The sites were backfilled in 2006.

- Strontium-90 concentrations in soil samples collected from the wells/borings further from the LWDFs along the 100-N Area shoreline indicate that the majority of strontium-90 is located in the top of the Ringold Formation unit 5 and the bottom of the Hanford formation. The water table near the Columbia River is located in the top of the Ringold Formation unit 5 during low river-level conditions (July through March), but the water table can rise up into the Hanford formation when river levels are elevated (late March/April to June). This causes the strontium-90 contamination to smear vertically within the areal extent of the plume. The majority of the contamination in soil along the Columbia River is in the immediate vicinity of the current apatite permeable reactive barrier (PRB), between wells 199-N-123 to 199-N-121.

- The size and shape of the strontium-90 plume in groundwater has varied little over the years due to the way strontium and strontium-90 act in the environment. The plume currently has nearly the same areal extent and shape as in 1996, prior to startup of 100-N Area pump-and-treat operations. Effluent discharge totals of strontium-90 to 116-N-1 and 116-N-3 LWDFs from 1964 through 1993 were slightly more than 2,997 curies. As of 2010, this amount was ~1,325 curies, corrected for radioactive decay. The 2010 value does not reflect any contamination that was removed during the 2005/2006 excavation of the 116-N-1 and 116-N-3 LWDFs; therefore, some of the remaining 1,325 curies have been removed to the Environmental Restoration Disposal Facility. In a previous calculation for the 116-N-1 Crib and Trench sediments, the strontium-90 inventory was estimated at 500 curies, assuming an average strontium-90 concentration from soil analyses, distributed through a 1-meter-thick crib/trench/vadose zone interface. Of the inventory remaining, ~99% is absorbed on the soil in the vadose zone and upper aquifer and 1% is actually in groundwater. The plume extends from beneath the 116-N-1 and 116-N-3 LWDFs to the Columbia River at levels exceeding the drinking water standard (DWS)

of 8 pCi/L. Concentrations exceeding 100 pCi/L are limited to the upper ~3 meters of the aquifer.

- The highest strontium-90 concentrations along the Columbia River in soil and groundwater are found near the current apatite PRB and immediately downriver to the northeast. This area is the focus of increased monitoring and remediation activities. The apatite barrier helped to reduce strontium-90 concentration in its immediate vicinity, including wells within the barrier itself, on both sides of the injection wells on each end of the barrier, and monitoring wells downgradient of the barrier. It also includes one well upgradient of the barrier; 199-N-46 has shown a decrease in strontium-90 concentration from a high in September 2006 of 6,040 pCi/L to 530 pCi/L in April 2010. Prior to apatite PRB installation, strontium-90 concentrations in this well were consistently above 1,000 pCi/L; however, since December 2008, the concentration has been below 650 pCi/L.

- Strontium-90 in monitoring wells near the former 116-N-1 LWDF and the former 116-N-3 LWDF show no obvious long-term decline in concentrations, but concentrations do vary significantly in relation to water levels within the wells. Water levels were significantly higher below the LWDFs in the 1980s and early 1990s, when discharges were still occurring. As the water level decreased, strontium-90 remained in the vadose zone above the water table. Therefore, when the water table rises beneath the former LWDFs, strontium-90 from the vadose zone is remobilized and the concentrations in groundwater increase. Levels have been consistent for the last few years, with the increase and decrease of strontium-90 concentrations mirroring changes in the water table elevation. Seven wells are showing increasing strontium-90 concentration trends: three wells are former 100-N Area pump-and-treat extraction wells (199-N-75, 199-N-103A, and 199-N-105A); three wells (199-N-2, 199-N-67, and 119-N-14) are downgradient of the 116-N-1 LWDF; and the fourth well, 199-N-122, is a monitoring well in the apatite PRB. Well 199-N-122 is located in one of the most contaminated portions of the shoreline. The concentrations in all seven of these wells have increased since the pump-and-treat system shutdown in 2006. Six of the seven wells have higher concentrations now than in 1996, before the pump-and-treat system was started. It appears that the increase may be due to a rebound effect that has been occurring since pump-and-treat operations ceased. Another possible explanation is that higher river levels in the last few years have caused the lower vadose zone to be rewetted and allowed remobilization of strontium-90 from these contaminated sediments.

As the river and aquifer levels decrease, contamination is smeared back, down into the aquifer, and could cause higher concentrations in the monitoring wells over time. This effect will be studied further in next year's report to determine if it is contributing to the uptrend observed in these six wells. Well 199-N-122 is the only exception, because it was not drilled and installed until October 2005, and the concentration of this well is under the influence of the apatite PRB. As the development of apatite continues along the barrier, changes occur in strontium-90 concentrations due to interaction with nearby treated wells and changes in river stage, remobilizing strontium-90 from rewetted contaminated sediment above the water table. All other wells in the 100-N Area that were monitored in 2010 are showing slight downward strontium-90 trends.

3 Methodology

The original model developed by HydroGeoLogic (1999; 2004) and implemented in the STOMP (Subsurface Transport Over Multiple Phases) software was modified to meet the requirements of this calculation, and the vadose zone strontium-90 flux entering the groundwater was calculated, following the methodology detailed in this section.

3.1 Extension of the Model Grid

The model grid in the original model was only included few meters of the vadose zone. For the calculation of SSL and PRG for strontium-90, it is assumed that contamination is distributed vertically throughout the vadose zone. Accordingly, the model grid was extended upward to the land surface to support this assumption. The extended model was used for the strontium-90 flux, SSL and PRG calculations. Figure 6 shows both the original and extended model domain.

3.2 Modification of the Boundary Conditions

The boundary conditions in the original model were based on the hourly water level data in the river and well N-67. For reducing the simulation time, the hourly boundary conditions were changed to daily by using the daily averages of the hourly water level data.

3.3 Calculation of Strontium-90 Fluxes

To calculate the strontium-90 flux coming from the vadose zone, STOMP's surface flux feature (PNNL-15782, *STOMP Subsurface Transport Over Multiple Phases: User's Guide Version 4.0*) was used. This feature allows flux planes to be defined at user-specified locations in the model domain. STOMP reports both the flux rate and the total integrated (cumulative) flux in each time step for user-specified quantities, in this case solute mass and aqueous volumetric flow, across these defined flux planes. This output is recorded to STOMP's 'surface' flux output file.

Three surface flux planes were defined to determine the flux of strontium-90 entering groundwater from the vadose zone. These surfaces were named as 1st, 2nd, and 3rd, as shown in Figure 7. The locations of these flux planes were chosen based on their proximity to selected high concentration areas of strontium-90, rather than at specific distances from the Columbia River. The maximum water table line drawn in the Figure 7 is based on maximum daily averaged water level data in the river and well N-67. Figure 7 also shows the initial aqueous phase strontium-90 concentration distribution. The surfaces were placed few meters above the maximum water table so that the capillary fringe does not have any effect on the flux.

The model was run to simulate 30 years starting from calendar year 1995 and the strontium-90 flux coming through the surfaces were evaluated at four different calendar years: 1995, 2005, 2015 and 2025. The integrated flux obtained from the STOMP surface flux file was then normalized so that it can be used for any initial concentration and recharge rate. Equation 1 was used to obtain the normalized integrated flux.

