ECF-200IA1-20-0107
Revision 1

Predictive Flow Simulation with the P2R Model for the 200-IA-1 Preliminary Remediation Goal Saturated Zone Abstraction

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

Contractor for the U.S. Department of Energy
under Contract 89303320DEM000030

CPCCo
Central Plateau Cleanup Company

P.O. Box 1464
Richland, Washington 99352

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Document Type: ECF Program/Project: 200-IA-1

H. Pham
INTERA, Inc.

R. Nell
INTERA, Inc.

T. Budge
INTERA, Inc.

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P.O. Box 1464
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APPROVED
By Sarah Harrison at 8:17 am, Jan 26, 2022

Release Approval Date

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ENVIRONMENTAL CALCULATION COVER PAGE

SECTION 1 - Completed by the Responsible Manager

Project: 200-IA-1	**RELEASE / ISSUE**
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Calculation Title and Description: Predictive Flow Simulation with the P2R Model for the 200-IA-1 Preliminary Remediation Goal Saturated Zone Abstraction	

Qualifications Summary

Preparer(s):

Name: Hai Pham

Degree, Major, Institution, Year: PhD, Civil Engineering, Louisiana State University, 2015

Degree, Major, Institution, Year: MS, Civil Engineering, Dongguk University (Korea), 2011

Degree, Major, Institution, Year: BS, Engineering in Hydrology and Environment, Water Resources

Professional Licenses:

Brief Narrative of Experience: Dr. Hai Pham has over a decade of research and applied experience in the areas of groundwater modeling, optimization, uncertainty analysis, data analytics, GIS and remote sensing, and high-performance computing. In support of water resource evaluations, he has performed analyses to interpret hydrogeologic data, automate data retrieval, and verify model inputs and outputs for quality-control. His experience includes developing and applying groundwater flow and transport models, customizing scripts to automate parameter estimation, performing sensitivity and uncertainty analyses, and implementing model simulations. He has applied his advanced computer program and software skills for various purposes including numerical modeling (MODFLOW, MODPATH, MT3DMS, SEAWAT, GMS, dfnWorks, PFLOTRAN, Rockworks), optimization (PEST, CMA-ES, PySOT), programming (Python, Matlab, Bash, Git), InSAR satellite image processing (ISCE, MintPy), and data visualizations (ArcMap, ParaView, Tecplot, Surfer, AutoCAD, Illustrator, Latex). Dr. Pham has provided his technical expertise related to groundwater investigation and management, saltwater intrusion, land subsidence, and radionuclide transport to support state, federal, and municipal agencies on projects throughout the US and in Niger and Vietnam. He has authored eight articles in peer-reviewed journals, one book chapter, and numerous project reports.

Checker(s):

ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

Name: Ryan Nell

Degree, Major, Institution, Year: PhD, Environmental Chemistry, University of Notre Dame, 2016

Degree, Major, Institution, Year: BA, Geology, University of Colorado, 2010

Professional Licenses: Professional Geologist

Brief Narrative of Experience: Ryan Nell brings applied and theoretical laboratory experience in geochemistry and environmental science, and research expertise in designing and executing experiments pertaining to heavy metal remediation using biotic systems. His experience includes collecting and analyzing data to evaluate metal fate and transformation in microbial ecosystems, developing standard operating procedures for fluorescent microscopy imaging of manganese oxidizing fungi, and preparing biological samples for x-ray adsorption spectroscopy analysis. He also led field data collection and analysis of dioritic rock samples for U-Th/He analysis. Ryan has presented the results of his work at conferences and authored several publications in peer-reviewed journals, including Geochimica et Cosmochimica Acta and Chemical Geology.

Senior Reviewer(s):

Name: Trevor Budge

Degree, Major, Institution, Year: PhD, Geological Sciences, The University of Texas at Austin,

Degree, Major, Institution, Year: MS, Civil and Environmental Engineering, Brigham Young Univer

Degree, Major, Institution, Year: BS, Civil and Environmental Engineering, Brigham Young Univer

Professional Licenses:

Brief Narrative of Experience: Trevor Budge's experience encompasses characterizing and modeling hydrologic and hydrogeologic systems in support of a wide range of water resources, environmental, and waste isolation projects. His work has included analyzing and optimizing remediation well configuration and operation, investigating long-term remediation costs, characterizing complex geological settings with the use of geophysical and remote sensing data, designing slurry walls and hydraulic barrier walls near sensitive water bodies, emergency planning-based modeling of catastrophic dam failures and large storm events, and developing geographic information system tools to efficiently process data and modeling results. These tasks have been completed using a wide range of numerical, analytical, and geostatistical tools. His knowledge of computer hardware and software, including GIS and programming languages, allows him to solve problems that arise specific to each project that cannot be resolved using standard out-of-the-box software and hardware. Trevor has completed projects for organizations ranging from small municipalities and local water authorities to state and federal government agencies, and he has authored and developed software applications used by the US Environmental Protection Agency and the US Department of Defense.