$$IF_{norm} = \frac{IF}{C_s V_z S_a} \qquad \text{Equation 1}$$

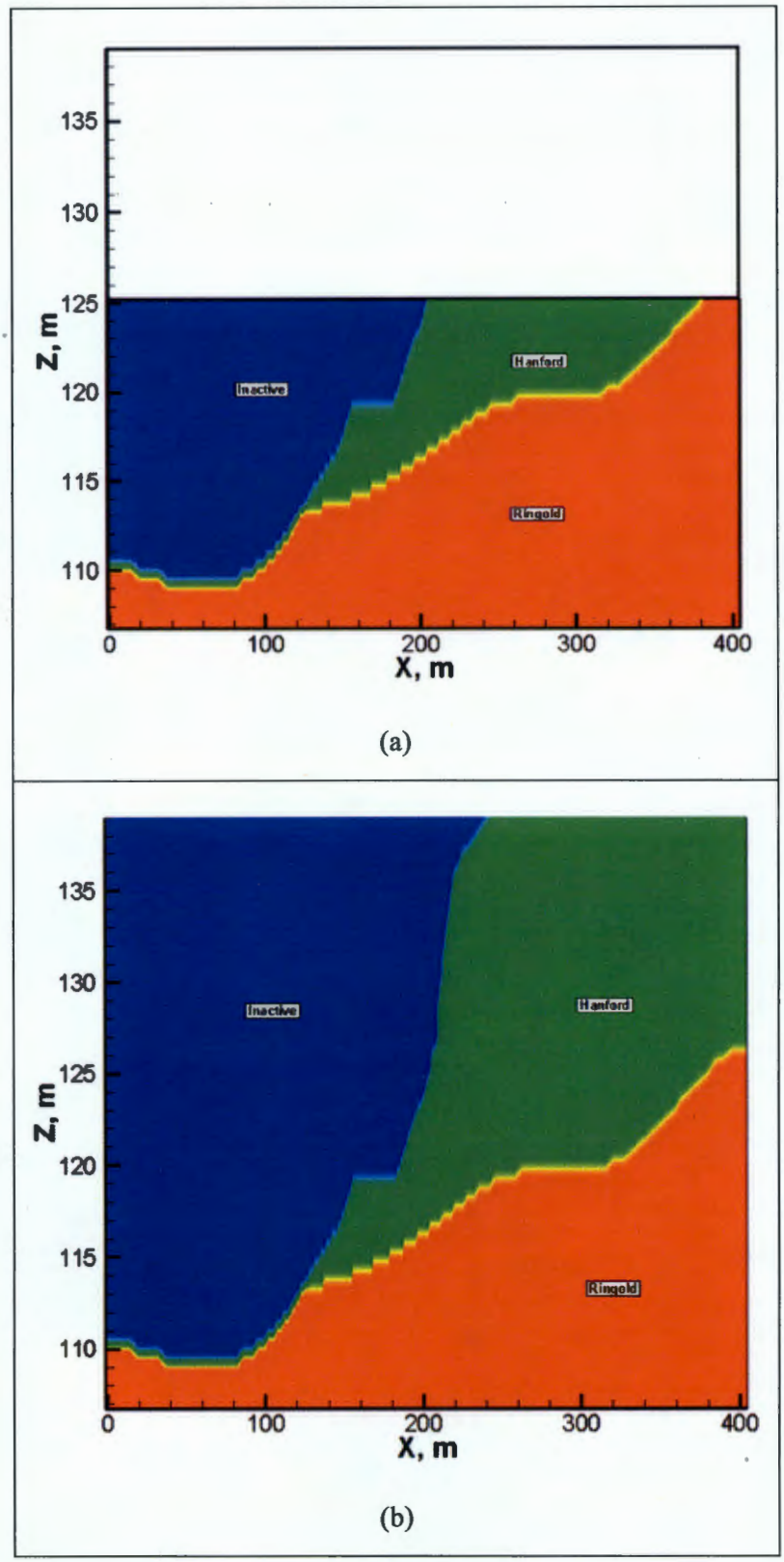


Figure 6. (a) Original Model Domain (b) Extended Model Domain

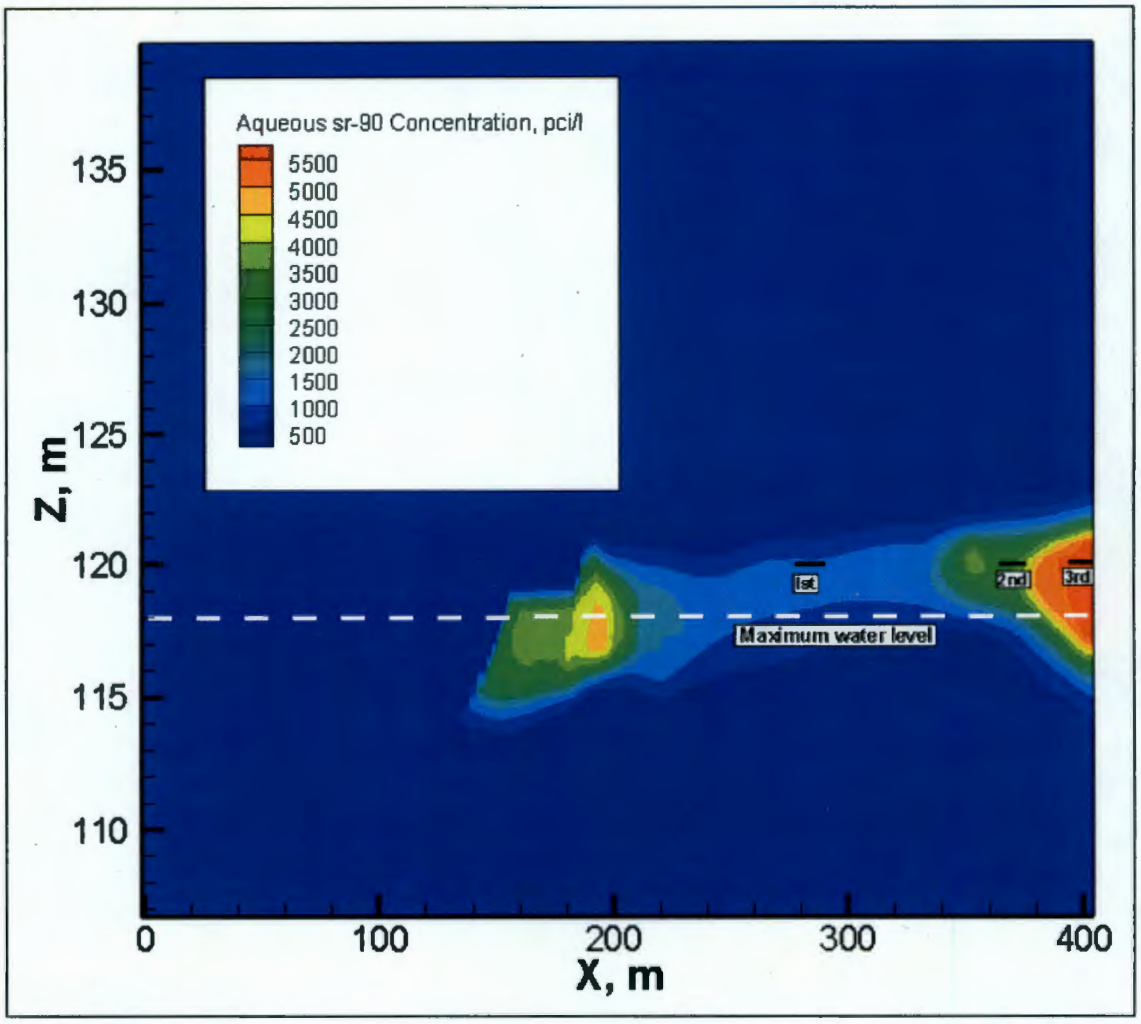


Figure 7. Location of the Surfaces used for Strontium-90 Flux Calculation

where:

IF_{norm} = normalized integrated flux, $\frac{(\text{pCi})}{\left(\frac{\text{pCi}}{\text{g}} * \frac{\text{m}}{\text{d}} * \text{m}^2\right)}$

IF = integrated flux (pCi)

V_z = average velocity in the vertical direction (m/day)

C_s = average sorbed concentration within 1 m above the surface (pCi/g)

S_a = surface area of the defined flux surfaces (m^2)

3.4 Calculation of Soil Screening Level and Preliminary Remediation Goal Values for Strontium-90

Part of the risk analysis conducted for the 100-N Area RI/FS is the determination of SSL and PRG for strontium-90. The SSL is used in a screening step to identify areas needing further investigation. The PRG is used to define the maximum soil concentration of strontium-90 that can remain within the vadose zone without causing an exceedance of groundwater regulatory standard.

The extended model was utilized for calculation of a groundwater SSL and PRG for strontium-90. Because of extensive contamination throughout the domain of that model (in both vadose zone and the saturated zone), it is difficult to isolate the impact on groundwater from primarily vertical transport of strontium-90 through the vadose zone underneath a waste site from that caused by lateral movement of dissolved strontium-90 mass from surrounding locations in the saturated zone and periodically rewetted zone (PRZ). To find the impact of soil contamination of strontium-90 from a waste site on groundwater concentrations a stylized analysis was conducted, where the mass distribution of strontium-90 from a waste site was conceptualized and guided by the simulated results from 2-D cross-section model. Figure 8 shows a rectangular solid region where the strontium-90 mass was placed below the 1310-N LWDF trench, where maximum strontium-90 concentration was observed (HydroGeoLogic, 2004) in the model along with the observation well used for the SSL and PRG calculations. The background image is the different zones of the models (blue: inactive, green: Hanford formation, red: Ringold Formation). The base of the initial mass rectangular region was placed above the top of the PRZ, uniformly distributing the initial strontium-90 mass throughout the full thickness of the vadose zone above the PRZ. The width of the region was selected to be 30 m, chosen to represent a conservative zone of contamination along the flow direction under a given waste site in the 100-N Area. Note that the SSL/PRG calculations performed using this width can be linearly scaled if a different width of the contamination for a waste site is desired. An observation well that is screened for 4.5 m (15 feet) is placed at the downgradient edge of the rectangular zone of contamination that extends down from the middle of the PRZ into the saturated zone. Using the upper 4.5 meters of the aquifer is consistent with the requirements for aquifer mixing zone thickness in WAC 173-340-747[5][f][i]. No other mass of strontium-90 is placed in the cross-section except for that in the rectangular region. The average concentration along the 4.5 m screened interval of the observation well was calculated as a function of time to determine the peak concentration. The calculations are performed by setting the initial strontium-90 concentration to 1000 pCi/g in the rectangular region. Recharge values applied for the SSL and PRG calculation are consistent with those used in ECF-100NR1-12-0017, *STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for the 100-NR-1 Source Operable Unit.* Two recharge scenarios are considered: (i) an irrigation recharge scenario, applied for the SSL calculation, and (ii) a native vegetation recharge scenario, applied for the PRG calculation.

The SSL for strontrium-90 is computed (in the back-calculation step) as:

$$SSL = aC_I \frac{WQS}{CPK} \qquad \text{Equation 2}$$

where,

SSL = soil screening level, expressed in units of Strontrium-90 activity per unit mass of soil

a = constant selected to balance units

C_I = initial soil concentration, expressed as contaminant mass or activity per unit mass of soil (1000 pCi/g)

WQS = water quality standard, expressed as contaminant mass or activity per unit volume of water

CPK = peak groundwater concentration, expressed as contaminant mass or activity per unit volume of water

For SSL calculations using Equation 2, the *CPK* value is obtained from STOMP simulations using the irrigation recharge scenario.

Similarly, the PRG for each COPC is computed (in the back-calculation step) as:

$$PRG = aC_I \frac{WQS}{CPK} \qquad \text{Equation 3}$$

For PRG calculations with Equation 3, the *CPK* value is obtained from STOMP simulations using the native vegetation recharge scenario.

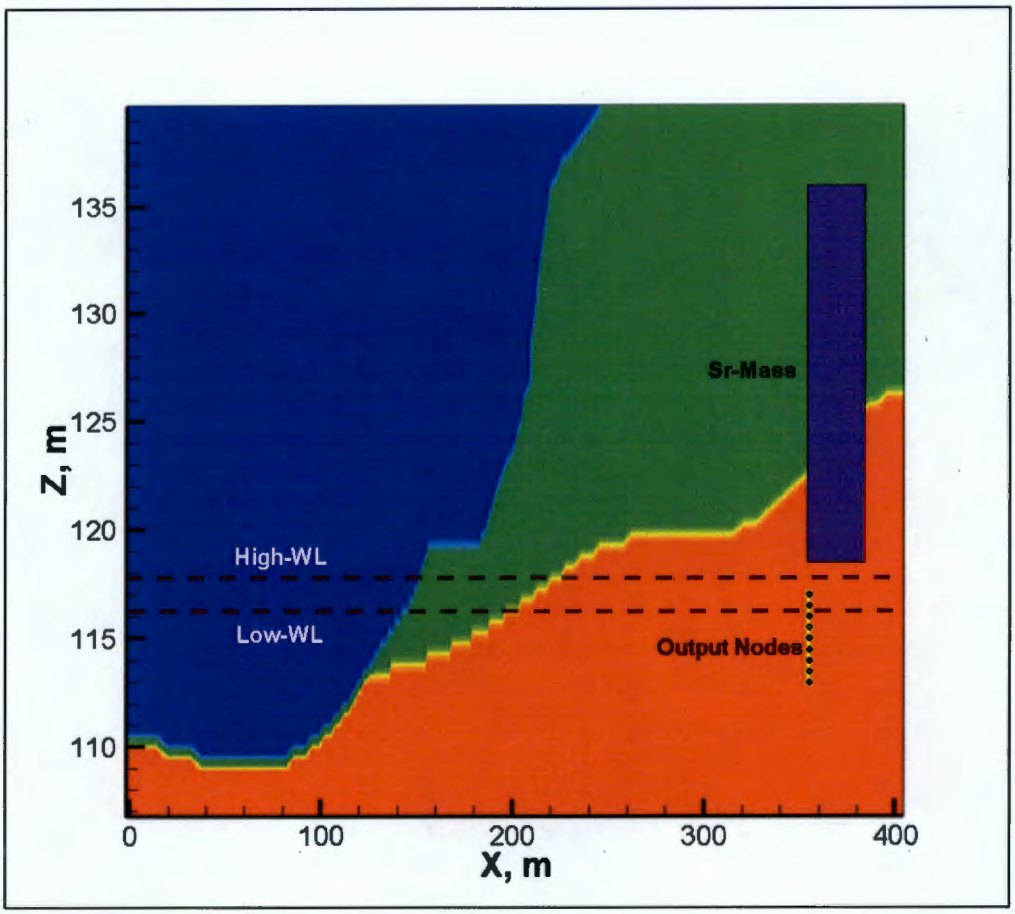


Figure 8. Strontrium-90 Initial Source Distribution for PRG Calculation

4 Assumptions and Inputs

The model construction reflects the assumptions and limitations listed in Table 1.

Table 1. Model Assumptions

Assumption	Rationale
No impediment to flow between the Columbia River and the unconfined aquifer (i.e. no low conductivity zone at the river bottom)	Water levels in wells close to the river respond immediately to Columbia River's water level changes
Model has only two property types (Hanford Gravels and Ringold Unit E)	Characterization in the vicinity of cross-sectional model indicates the gravels of these formations are the principal rock types
Anisotropic ratio of 1:10 for vertical to horizontal hydraulic conductivity was used for both Hanford formation and the Ringold Formation	Typical anisotropic ratio used at the site
Base of the unconfined aquifer is the Ringold Mud Unit and is assumed to be impermeable	Mud Unit approximately 60 m thick

4.1 Model Discretization

The model is implemented using a two-dimensional Cartesian grid. This grid is aligned along a transect (Figure 9) defined by well 199-N-67 (right boundary) and extending 403 m to the northwest. The transect passes through well N-8S and extends approximately 140-m into the Columbia River (left boundary). Vertically, the base of the model grid is the very low permeability Ringold Mud Unit at an elevation of 107 m, and the top of the model grid is at an elevation of 139.5 m above mean sea level (MSL).

The Cartesian grid is discretized into 18,348 finite difference cells, with 278 cells in the horizontal direction and 66 cells in the vertical direction. Of these 18,348 cells, 9504 cells lie above the riverbed and/or land surface and are excluded from the model using STOMP's inactive nodes feature. Variable grid spacing is used to permit increasing the spatial resolution near the Columbia River to accommodate large pressure gradients associated with near-river locations. The grid spacing is fine (0.5-m × 0.5-m) where a vadose zone seepage face is expected, but coarsens away from the expected seepage faces (3.0-m [horizontal] × 0.5-m [vertical]).