SECTION 2 - Completed by Preparer

Calculation Number: ECF-200IA1-20-0107 | Revision Number: 1

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

Revision History

Revision No.	Description	Date	Affected Pages
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SECTION 4 - Document Review and Approval

Preparer(s):

Print First and Last Name	Position	Signature	Date
Hai Pham	Hydrogeologist	Hai Pham	Digitally signed by Hai Pham Date: 2022.01.14 13:32:45 -06'00'

Checker(s):

Print First and Last Name	Position	Signature	Date
Ryan Nell	Hydrogeologist	RYAN NELL (Affiliate)	Digitally signed by RYAN NELL (Affiliate) Date: 2022.01.14 11:22:16 -08'00'

Senior Reviewer(s):

Print First and Last Name	Position	Signature	Date
Trevor Budge	Senior Hydrogeologist	TREVOR BUDGE (Affiliate)	Digitally signed by TREVOR BUDGE (Affiliate) Date: 2022.01.14 12:15:31 -08'00'

Responsible Manager(s):

Print First and Last Name	Position	Signature	Date
Will Nichols	Risk & Modeling Manager	WILLIAM NICHOLS (Affiliate)	Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2022.01.19 09:25:54 -08'00'

SECTION 5 - Applicable if Calculation is a Risk Assessment or Uses an Environmental Model

Prior to Initiating Modeling:

Required training for modelers completed:
Integration Lead:

Christopher Farrow — *Print First and Last Name*

CHRISTOPHER FARROW (Affiliate) — Digitally signed by CHRISTOPHER FARROW (Affiliate) DN: C=US, O=U.S. Government, OU=Department of Energy, OID.0.9.2342.19200300.100.1.1=89001003727219 + CN=CHRISTOPHER FARROW (Affiliate) Reason: I have reviewed this document Location: your signing location here Date: 2022.01.18 14:46:49-08'00' Foxit PhantomPDF Version: 10.1.6 — *Signature / Date*

Safety Software Approved:
Integration Lead:

Christopher Farrow — *Print First and Last Name*

CHRISTOPHER FARROW (Affiliate) — Digitally signed by CHRISTOPHER FARROW (Affiliate) DN: C=US, O=U.S. Government, OU=Department of Energy, OID.0.9.2342.19200300.100.1.1=89001003727219 + CN=CHRISTOPHER FARROW (Affiliate) Reason: I have reviewed this document Location: your signing location here Date: 2022.01.18 14:50:29-08'00' Foxit PhantomPDF Version: 10.1.6 — *Signature / Date*

Calculation Approved:

Risk/Modeling Integration Manager:

Will Nichols — *Print First and Last Name*

WILLIAM NICHOLS (Affiliate) — Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2022.01.19 09:26:15 -08'00' — *Signature / Date*

Contents

Appendix

Figures

Tables

Terms

CPCCo	Central Plateau Cleanup Company
ECF	environmental calculation file
FFS	focused feasibility study
HISI	Hanford Information System Inventory
OU	operable unit
P&T	pump and treat
P2R	Plateau to River
PA	performance assessment
PRG	preliminary remediation goal
RET	recharge evolution tool
LSQR	Least Squares Regression

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1 Purpose

In order to develop and evaluate alternatives for remediation of waste sites constituting the 200-IA-1 Operable Unit (OU), a focused feasibility study (FFS) is currently underway. The 200-IA-1 OU FFS requires preliminary remediation goals (PRGs) protective of groundwater be evaluated which includes estimates of fate and transport of contaminants in the groundwater from multiple sources within the Central Plateau Inner Area. This document details the application of the Plateau-to-River (P2R) Model version 8.3 to predict the flow of groundwater on the Central Plateau for the 10,000-year simulation to support the 200-IA-1 OU PRG calculation. The simulated flow field will support the simulation of fate and transport of contaminants for use in estimating peak unit-length concentration as part of the 200-IA-1 OU PRG calculation presented in a separate environmental calculation file (ECF) (ECF-200IA1-20-0108, *Determination of Preliminary Remediation Goals for 200-IA-1 Source Operable Unit*).

2 Background

The P2R Model is a numerical groundwater simulator with a spatial extent that encompasses the Central Plateau of the Hanford Site along with areas downgradient of the Central Plateau toward the Columbia River. The current version of the model, documented in CP-57037, *Model Package Report: Plateau to River Model Version 8.3,* was developed as the tool to use in support of groundwater projects within the Central Plateau. CP-57037 provides a discussion of the site conceptual model, the model construction, and model calibration including limitations in its application. This document describes the changes made to model inputs in order to simulate a predicted groundwater flow field for the 200-IA-1 OU PRG calculation. Simulation results for hydraulic head and flow magnitude will be extracted from the model for use in the PRG calculation.

3 Methodology

Development of the predictive flow field using the P2R model is completed using the acquired computer software MODFLOW (see Section 5). The model simulates hydraulic head and groundwater fluxes on a cell-by-cell basis within the model domain. The details of the model extent and discretization are found below. The governing equations of MODFLOW are solved based input parameters stored in the model files. Development and calibration of many of the model input parameters are documented in CP-57037. Those input parameters that differ from the parameter values documented in CP-57037 are discussed in Section 4 of this document. For details on other model input parameters please refer to CP-57037.

3.1 Model Domain and Discretization

The P2R Model domain has the following lateral extent and boundaries: extent north to south is 26.6 km (16.5 mi) and extent east to west is 37.6 km (23.3.3 mi). The lower left corner of the model domain is located at easting 557,800 m and at northing 116,200 m in the Washington State Coordinate System (NAD_1983_StatePlane_Washington_South_FIPS_4602). The vertical extent of the model comprises the subsurface sediments from ground surface to the uppermost unit of the Columbia River basalt Group. The basalt that is assumed to constitute an impermeable lower boundary defines the base of the domain.

The model domain is discretized into a finite difference grid. The grid in the lateral directions is broken up into variably sized cells of 100 m by 100 m (328.1 ft by 328.1 ft), 100 m by 200 m (328.1 ft by 656.2 ft), and 200 m by 200 m (656.2 ft by 656.2 ft). A total of 274 columns and 201 rows constitutes a total of 55,074 laterally distinct cell locations within the model domain. The model is vertically divided into seven model layers between the ground surface elevation and the top of the uppermost basalt surface. The discretization of the vertical layers varies in order to represent the thickness of geologic formations found within the model domain. A maximum 34,421 of those 55,074 laterally distinct cells are active in the model within each model layer. Figure 1 shows the lateral extent of the P2R version 8.3 Model domain along with the groundwater OU, lateral discretization, and boundary conditions.

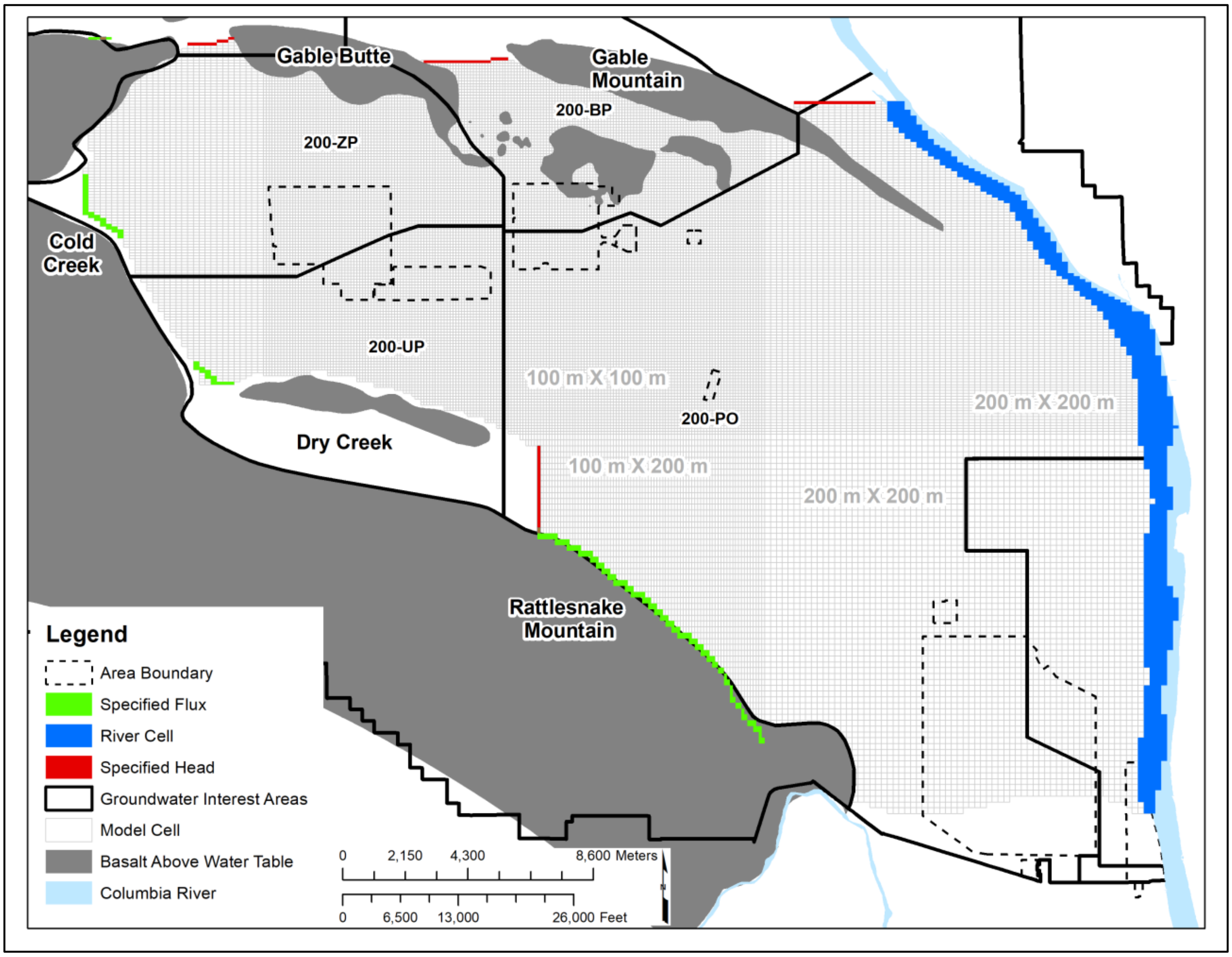

Figure 1. P2R Version 8.3 Model Extent and Boundary Conditions

4 Assumptions and Inputs

This section summarizes the inputs and assumptions that are specific to the calculations presented in this document. Features and inputs to the P2R Model (e.g., model layer elevations, hydraulic properties, specific storage, and specific yield) that did not change for the development of the predictive flow field are not presented. The principal inputs to the calculations are:

- Temporal discretization
- Boundary conditions
- Initial head
- Extraction and injection well flow rates by stress period

4.1 Temporal discretization

The simulation period for the predictive flow model starts in 2018 and runs for 10,052 years, ending in 12070. A total of 101 stress periods were used with varying stress period length (Table 1). The length of any stress period through 2570 matched the time periods taken by the recharge evolution tool (RET) documented in ECF-HANFORD-15-0019, *Hanford Site-Wide Natural Recharge Boundary Conditions for Groundwater Models*. By staying consistent with the RET temporal discretization major changes to land use were represented in the boundary conditions of the simulation.