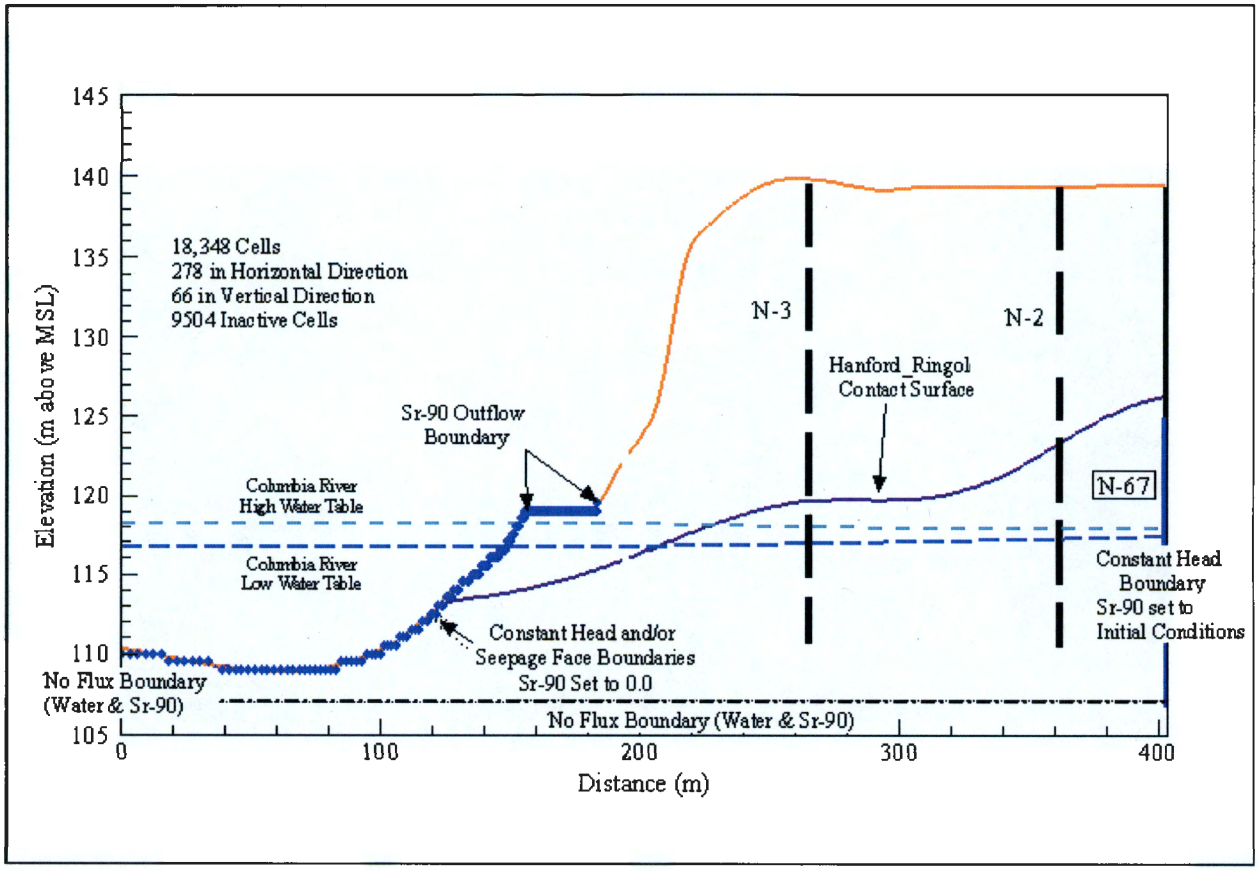


Figure 9. Two-Dimensional Finite Difference Grid Used in the Bank Storage Simulation (Cross-Section A-A')

4.2 Hydraulic and Transport Parameters

To the extent possible, hydraulic and transport parameter values specific to the 100-NR-2 Operable Unit were used in the STOMP simulations. Based on previous Hanford studies and on the fact that all available measurements of hydraulic properties were prepared for the same constitutive relationships, the sediments were assumed to follow the van Genuchten (1980) moisture retention constitutive relation and the Mualem –van Genuchten relative permeability constitutive relation (Mualem, 1976). Thus, the required values that must be specified in for each lithologic unit for input to STOMP are:

- K_s, saturated hydraulic conductivity, (LT^{-1})
- n_T, total porosity (L^3L^{-3})
- n_D, saturated volumetric water content, called diffusive porosity in STOMP (L^3L^{-3})
- s_r, residual saturation (dimensionless), equal to the residual volumetric water content divided by the saturated volumetric water content
- van Genuchten α (L^{-1}), proportional to the inverse of the air entry matric potential
- van Genuchten n fitting parameter (dimensionless)

The van Genuchten m parameter was assumed to be fixed and equal to $(n-1)/n$ and the Mualem β exponent was assumed to be fixed at 0.5 (Mualem, 1976; RPP-20621, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment*).

Within the 100-N area, the Hanford formation tends to be coarser grained than the Ringold E. The former tends to contain larger gravel clasts than the latter, but the Ringold E can locally contain significant amounts of gravel (SGW-46279, *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model*). The Ringold E unit in the vadose zone is described as silty sandy gravel in 100-N, the RUM was assumed to act as a lower bound (aquitard) for the aquifer (SGW-46279) and so was not directly included in the simulations.

Mualem-van Genuchten hydraulic parameters values specific to the 100-N Area were obtained for the Hanford formation from DOE/RL-96-11, *1301-N and 1325-N Liquid Waste Disposal Facilities Limited Field Investigation Report*, and four raw data points obtained from HEIS. The RETC (RETention Curve) computer code (EPA/600/2-91/065, *The RETC Code for Quantifying the Hydraulic Functions of Unsaturated Soils*) was used to analyze the raw data to obtain the unsaturated hydraulic properties. These property values are all gravel corrected. The gravel correction was done according to method described in Khaleel and Relyea (1997). There were eight other samples of 100-N Area that has been reported in DOE/RL-96-11. Table 2 reports the available vadose zone parameter values. These 100-N Area sediments are dominated by the gravel fraction (> 2-mm size), with gravel clasts accounting for 4 to 82% of the total sample mass. Moisture retention data were measured on the non-gravel sediment fraction (< 2mm size) and corrected for gravel fraction.

Horizontal saturated hydraulic conductivity ($K_{s,h}$) measurements from aquifer slug tests for the several areas presented therein were reviewed (ECF-100NR2-12-0031) and geometric means were calculated for aquifer test measurements only (Table 3). The mean $K_{s,h}$ values ranged between 2.6 and 5 m/day.

The geometric mean horizontal $K_{s,h}$ values shown in Table 3 for the Ringold E in 100-N were checked against the range of preliminary calibration values currently in use for the 100 Area groundwater flow and transport model. Vertical anisotropy is commonly assumed to be 0.1 for Hanford Site soils (SGW-46279).

The Mualem-van Genuchten hydraulic properties for the Hanford formation were estimated for 100-N Area by averaging the individual parameter values for all samples (Table 2). An exception is the saturated volumetric water content, termed θ_s in the van Genuchten moisture retention relationship, and termed diffusive porosity (n_D) in STOMP. The θ_s values in Table 2 were determined by applying a gravel correction factor to the values determined in the laboratory on the < 2mm fraction. The absence of the gravels may have resulted in underestimation of the void volume available for flow because it is very hard to reconcile the high K_s values with such small porosity values. Therefore, the Hanford site-wide estimate of 0.25 and Ringold site-wide estimates of 0.28 were used (PNNL-18564, *Selection and Traceability of Parameters to Support Hanford-Specific RESRAD Analyses*).

Mualem-van Genuchten parameters for the Hanford formation in the 100-N Area were determined from the six samples taken from boreholes 199-N-108A and 199-N-109A. The arithmetic mean was calculated for the six samples for the model input. But for K_s geometric mean was calculated for sample no BOGL72 and BOGL98 and was used as model input. Because there were no aquifer test data for the Hanford formation in the 100-N Area, the horizontal aquifer hydraulic conductivity $K_{s,h}$ was estimated as 10 times the vertical hydraulic conductivity $K_{s,v}$. Compared to the Hanford formation, the Ringold E unit has a greater influence on determining the groundwater concentration in the aquifer because the Ringold E unit usually has a much lower K_s value.

Mualem-van Genuchten parameters for the Ringold formation in100-N were determined from the six samples taken from boreholes 199-N-108A and 199-N-109A. The arithmetic mean was calculated for the six samples for the model input. But for K_s geometric mean was calculated for all the samples and was used as model input. The horizontal aquifer K_s was considered as 10× vertical K_s.

For transport simulations, STOMP requires the particle density (ρ_p) values of the Hanford, and Ringold units. The particle density of each unit can be calculated using the bulk density (ρ_B) and porosity. Bulk density is necessary for retardation scaling factor calculations. Estimates of bulk density for Hanford formation and the Ringold units were obtained from PNNL-14702, *Vadose Zone Hydrology Data Package for Hanford Assessments*, which reports 1.91 g/cm^3 for the Hanford formation and 1.90 g/cm^3 for the Ringold Formation. All the hydraulic and transport parameters used in the strontium-90 flux calculation are reported in Table 4.

Table 2. Mualem-van Genuchten Hydraulic Parameters for Sandy Gravels in the 100-N Area Vadose Zone

Sample	HSU [a]	Source Area	Well Number	Depth (m)	% Gravel	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)*
2-3055	Hanford	100-NR-2	199-N-108A	25 – 26	82	0.063	0	0.00512	1.31866	_
2-3056	Ringold	100-NR-2	199-N-108A	46.5 – 47.5	60	0.129	0.0185	0.0375	1.6767	_
2-3057	Ringold	100-NR-2	199-N-108A	53 – 54	60	0.152	0.0083	0.01805	1.8545	_
2-3058	Ringold	100-NR-2	199-N-108A	93.5 – 94.5	60	0.139	0.0168	0.01388	1.788	_
BOGL7*	Hanford	100-NR-2	199-N-108A	15 – 15.5	69	0.154	0.00	0.0018	1.648	3.20E-04
BOGL7*	Hanford	100-NR-2	199-N-108A	24 – 24.5	4	0.483	0.00	0.0081	1.448	2.99E-05
BOGL8*	Ringold	100-NR-2	199-N-108A	43 – 43.5	60	0.170	0.00	0.0032	1.518	8.21E-04
BOGL8*	Ringold	100-NR-2	199-N-108A	62.8 – 63.3	51	0.213	0.00	0.0024	1.686	7.38E-04
BOGL9*	Hanford	100-NR-2	199-N-109A	10.5 – 11	76	0.056	0.00	0.0148	1.348	5.89E-02
BOGLB*	Hanford	100-NR-2	199-N-109A	17.5 – 18	65	0.107	0.00	0.0213	1.318	5.80E-02
BOGLB*	Hanford	100-NR-2	199-N-109A	24.5 – 25	72	0.077	0.00	0.0084	1.379	6.20E-03
BOGLB*	Ringold	100-NR-2	199-N-109A	39.5 – 40	72	0.063	0.00	0.0043	1.457	5.29E-03

a. HSU = Hydrostratigraphic unit

Table 3. Source-area-specific Aquifer Horizontal Saturated Hydraulic Conductivity Data

Source Area	Aquifer Formation	Number of Tests	Minimum Horizontal $K_{s,h}$ (m/day)	Maximum Horizontal $K_{s,h}$ (m/day)	Geometric Mean Horizontal $K_{s,h}$ (m/day)	Geometric Mean Horizontal $K_{s,h}$ (cm/s)
100-N	Ringold	8	2.6	9.4	5.0	5.78E-03

Table 4. Hydraulic and Transport Parameters used in the Model

Physical Property (unit)	Hanford formation	Ringold Formation
Hydraulic and Mechanical Properties		
$K_{s,h}$ horizontal hydraulic conductivity (m/d)	37.51	5.0
$K_{s,v}$ vertical hydraulic conductivity (m/d)	3.751 [a]	0.50 [a]
n_D diffusive porosity (unitless)	0.28	0.25
ρ_p particle density (g/cm^3)	2.68	2.68
ρ_b bulk density (g/cm^3)	1.91	1.90
S_s specific storage (unitless)	1.0×10^{-6}	1.0×10^{-6}
Water Retention Characteristic Properties		
van Genuchten α (1/cm)	0.0099	0.0132
van Genuchten n (unitless)	1.41	1.66
S_r residual saturation (unitless)	0.0	0.052
Solute / Rock Interaction Transport Properties		
K_d bulk distribution coefficient for strontium-90 (mL/g)	15	15
α_L longitudinal dispersivity (m)	0.01	0.01
α_T transverse dispersivity (m)	0.001	0.001
Contaminant Physical Properties		
$t_{½}$ half-life of strontium-90 (years)	28.6	
D_m molecular diffusion coefficient for strontium-90 (m^2/s)	7.94×10^{-10}	

a. Based on anisotropic ratio of 10:1 (horizontal to vertical), assumed.

4.3 Boundary Conditions

4.3.1 Lower Boundary

The lower boundary condition was set to a no-flow boundary for both hydraulic and solute mass transport purposes, because of the presence of a relatively thick section of the Ringold mud unit having a hydraulic conductivity several orders of magnitude lower than the Ringold gravels.

4.3.2 Upper Boundary (Recharge)

For water flow, the net infiltration (or deep percolation) into the vadose zone that ultimately results in recharge to the aquifer is applied to the upper boundary condition in this model in the form of a step-wise constant Neumann-type (constant flux) boundary condition. In actuality, net infiltration is the result of completing processes of precipitation, evaporation, transpiration, run-off and run-on. In an arid or semi-arid climate such as at the Hanford Site, downward fluxes resulting from this competition are episodic and usually infrequent, but this effect is typically damped towards a nearly constant rate with depth as soil moisture variability with depth measured at Hanford Site lysimeters shows (PNNL-17841, *Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates*). This is the basis for representing recharge in model using a constant rate applicable to a given soil type and vegetation cover (DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*).

A number of studies have been carried out at the Hanford site to ascertain representative long-term averages of the episodic fluxes, i.e., recharge rates, such as those compiled in Pacific Northwest National Laboratory (PNNL); e.g., PNNL-14702, and reported also in DOE/RL-2011-50. The 100 Area-specific recharge rates in PNNL-14702 vary with surface soil type, and so provide an estimate of the range of possible recharge rates for various land uses (that is, for the nature and state of the surface vegetation cover). SGW-50776 notes for undisturbed conditions that three surface soils are present in the 100 Areas: Ephrata sandy or stony loam, Burbank sandy loam and Rupert sand. The recharge rate assigned for these surface soil types in the three periods of the simulation are presented in Table 5. The rate for the first period represents a bare soil condition, the rate for the second period represents a transitional state of developing shrub-steppe vegetation, and the third period represents a rate for a mature shrub-steppe vegetation cover.

For transport, the portion of the upper boundary that was set to natural recharge for the flow boundary was set to be an outflow boundary. Note that an outflow boundary condition in STOMP considers only advective transport across the boundary; diffusion transport is neglected.

Table 5. Recharge Rates for Soil Types by Period

Soil Type	Recharge Rate (mm/yr)		
	Period 1 (1st 5 years of simulation time)	Period 2 (next 30 years of simulation time)	Period 3 (rest of simulation time)
Ephrata sandy loam and stony loam	17.0	3.0	1.5
Burbank sandy loam	52.0	6.0	3.0
Rupert sand	44.0	8.0	4.0

4.3.3 Lateral Boundaries

For water flow, the right boundary was set as a no-flow boundary in the vadose zone portion as a time-dependent, constant head boundary for the unconfined aquifer portion of this boundary. The time-dependent, constant head applied in the unconfined aquifer portion was changed on an hourly basis using the real-time water level data recorded for well 199-N-67 shown as an orange line on Figure 10.

For water flow, the left boundary was set as no-flow boundary due to symmetry. The nodes on the riverbed were set to a time-dependent, constant-head boundary condition. This boundary condition was applied when the node was below the water table. If the node was above the water table, a seepage face boundary was applied. The head values applied to these nodes are from the real-time 100-N Area River Stage monitoring station shown as a blue line in Figure 10. The river stage recorder went offline twice, as indicated by the red line in Figure 10. For these offline periods, water levels were interpolated from previous day's records to substitute for the missing data.

For transport, the left boundary was set to a no-flow boundary condition. The right boundary condition for transport was set to maintain the initial conditions as a constant solute concentration boundary.

4.4 Initial Conditions

Initial hydraulic conditions (hydraulic head) for all nodes in the simulation must be specified prior to beginning a transient simulation. The following process was used to establish the initial hydraulic conditions for the model:

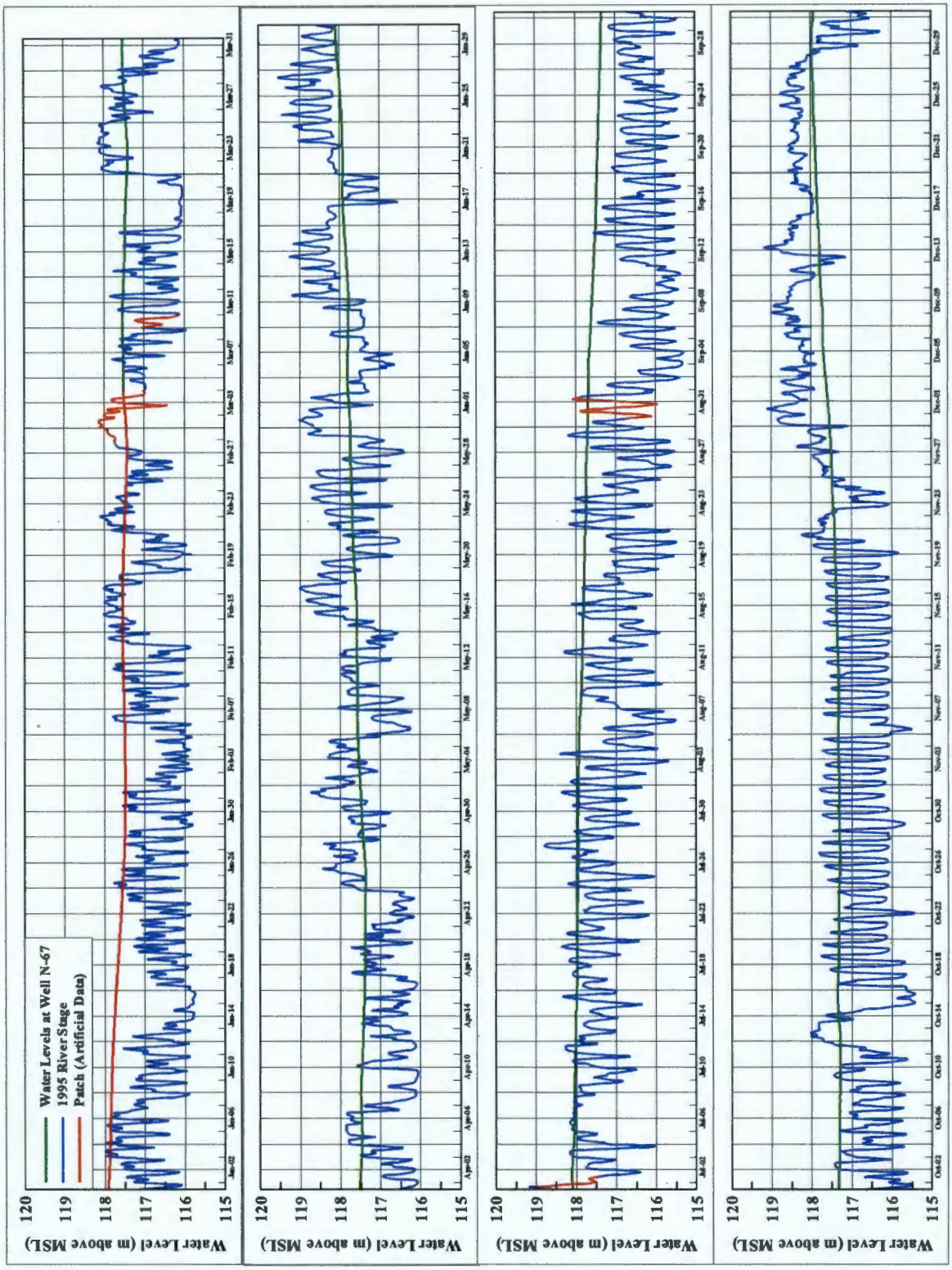
1. Constant head boundaries were set to the river's water-levels (riverbed boundary) and at well N-67 (right boundary for the unconfined aquifer) as observed at midnight for April 1, 1995.
2. A constant recharge rate of 52 mm/yr was applied to the upper boundary.
3. Steady state conditions were simulated for April 1, 1995 by running the model for a long simulation time (with the constant boundaries set in steps 1 and 2) until there were no changes in hydraulic heads between time steps in any model node.

For the transient simulations, the lateral boundary conditions were set to the daily averaged water levels observed at the river and in well N-67.

The initial solute concentration conditions for strontium-90 required the correlation of strontium-90 monitoring data with water levels in wells N-8S, N-2, N-3 and N-67 (Figure 11) as well as the evaluation soil sampling data from nearby boreholes (Figure 12). Using the information given on Figure 11 and Figure 12, the initial conditions for strontium-90 were interpolated onto the STOMP model grid (Figure 13).