Table 1. Temporal Discretization of Predictive Flow Model

Stress Periods	Duration	Description
1 to 82	82 years	82 transient annual stress periods that span from 2018 through 2099.
83	35 years	1 transient stress period that spans from 2100 through 2134.
84	16 years	1 transient stress period that spans from 2135 through 2150
85	343 years	1 transient stress period that spans from 2151 through 2493
86	23 years	1 transient stress period that spans from 2494 through 2516
87	3 years	1 transient stress period that spans from 2517 through 2519
88	1 year	1 transient annual stress period that spans the year 2520
89	4 years	1 transient stress period that spans from 2521 through 2524
90 to 91	2 years	2 transient annual stress period that spans from 2515 through 2526
92	2 years	1 transient stress period that span from 2527 through 2528
93	1 year	1 transient annual stress period that spans the year 2529
94	3 years	1 transient stress period that spans from 2530 through 2532
95	2 years	1 transient stress period that spans from 2533 through 2534
96	8 years	1 transient stress period that spans from 2535 through 2542
97	7 years	1 transient stress period that spans from 2543 through 2549
98 to 99	2 years	2 transient annual stress periods that span from 2550 through 2551
100	18 years	1 transient stress period that spans from 2552 through 2569
101	9500 years	1 transient stress period that spans from 2570 through 12070

4.2 Boundary Conditions

Boundary conditions for the P2R Model were adjusted to match the temporal discretization needed to simulate 10,000 years into the future from site closure in calendar year 2070. Updated boundary conditions include the Columbia River boundary, specified heads, and the recharge. Each of these is discussed in the following sections.

4.2.1 Columbia River Boundary

The Columbia River acts as the eastern boundary condition for the P2R Model. The details on the river boundary features such as river cell location, river-stage elevation, river bottom elevation, and river sediment conductance are documented in CP-57037. The process for building the Columbia River boundary condition was kept same as the one documented in CP-57037. The flow rates at the river gage for first two stress periods (2018 and 2019) were available during the predictive simulation period. The yearly averaged flow data were used to calculate river stage for 2018 and 2019. The river stage for the remainder of the simulation period was kept constant which was calculated by averaging the flow rates from last 20 years of river gage data (2000 to 2019). A twenty-year average was chosen because of its similarity to the 10-year and 71-year averages and was consistent with the average timeframe used for the specified heads at Gable Gap and Dry Creek.

4.2.2 Specified Heads

The basalt top elevation defines the bottom and most of the lateral boundaries of the model domain (depicted as dark gray-colored regions in Figure 1). Four locations where the water table is above the top of the basalt are defined by specified head boundaries (shown as red shading in Figure 1). For the historical period as documented in CP-57037, the specified head values at each of these specified head boundary locations were taken as the annual average observed head at observations wells near the boundary location. However, such observation data is not possible for the predictive model starting from 2020. For the western Gap and northeastern boundary, a constant value of 122.5 m and 110.98 m (representative of the average of the last 20 years of data) were used, respectively. For the Gable Gap and southern boundary near Dry Creek, the specified heads were developed using an exponential equation defined by the observed trend at wells 699-60-60, and 699-10-54A, respectively. The parameters for the exponential equations were estimated using the Least Squares Regression (LSQR) fitting of the observed values are presented in Table 2.

Table 2. LSQR Fitting Parameters used for Predicting Specified Head at Gable Gap and Southern Boundary near Dry Creek

Parameters	Gable Gap	Dry Creek
B (meters)	120.6	122.1
X (dimensionless)	0.0256	0.0076
Y_0 (year)	2003.5	2003.5
S (meters)	122.2	126.98

The following exponential equation was used for calculating the specified head boundary condition:

$$P_i = B + e^{[-X * (Y_i - Y_0)]} * (S - B) \quad \textbf{(Eq. 1)}$$

where:

P_i = the predicted head for the year i

B = the base head representing pre-Hanford (01/01/1945) water table

X = a fitting parameter

Y_i = the year of the specified head to be predicted

Y_0 = the starting year of the LSQR fitting dataset

S = the start head representative of the starting year, Y_0.

The observed head and the predicted head calculated using the corresponding fitted exponential equation are shown in Figure 2 and Figure 3.