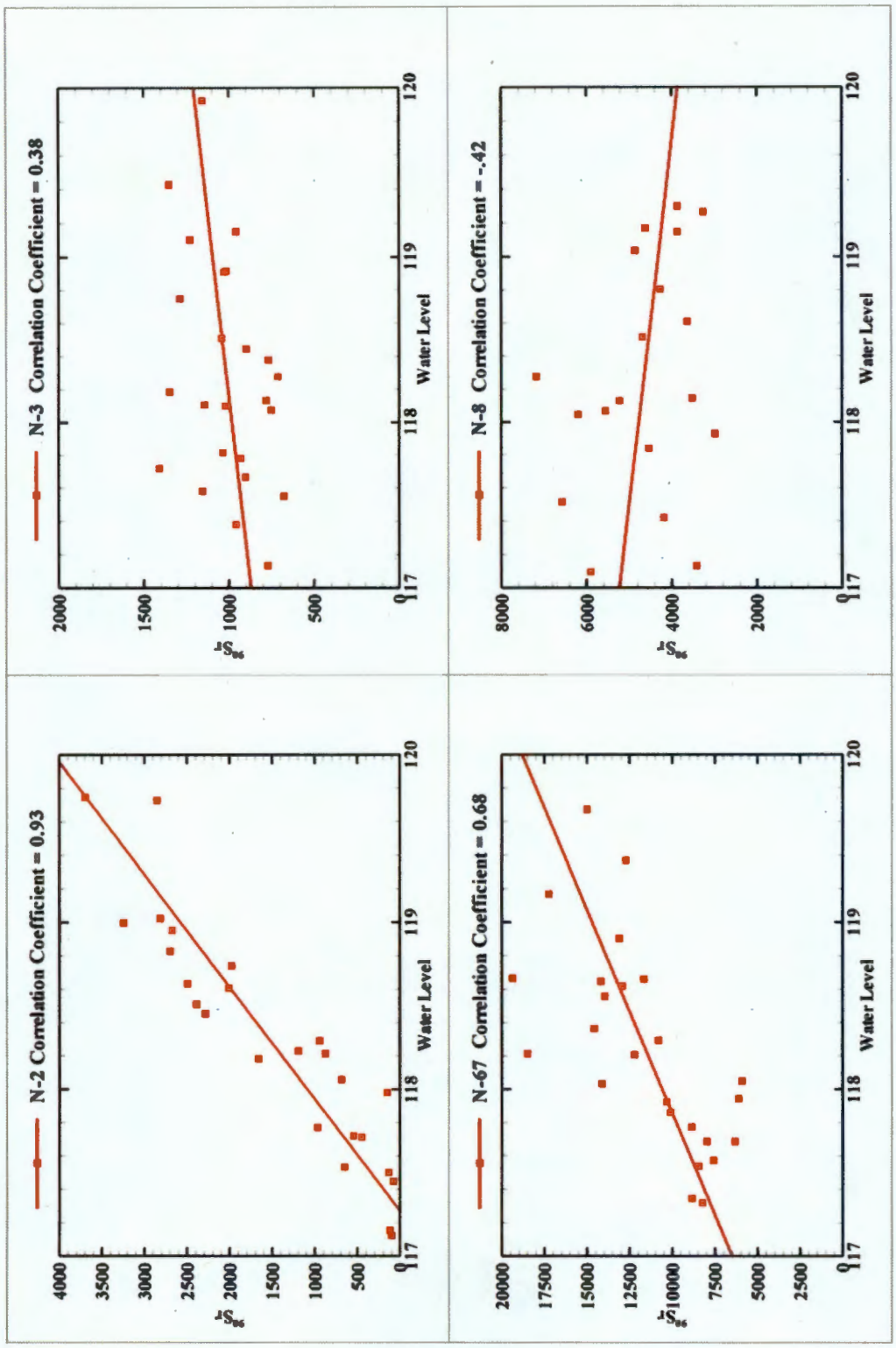
4.5 Calibration

The model was not directly calibrated to observed water-level measurements. The changes in water level in three different wells (N-8s, N-3, N-20 were compared between the updated and original model configurations. The comparisons are shown in Figure 16, Figure 15, and Figure 16, and shown collectively that the updated model results closely track the results of the original calibrated model.



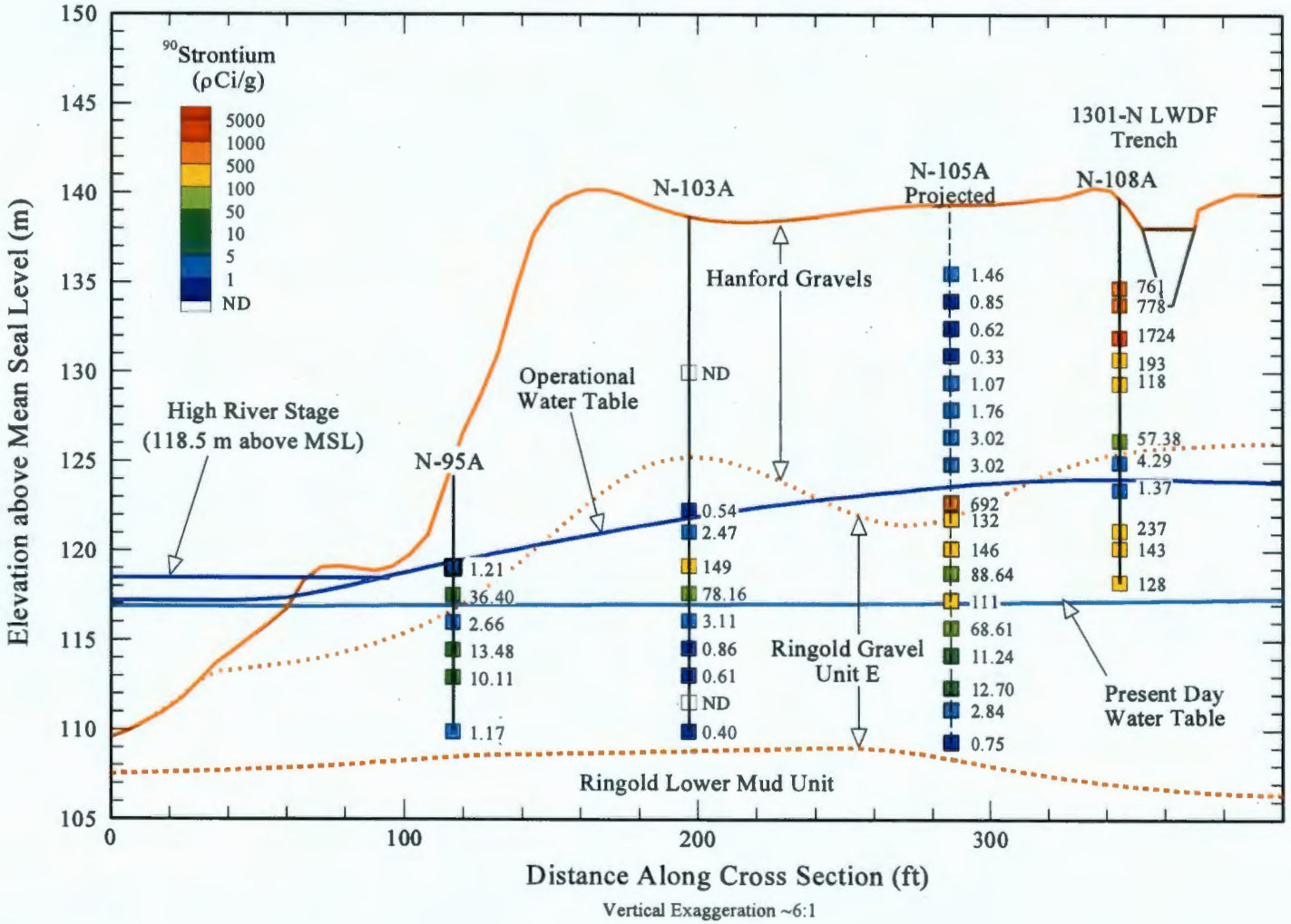
Source: HydroGeoLogic, Inc. (1999)

Figure 10. Transient, Constant-head Boundary Condition Applied at the Right Boundary (green line) and on the River Bottom (blue line)



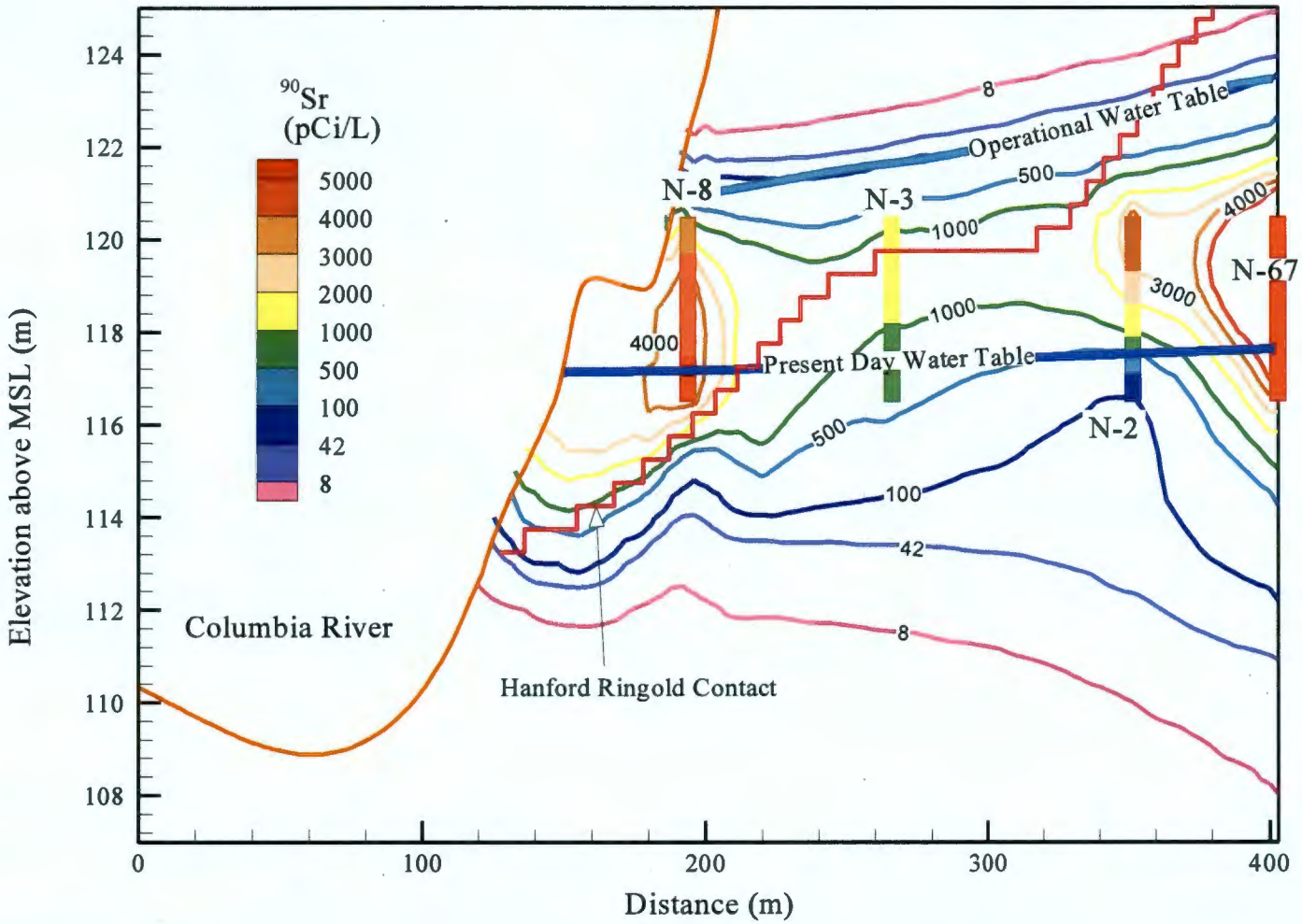
Source: HydroGeoLogic, Inc. (1999)

Figure 11. Correlation between Water Levels and Sr-90 Concentration Levels at Wells N-67, N-2, N-3 and N-8



Source: HydroGeoLogic, Inc. (1999)

Figure 12. Strontium-90 Concentration Levels on Soils in Nearby Boreholes



Source: HydroGeoLogic, Inc. (1999)

Figure 13. Initial Conditions for Strontium-90 Interpolated onto the STOMP Model Grid

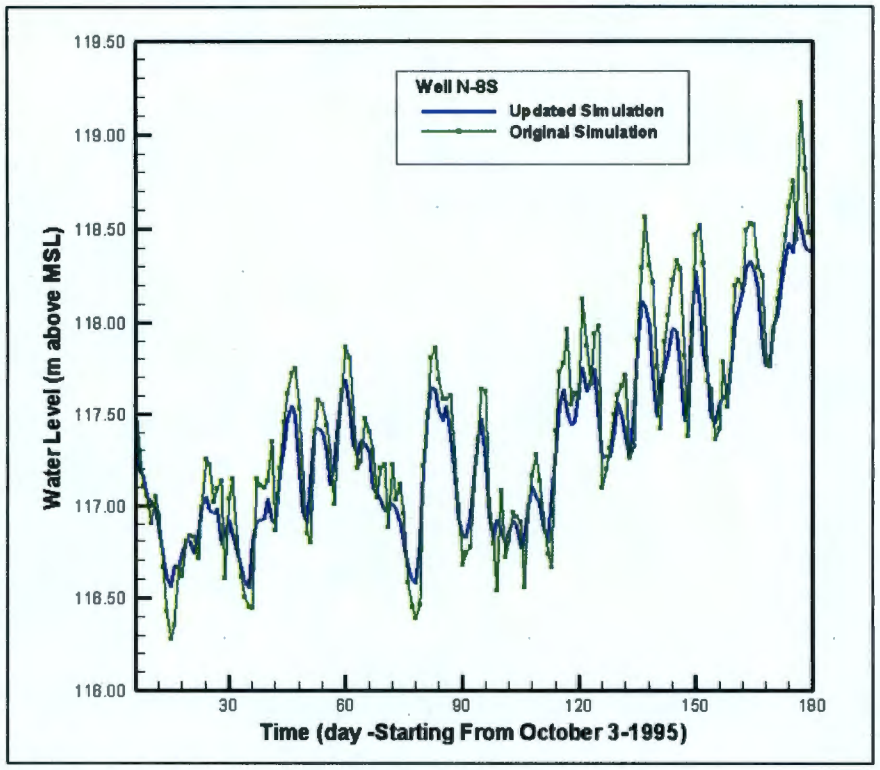


Figure 14. Comparison between Original Model and the Modified Model (Well N-8s)