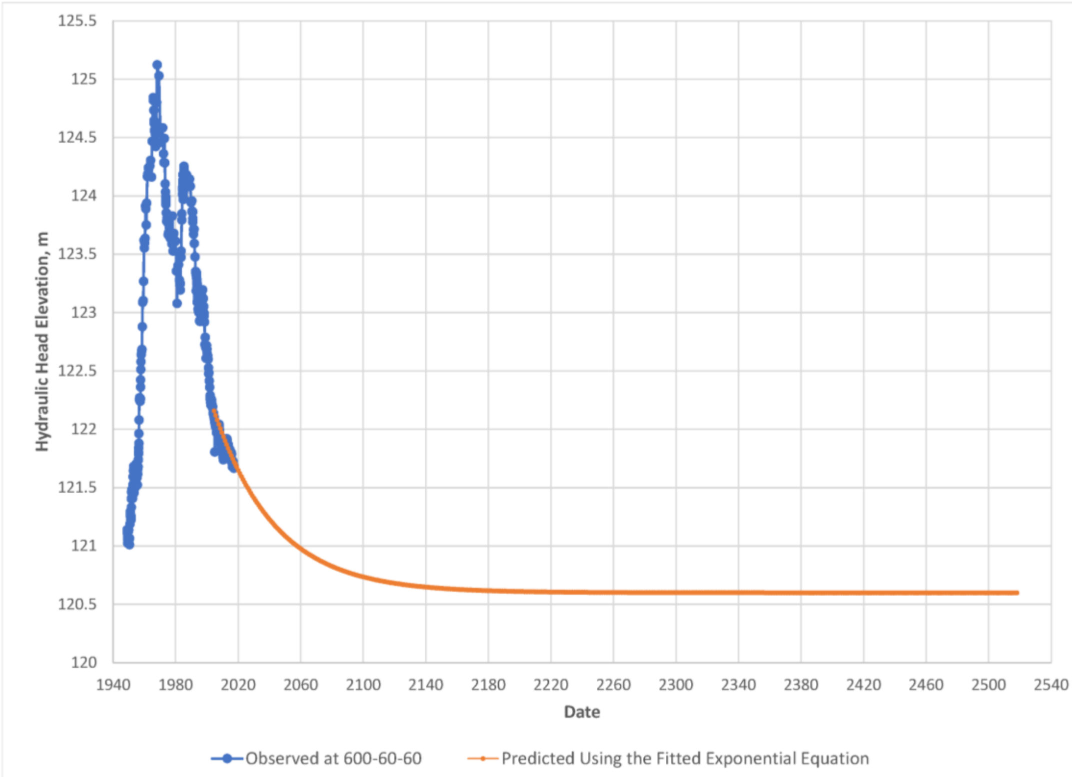

Figure 2. Observed Head Values and Estimated Exponential Regression Function at the Northern Specified Head Boundary at Gable Gap Near Well 699-60-60 for the Predictive Model

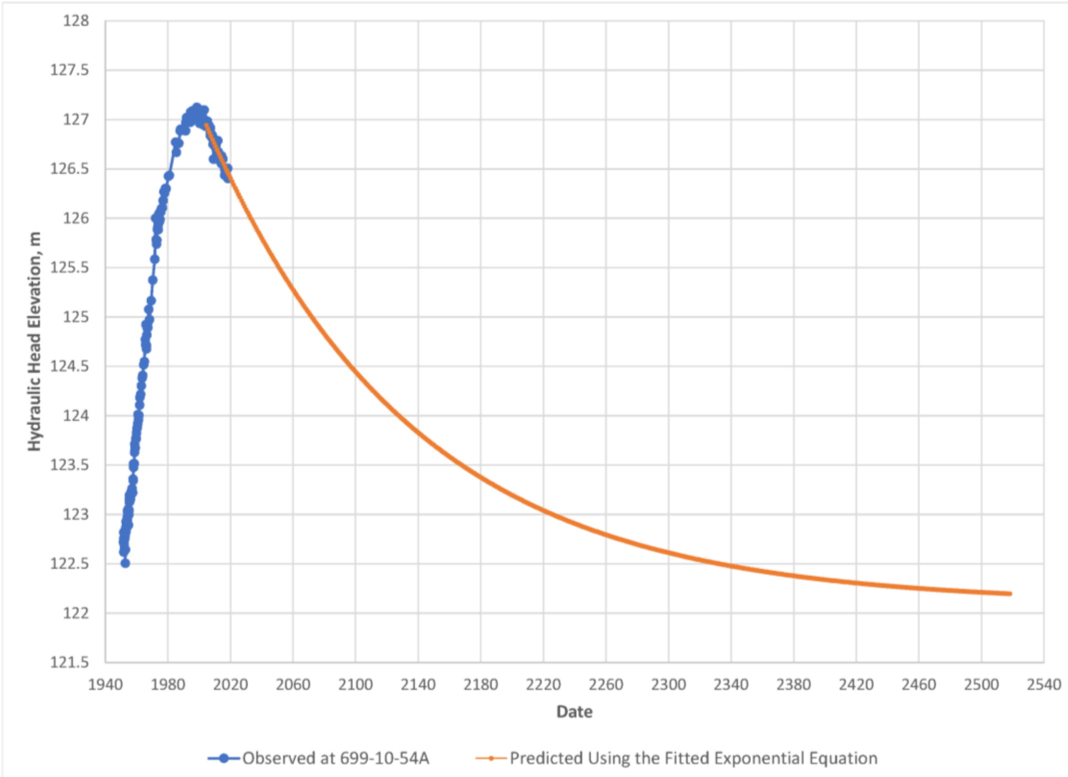

Figure 3. Observed Head Values and Estimated Exponential Regression Function at the Northern Specified Head Boundary at Dry Creek Near Well 699-10-54A for the Predictive Model

4.2.3 Recharge

Recharge at the water table in the P2R Model includes the contributions to total recharge from the following components:

- **Natural recharge:** Deep percolation of precipitation that is not evaporated/transpired and is not retained in storage in the vadose zone.
- **Mountain-front recharge:** Contribution to the groundwater flux from upgradient sources to the aquifer including Rattlesnake Mountain and the Dry Creek and Cold Creek watersheds.
- **Anthropogenic recharge:** Historical wastewater discharges at the Hanford Site.

For each stress period of the model, these individual components are summed to create the total recharge to the aquifer. The summed values are input into a MODFLOW recharge package for inclusion in the model simulation. The recharge components for the predictive model are consistent with the methodologies documented as part of the historic calibration documented in CP-57037. Changes were made to values to match the difference in the temporal domain of the model. These aspects are discussed below:

1. According to the most recent performance assessment (PA), the Hanford prototype barrier at the Environmental Restoration Disposal Facility is supposed to be active from 2035 and is assumed to fail in 2135. This feature is implemented in the predictive model recharge package prepared for this ECF. Other PA based recharge rates (e.g., Integrated Disposal Facility, Waste Management Area C)

were also implemented in the predictive model recharge package. The details on the recharge rates at the Hanford prototype barriers and PA models are documented in ECF-HANFORD-15-0019.