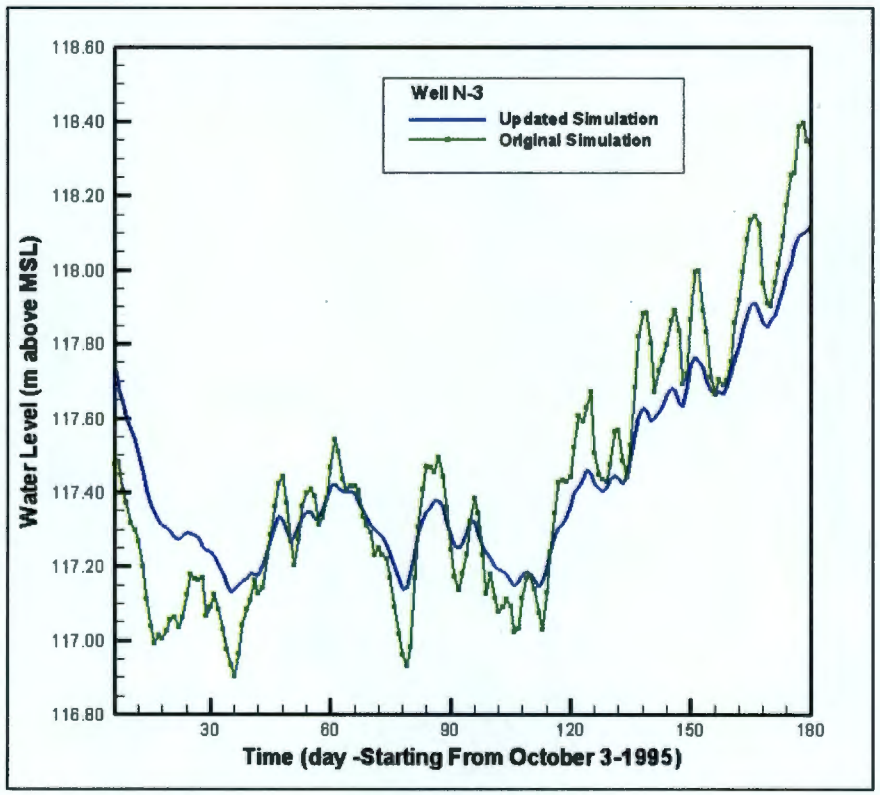


Figure 15. Comparison between Original Model and the Modified Model (Well N-3)

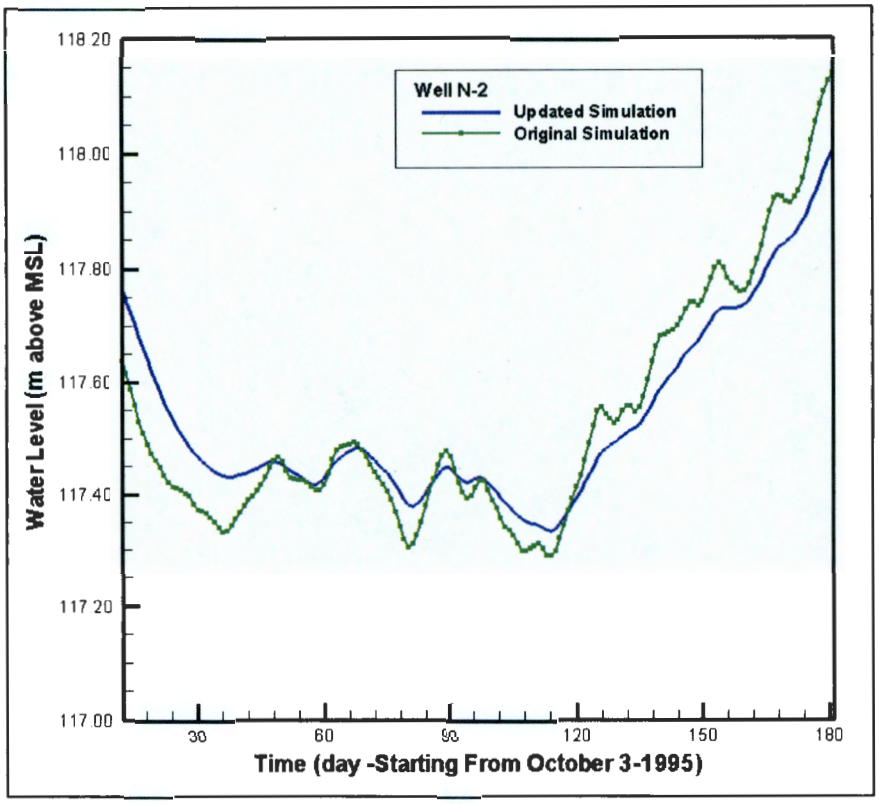


Figure 16. Comparison between Original Model and the Modified Model (Well N-2)

5 Software Applications

The STOMP software used to prepare this calculation is approved software under PRC-PRO-IRM-309, *Controlled Software Management*, and the required information on this software is provided in Section 5.1.

Microsoft Excel®[1] spreadsheets were used to calculate maximum strontium-90 aqueous concentration, back-calculate PRG values, and evaluate the results produced by STOMP. This use of Excel® constitutes a utility calculation, wherein the full calculation is checked as part of the development of this calculation and does not constitute software use under PRC-PRO-IRM-309. These Excel®-based calculations were performed on a desktop with ID INTERA-00295. The hardware is a Dell Precision E7200 with a 2.53-GHz Intel(R) Core(TM)2 Duo CPU processor and 3.25 GB of RAM loaded with the Windows®[2] XP Professional 64-bit operating system.

5.1 Approved Software

The vadose zone fate and transport calculations are performed using CHPRC Build 4 of the STOMP software (PNNL-12030, *STOMP Subsurface Transport Over Multiple Phases Version 2.0 Theory Guide*),

[1] Excel® and is a registered trademark of Microsoft Corporation in the United States and other countries.

[2] Windows® is a registered trademark of Microsoft Corporation in the United States and other countries.

registered in the Hanford Information System Inventory (HISI) with identification number 2471. STOMP use by CHPRC is managed under the following software lifecycle documents:

- CHPRC-00176, *STOMP Software Management Plan*
- CHPRC-00211, *STOMP Software Test Plan*
- CHPRC-00222, *STOMP Functional Requirements Document*
- CHPRC-00269, *STOMP Requirements Traceability Matrix*
- CHPRC-00515, *STOMP Acceptance Test Report*

5.1.1 Description

The STOMP software package was used in the calculation; required information on this software is provided here:

- Software Title: STOMP
- Software Version: CHPRC Build 4
- HISI Identification Number: 2471
- Workstation type and property number (from which software is run): STOMP was executed on the INTERA Richland GREEN Linux®[3] Cluster that is owned and managed by INTERA, Inc., a pre-selected subcontractor to CHPRC. The computer property tag for the frontend node is INTERA-00469, located at INTERA's Richland, Washington office. This node is a Dell®[4] PowerEdge® R510 with two six-core Intel®[5] Xeon® X5660 processors @ 2.80GHz and 48 GB of RAM. As given by the command "uname –a", the operating system details are:

```
Linux green 3.2.0-54-generic #82-Ubuntu SMP Tue Sep 10 20:08:42 UTC
2013 x86_64 GNU/Linux
```

The RETC software was used to estimate water retention and conductivity parameters; this software is in the process of being qualified for use by CHPRC and results of this calculation are contingent upon receiving approval for use of this software. The required information for this software is provided here:

- Software Title: RETC
- Software Version: CHPRC Build 1
- HISI Identification Number: 3272

5.1.2 Software Installation and Checkout

A copy of the *Software Installation and Checkout Form* for the STOMP installation used for this calculation is provided in Attachment A of this ECF.

RETC has been graded level D software in the HISI system, and hence a formal installation and checkout process is not required.

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[3] Linux is a registered trademark of Linus Torvalds in the United States and other countries.

[4] Dell and PowerEdge are registered trademarks of Dell Corporation in the United States and other countries.

[5] Intel and Xeon are registered trademarks of Dell Corporation in the United States and other countries.

5.1.3 Statement of Valid Software Application

DOE/RL-2011-50 contains a summary of the main model attributes and code selection criteria that serve as the basis for the demonstration of the adequacy of the STOMP code for use in vadose zone modeling at Hanford. The results of the evaluation in DOE/RL-2011-50 show that the STOMP code is capable of meeting or exceeding the identified attributes and criteria. The comparison of the code selection criteria to the STOMP code capabilities indicates the STOMP code is capable of simulating all of the necessary FEPs, and that STOMP meets all of the other required code selection criteria. Section 6.4.1 of DOE/RL-2011-50 addresses code selection criteria, including quality assurance documentation of verification studies for specific model attributes (e.g., unsaturated flow, solute transport, infiltration, and drainage), and includes a discussion of other code related criteria (i.e., inter-code comparisons, hardware requirements, solution methodology, dimensionality, and output capability).

The results of CHPRC software acceptance testing (CHPRC-00515) demonstrated that the STOMP software is acceptable for its intended use by the CHPRC. Installations of the software are operating correctly, as demonstrated by INTERA's Green Linux® cluster system producing the same results as those presented for selected problems from the STOMP application guide (PNNL-11216, *STOMP Subsurface Transport Over Multiple Phases: Application Guide*) in accordance with the *STOMP Software Test Plan* (CHPRC 00211).

RETC was applied to estimate retention and conductivity parameters consistent with its intended purpose as documented in EPA/600/2-91/065.

6 Calculation

Simulations were created and run using the representative stratigraphic columns, boundary conditions, initial conditions, and parameter values described in Section 4. The details of PRG value calculations are described in the following sub-sections.

6.1 Calculation of Strontium-90 Flux from Vadose Zone to Groundwater

The model was run to simulate 30 years starting from calendar year 1995 and the strontium-90 flux across the three defined flux planes were evaluated within four calendar years: 1995, 2005, 2015 and 2025. The strontium sorbed concentration above the surfaces were calculated by taking the average of the sorbed concentration within 1 m above the surfaces. Figure 17 shows the average sorbed concentrations with time for the surface at the 3rd location (Figure 7). The average sorbed concentrations for within a year remain almost constant because of high sorption of strontrium-90 into the sediments. The sorbed concentrations are decreasing after each 10 year of simulation because of high decay rate of strontium-90 ($t_{1/2}$ = 28.6 years). From Figure 17, it is evident that strontrium-90 is predicted by the model to moving very slowly and is essentially decaying in place.

Figure 18 shows the integrated flux of strontium-90 crossing through the surface with time for the same location. The negative sign in the integrated flux indicates that strontrium-90 flux direction is towards the groundwater. The integrated flux increases with time until 150 days, after that it decreases with time and later on it increases again. The reason for this behavior is due to the time varying boundary conditions which causes some upward strontrium-90 flux and reduces the integrated flux. The integrated flux was normalized to the sorbed concentration and presented in Figure 19. The normalized integrated flux does not change with one year to another year which indicates the integrated flux is proportional to the sorbed concentration. The higher the sorbed concentration the higher is the flux. Similar behavior was observed in case of 1st and 2nd location (Figure not presented here).

The integrated flux was then normalized according to Equation 1 and the absolute value of normalized integrated flux is presented in Figure 20 for all the three surfaces for the year 2015. As shown in Figure 20 the normalized flux will be same for the other years. The normalized value of the integrated flux can be used for different initial concentrations; recharge rate and surface are used here. An exponential fitting for the plots are also presented in Figure 20. Microsoft Excel "add trendline" option was used to generate this exponential fitting. This exponential regression equation can be used to calculate the strontium-90 flux across the water table from the vadose zone to the aquifer.

6.2 Calculation of Strontium-90 Soil Screening Level and Preliminary Remediation Goal Values

The average concentration along the 4.5-m screened interval of the observation well was calculated as a function of time to determine the peak concentration. The result is presented in Figure 21. The SSL value was calculated from the peak groundwater concentrations using Equation 2 with the irrigation recharge scenario and the applicable groundwater regulatory standard (8 pCi/L for strontium-90; EPA, 2000). The PRG value was calculated from the peak groundwater concentrations using Equation 3 with the native vegetation recharge scenario. The initial concentration applied to the model was 1000 pCi/g. The peak concentration for the SSL calculation was 89.62 pCi/L, and for the PRG calculation, it was 53.31 pCi/L (Figure 21).

Applying Equation 2, we calculate the SSL for strontium-90 as

$$SSL = \alpha C_I \frac{WQS}{CPK} = (1.0)\left(1000\ \frac{\text{pCi}}{\text{g}}\right)\left(\frac{8.0\ \frac{\text{pCi}}{\text{L}}}{89.62\ \frac{\text{pCi}}{\text{L}}}\right) = 89.26\ \text{pCi/g}$$

Applying Equation 3, we calculate:

$$PRG = \alpha C_I \frac{WQS}{CPK} = (1.0)\left(1000\ \frac{\text{pCi}}{\text{g}}\right)\left(\frac{8.0\ \frac{\text{pCi}}{\text{L}}}{53.31\ \frac{\text{pCi}}{\text{L}}}\right) = 150.10\ \text{pCi/g}$$

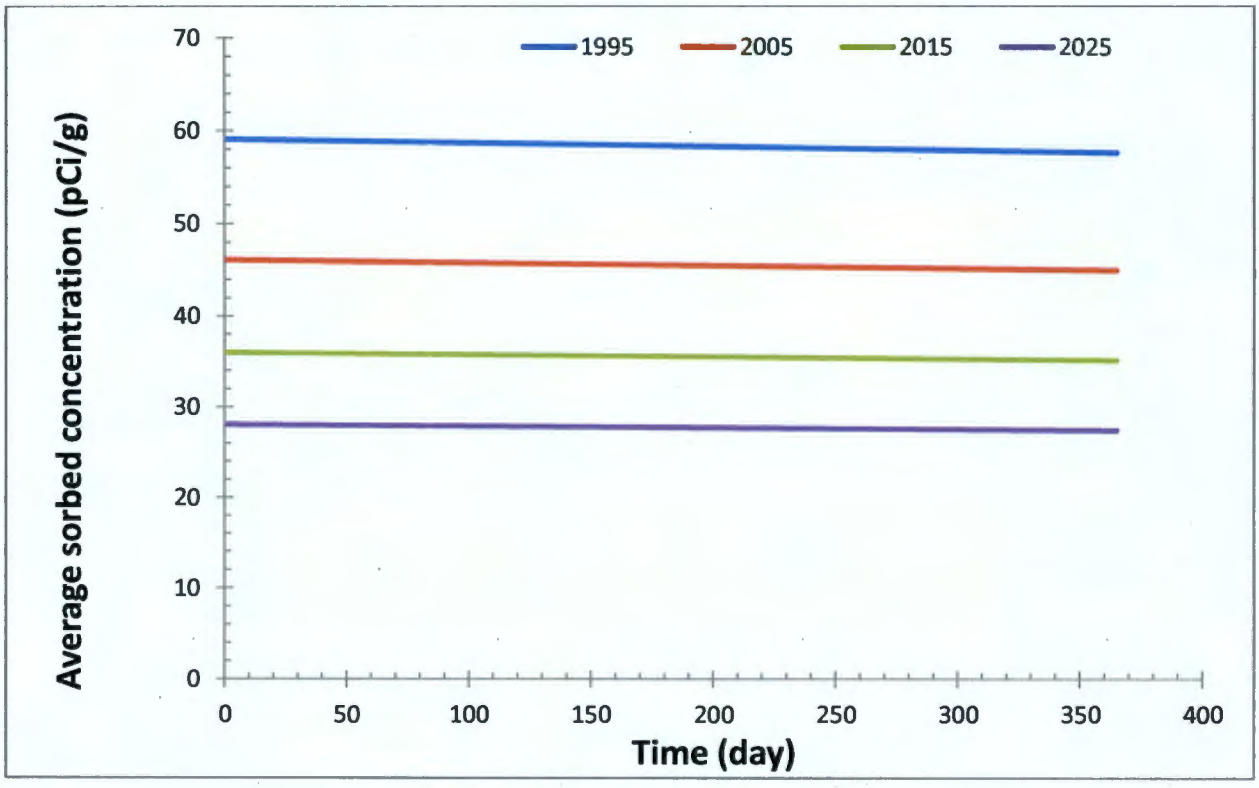

Figure 17. Variation of Average Sorbed Concentration with Time

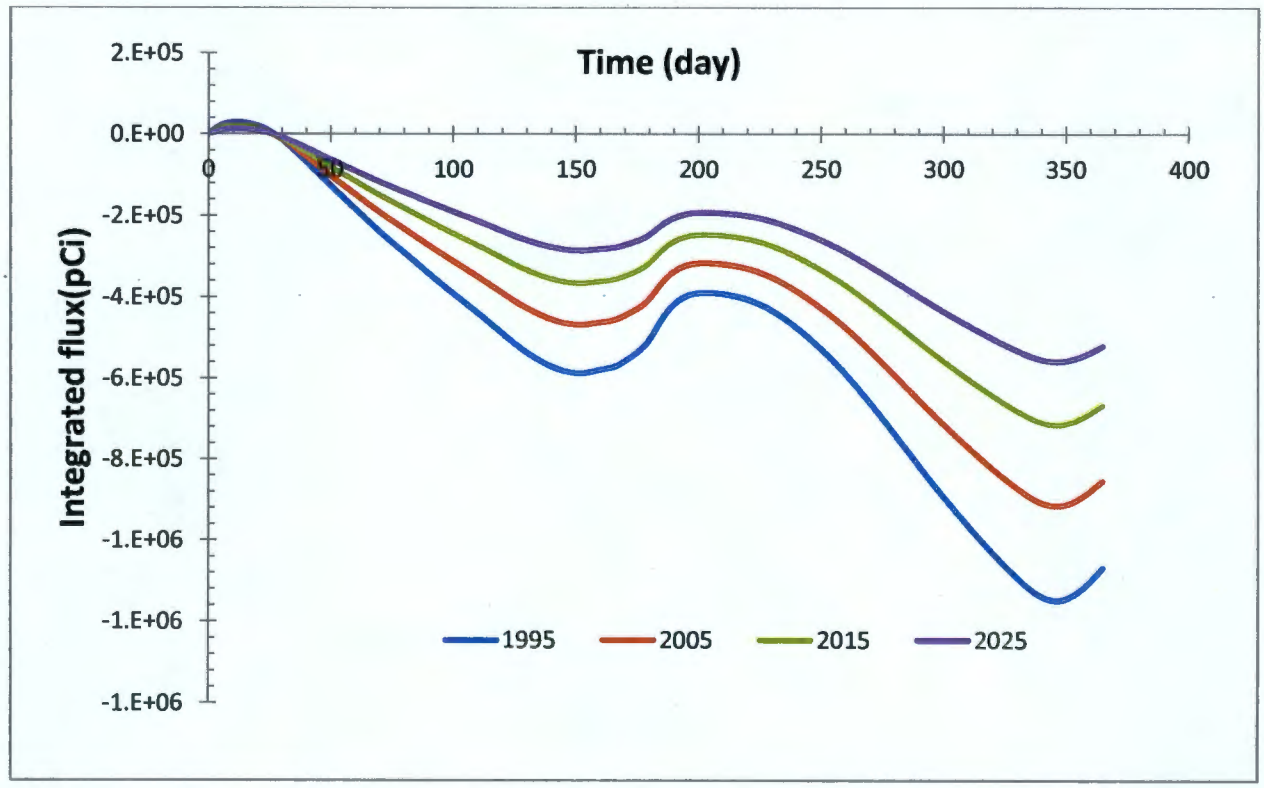

Figure 18. Variation of Integrated Flux with Time

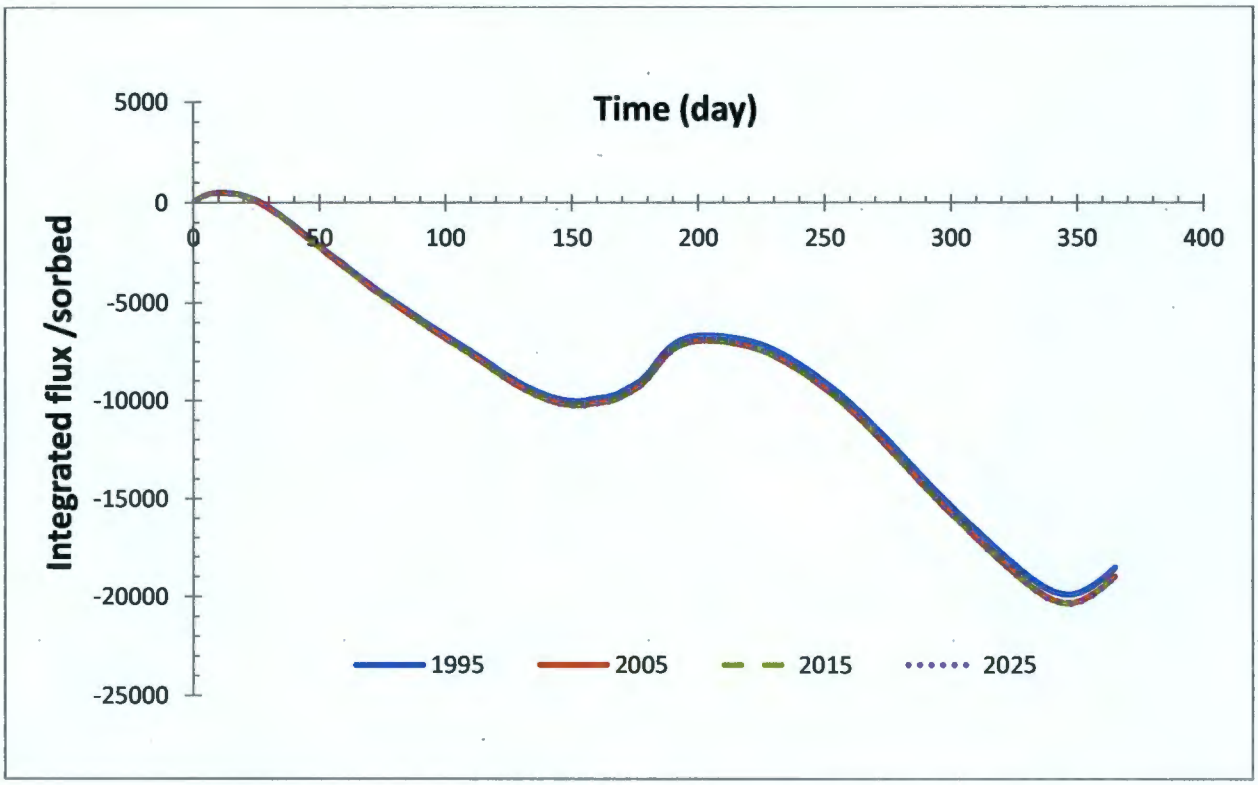

Figure 19. Variation of Integrated Flux Normalized to Sorbed Concentration with Time