2. The ancillary recharge, a component of anthropogenic recharge defined for two areas, is a calibrated parameter in calibrated P2R version 8.3 Model (CP-57037). The calibrated values for these areas were set to be constant during the historical period of the predictive model. However, it is assumed that ancillary recharge will decline linearly from 2070 and to zero in 2100 due to the cessation of activities at Hanford Site.

Natural recharge was computed and assigned across the model extent using a GIS approach. Natural recharge takes into account for soil and vegetation types, man-made impacts including caps and vegetation suppression efforts. Figure 4 and Figure 5 show natural recharge rates for select years that show variation in natural recharge rates as the simulation progresses. Total recharge is the sum of the natural, mountain front, and anthropogenic (operational and ancillary) recharge.

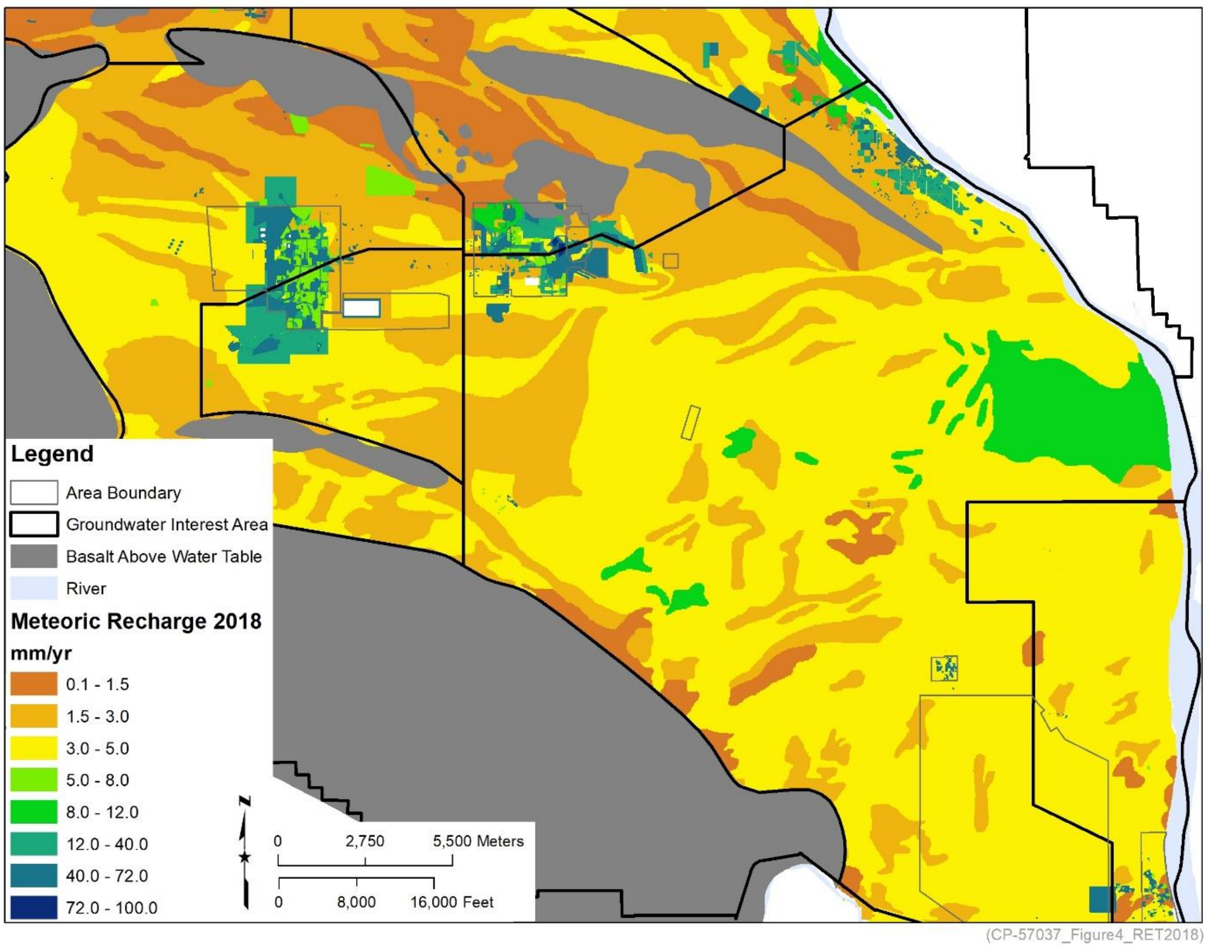

Figure 4. Natural Recharge Assigned to the Model Domain in 2018

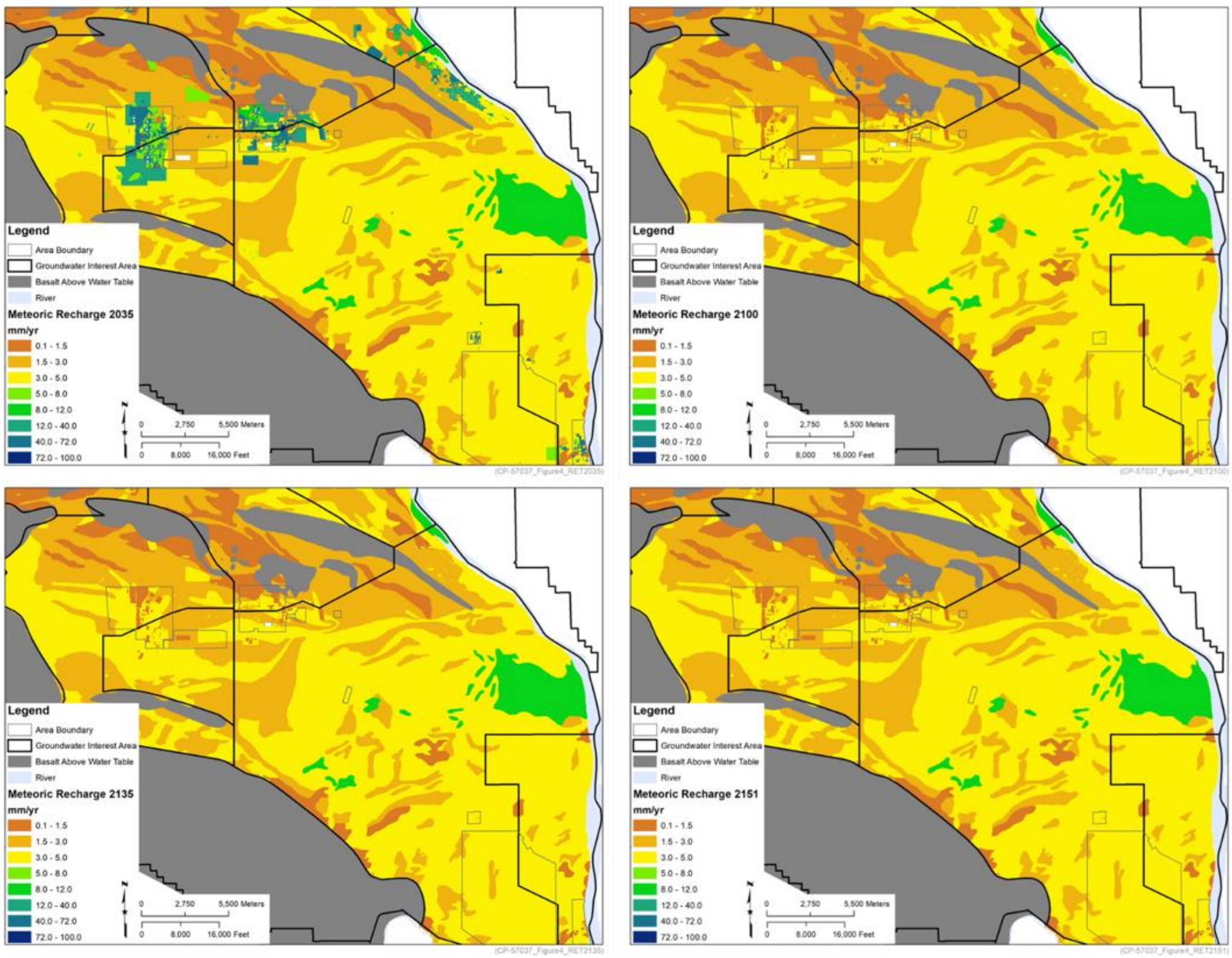

Figure 5. Natural Recharge Assigned to the Model Domain in 2035 and 2100 (top left and right) and 2135 and 2151 (bottom left and right)

4.3 Initial Head

The initial hydraulic head for the predictive model was extracted from the simulated head output of the historic calibration of the P2R Model version 8.3 (CP-57037) at the end of 2017. This coincided with stress period 141 timestep 1 of the P2R Model historic calibration.

4.4 Pumping Scenarios

The predictive flow model includes all the extraction/injection wells used in ECF-HANFORD-20-0049, *Groundwater Pump and Treat (P&T) Report*. The pump and treat (P&T) model had pumping starting in either 2012 or 2015 and ending at the end of September 2037 with monthly stress periods from the model start through the end of September 2022. It then uses annual stress periods from October 2022 through

September 2037. The P2R model utilizes annual stress period during that time period. In order to assign the appropriate pumping rates to the P2Rv8.3 predictive model, the following method was used:

- Monthly stress periods in the P&T model (SP 37-84 for the 2015-start model) representing January 2018- December 2021, were used to create a single average value for calendar years 2018 - 2021 (P2Rv8.3 stress periods 1-4).
- For model year 2022, a weighted average of P&T model monthly values for January through September (SP 85-93) and the annual value starting in October 2022 (SP 94) was computed for calendar year 2022 (P2Rv8.3 stress period 5).
- For model years 2023 - 2037, a weighted average of the P&T model annual values for October 2022 - September 2037 (P&T SP 94-109) was computed for calendar year 2023 -2037 values (P2Rv8.3 stress periods 6–20)
- For model year 2038 and all subsequent P2Rv8.3 stress periods, all pumping was shut off (P2Rv8.3 stress periods 21–101)

The resulting injection and extraction rates are summarized in Table 3.

Table 3. Extraction and Injection Rates for Each Stress Period

Date	2018	2019	2020	2021	2022-2036	2037	2038-12070
Stress Period	**1**	**2**	**3**	**4**	**5-19**	**20**	**21-101**
Well Name							
299-E11-1	76.4	72.9	50.0	50.0	50.0	37.5	0.0
299-E20-1	71.7	71.4	50.0	50.0	50.0	37.5	0.0
299-E20-2	75.3	66.4	50.0	50.0	50.0	37.5	0.0
299-E33-268	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-E33-360	-162.8	-125.7	-110.0	-110.0	-110.0	-82.5	0.0
299-E33-361	0.0	-35.2	-50.0	-50.0	-50.0	-37.5	0.0
299-W10-35	108.5	118.9	130.0	128.3	130.0	97.5	0.0
299-W10-36	60.7	17.8	130.0	128.3	130.0	97.5	0.0
299-W11-103	0.0	0.0	0.0	-129.2	-130.0	-97.5	0.0
299-W11-104	0.0	0.0	0.0	-132.5	-130.0	-97.5	0.0
299-W11-45	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W11-46	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W11-49	-133.1	-114.7	-130.0	-125.8	-120.0	-90.0	0.0
299-W11-50	-58.0	-55.9	-60.0	-83.3	-100.0	-75.0	0.0
299-W11-90	-88.4	-87.5	-100.0	-114.2	-100.0	-75.0	0.0
299-W11-92	-78.1	-96.1	-110.0	-89.2	-50.0	-37.5	0.0
299-W11-96	-106.6	-78.2	-100.0	-113.3	-120.0	-90.0	0.0
299-W11-97	-92.8	-103.6	-125.0	-118.8	-60.0	-45.0	0.0