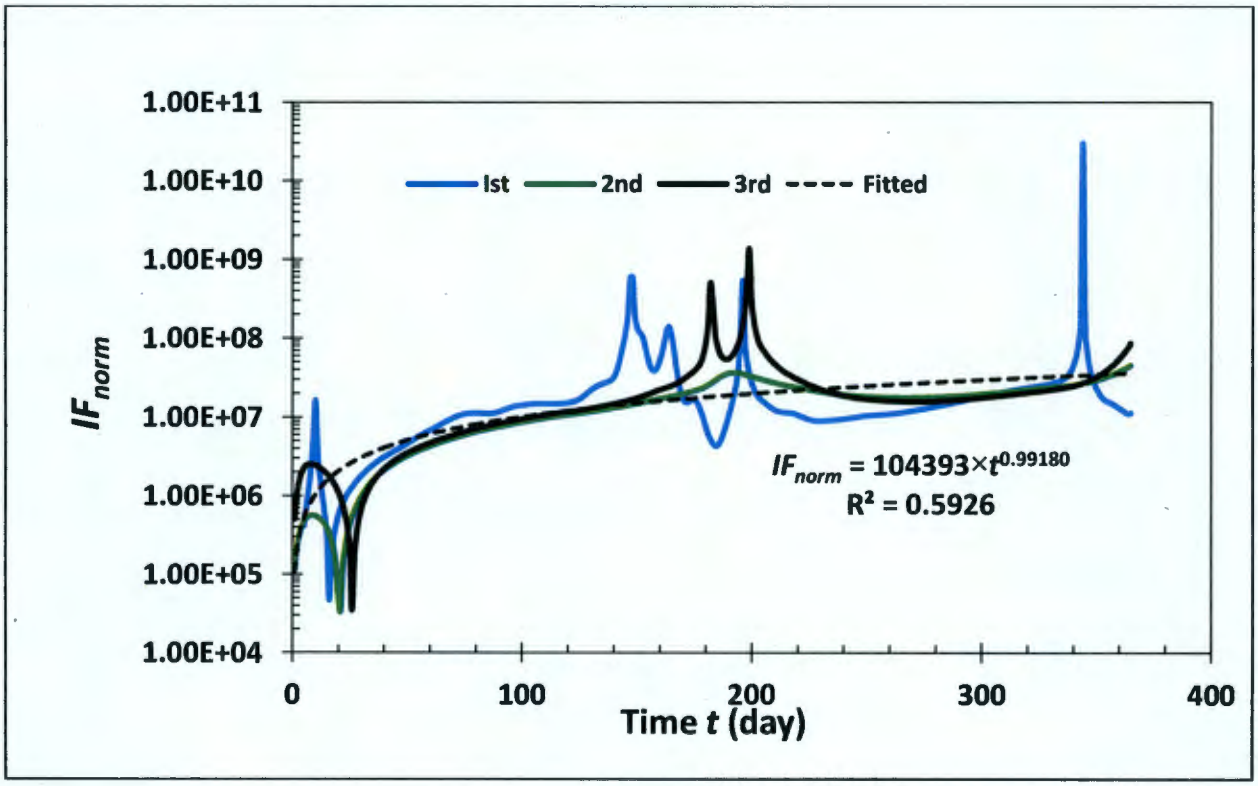

Figure 20. Variation of Normalized Integrated Flux with Time

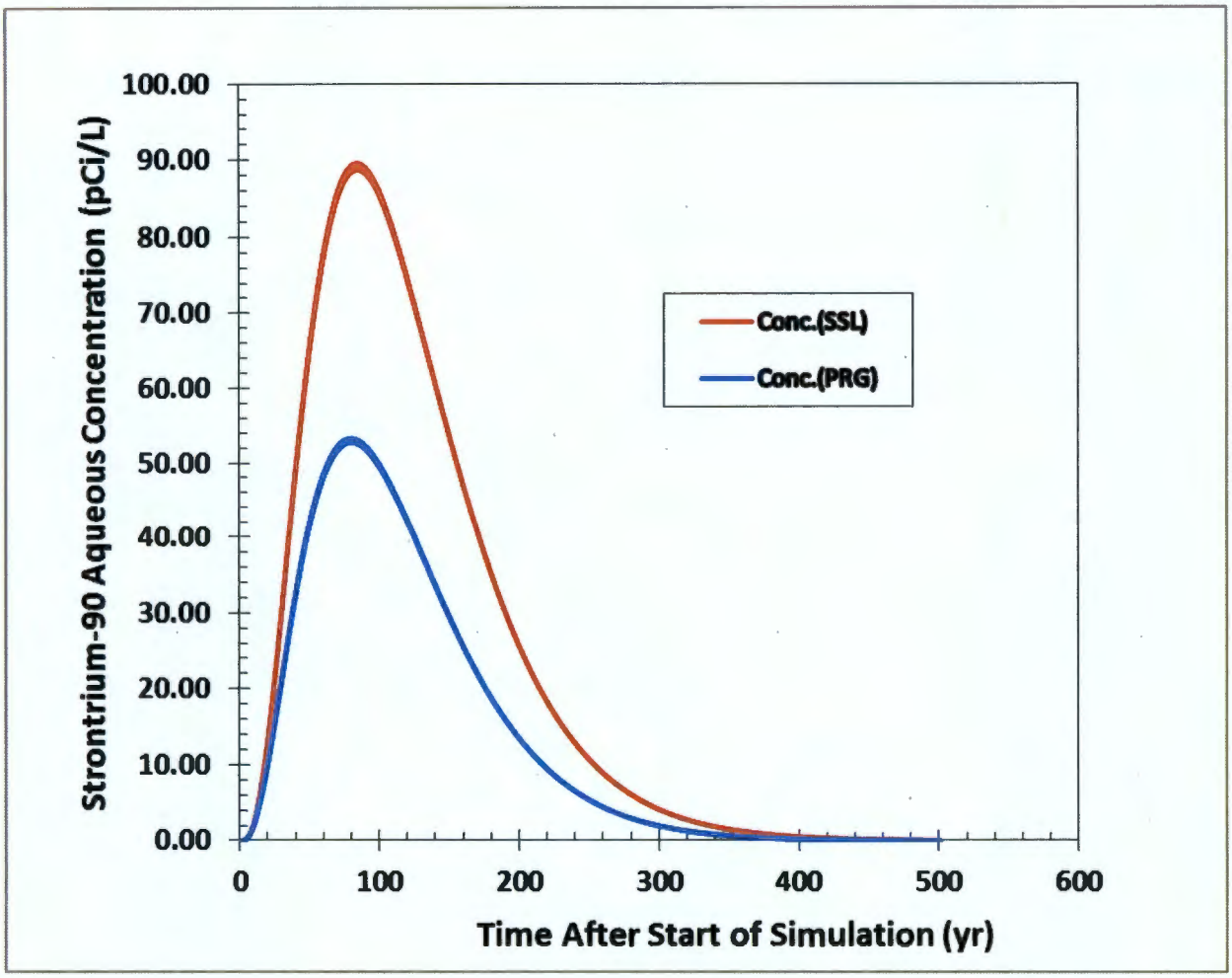

Figure 21. Breakthrough Curve for Strontrium-90

7 Results/Conclusions

STOMP simulations of the expanded model were used to calculate strontrium-90 flux entering the groundwater. The flux of strontium-90 to groundwater was normalized and the variation of the normalized integrated flux with time was represented with a exponential equation obtained through regression analysis. This regression equation was used to predict the flux of strontrium-90 entering the groundwater from the vadose zone.

STOMP simulations were also used to calculate the SSL and PRG of strontrium-90. The SSL value for strontrium-90 is calculated to be 89.26 pCi/g. The PRG value for strontrium-90 is calculated to be 150.10 pCi/g.

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Attachment A

Software Installation and Checkout Form for STOMP Build 4 on GREEN Server

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: STOMP (Subsurface Transport Over Multiple Phases) Software Version No.: Bld 4

EXECUTABLE INFORMATION:

2. Executable Name (include path):

All executable files installed in directory /srv/samba/saved_data/bin

MD5 File Signature	Executable File Name
6536b8e12d8c5b83dca76f2c947b6153	stomp-wae-bcg-chprc04i.x
e0cdf04bc1a2f6c55c5a1b499939f663	stomp-wae-bcg-chprc04l.x
6e72340bb39f6056e232fe5ff241c4d4	stomp-wae-bd-chprc04i.x
3f837a0fb8d9f47dbcada686f542d7fc	stomp-wae-bd-chprc04l.x
7e5b4cc36a8991b3d5a8ea2ed155ce47	stomp-wae-cgsq-chprc04i.x
00a898c0c3ec06817485781ad1c9ec46	stomp-wae-cgsq-chprc04l.x
f18ff5ab5667065d8ab12657344fb6a0	stomp-wae-cgst-chprc04i.x
061af86cf21ad8435b046d0efabe971b	stomp-wae-cgst-chprc04l.x
3c8111a9855dc0e430bf3c8a7abcf37e	stomp-w-bcg-chprc04i.x
20436d615a94955a2ce8eecdb8cba546	stomp-w-bcg-chprc04l.x
8b3df29df21d040189c3e2a50ef823bb	stomp-w-bd-chprc04i.x
066a289a75aedb933eb2536da5d7d1ff	stomp-w-bd-chprc04l.x
c8e62ad7a0d9b6fca39d8a8952ef5d8e	stomp-w-cgsq-chprc04i.x
28ad16806e1307aca51fd7bf89793e75	stomp-w-cgsq-chprc04l.x
6c25051016db2fe1f883a7caaaab1e97	stomp-w-cgst-chprc04i.x
ff9ff6f29b3469419ffaece87d7e772b	stomp-w-cgst-chprc04l.x
0c3e3fba40f5b93e71bcf9586432fd27	stomp-w-r-bcg-chprc04i.x
78492aee80a8c2d0a4e82aabf4a9c213	stomp-w-r-bcg-chprc04l.x
84b129786aba9c4be884e15e45a67389	stomp-w-r-bd-chprc04i.x
e990f1566c8099a8d54508de3da9cd88	stomp-w-r-bd-chprc04l.x
18a589a2b55aab2db290efea19b39351	stomp-w-r-cgsq-chprc04i.x
6569959476772a137df35ce874821889	stomp-w-r-cgsq-chprc04l.x

3. Executable Size (bytes): MD5 signatures above uniquely identify each executable file

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Tellus Subsurface Modeling Platform

5. Operating System (include version number):

Linux tellusmgmt.rl.gov 2.6.18-308.4.1.el5 #1 SMP Tue Apr 17 17:08:00 EDT 2012 x86_64 x86 64 x86 64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

Green Linux Cluster

7. Operating System (include version number):

Linux green 3.2.0-35-generic #55-Ubuntu SMP Wed Dec 5 17:42:16 UTC 2012 x86_64 x86_64 x86 64 GNU/Linux

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: STOMP (Subsurface Transport Over Multiple Phases) Software Version No.: Bld 4

8. Open Problem Report? (●) No ( ) Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

/srv/samba/saved data/test/stomp/build-04/itc

10. Procedure(s):

CHPRC-00211 Rev 1, STOMP Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

Input files for ITC-STOMP-1, ITC-STOMP-2, and ITC-STOMP-2
(Baseline for comparison are results files from ATC-STOMP-1, ATC-STOMP-2, and ATC-STOMP-3 prepared on Tellus during acceptance testing)

13. Output Files:

plot.* files produced by STOMP in testing

14. Test Cases:

ITC-STOMP-1, ITC-STOMP-2, and ITC-STOMP-3

15. Test Case Results:

Pass for all executable files listed above.

16. Test Performed By: WE Nichols

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update):

Accepted; Installation noted in HISI for users TJ Budge, N Hasan, A Mayenna, WJ McMahon, WE Nichols, S Mehta, H Rashid.

Prepared By:

19.	WE Nichols	25 APRIL 2013
Software Owner (Signature)	Print	Date

20. Test Personnel:

	WE Nichols	25 APRIL 2013
Sign	Print	Date
Sign	Print	Date
Sign	Print	Date

Approved By:

21.	N/R (per CHPRC-00211 Rev 1)	
Software SME (Signature)	Print	Date