Table 3. Extraction and Injection Rates for Each Stress Period

Date	2018	2019	2020	2021	2022-2036	2037	2038-12070
Stress Period	1	2	3	4	5-19	20	21-101
Well Name							
299-W12-2	-107.5	-95.8	-105.0	-104.2	-100.0	-75.0	0.0
299-W12-3	-98.2	-90.1	-100.0	-100.0	-80.0	-60.0	0.0
299-W12-4	-129.3	-121.7	-130.0	-125.0	-110.0	-82.5	0.0
299-W12-5	0.0	0.0	0.0	-129.6	-130.0	-97.5	0.0
299-W14-20	-74.9	-99.6	-105.0	-102.9	-100.0	-75.0	0.0
299-W14-21	-93.2	-89.7	-90.0	-90.0	-90.0	-67.5	0.0
299-W14-22	-103.2	-102.5	-115.0	-114.6	-100.0	-75.0	0.0
299-W14-27	0.0	0.0	0.0	-95.8	-150.0	-112.5	0.0
299-W14-28	0.0	0.0	0.0	-119.6	-130.0	-97.5	0.0
299-W14-30	0.0	0.0	0.0	-69.2	-130.0	-97.5	0.0
299-W14-31	0.0	0.0	0.0	-56.7	-130.0	-97.5	0.0
299-W14-32	0.0	0.0	0.0	-21.7	-130.0	-97.5	0.0
299-W14-33	0.0	0.0	0.0	-10.8	-130.0	-97.5	0.0
299-W14-73	-135.3	-82.7	-130.0	-125.0	-110.0	-82.5	0.0
299-W14-74	-100.9	-95.7	-105.0	-104.2	-100.0	-75.0	0.0
299-W15-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-225	-39.0	-79.9	-100.0	-84.2	-50.0	-37.5	0.0
299-W15-226	168.6	142.8	130.0	128.3	130.0	97.5	0.0
299-W15-227	140.0	142.1	140.0	130.0	130.0	97.5	0.0
299-W15-228	109.8	111.0	130.0	130.0	130.0	97.5	0.0
299-W15-229	75.0	82.7	120.0	136.7	150.0	112.5	0.0
299-W15-29	60.4	91.1	120.0	120.0	120.0	90.0	0.0
299-W15-32	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-33	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-34	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-35	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-36	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-40	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-44	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. Extraction and Injection Rates for Each Stress Period

Date	2018	2019	2020	2021	2022-2036	2037	2038-12070
Stress Period	**1**	**2**	**3**	**4**	**5-19**	**20**	**21-101**
Well Name							
299-W15-45	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-46	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W15-765	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W17-2	0.0	-58.2	-100.0	-102.1	-50.0	-37.5	0.0
299-W17-3	-73.2	-99.4	-110.0	-93.3	-50.0	-37.5	0.0
299-W18-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W18-36	16.1	64.6	100.0	100.0	100.0	75.0	0.0
299-W18-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W18-38	66.3	44.9	95.0	102.5	110.0	82.5	0.0
299-W18-39	2.0	25.0	15.0	17.5	25.0	18.8	0.0
299-W18-4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W18-41	133.4	115.5	130.0	129.2	130.0	97.5	0.0
299-W18-42	134.7	85.6	130.0	138.3	150.0	112.5	0.0
299-W18-43	139.6	69.5	110.0	130.4	135.0	101.3	0.0
299-W18-44	0.0	0.0	0.0	119.2	130.0	97.5	0.0
299-W19-111	0.0	-7.6	-10.0	-10.0	-10.0	-7.5	0.0
299-W19-113	-43.5	-46.6	-50.0	-50.0	-50.0	-37.5	0.0
299-W19-114	-54.3	-71.5	-80.0	-80.0	-80.0	-60.0	0.0
299-W19-125	-49.4	-47.6	-40.0	-40.0	-40.0	-30.0	0.0
299-W19-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-36E	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-36I	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-39	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W19-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
299-W22-90	-24.7	-20.5	-25.0	-25.0	-25.0	-18.8	0.0
299-W22-91	-29.3	-29.5	-30.0	-30.0	-30.0	-22.5	0.0
299-W22-92	-24.8	-24.4	-25.0	-25.0	-25.0	-18.8	0.0

Table 3. Extraction and Injection Rates for Each Stress Period

Date	2018	2019	2020	2021	2022-2036	2037	2038-12070
Stress Period	**1**	**2**	**3**	**4**	**5-19**	**20**	**21-101**
Well Name							
299-W5-1	-78.0	-86.4	-100.0	-87.5	-50.0	-37.5	0.0
299-W6-13	57.9	54.5	130.0	129.2	130.0	97.5	0.0
299-W6-14	174.0	101.1	140.0	130.0	130.0	97.5	0.0
299-W6-15	-95.9	-75.3	-90.0	-101.7	-100.0	-75.0	0.0
299-W6-16	0.0	0.0	0.0	119.2	130.0	97.5	0.0
299-W7-14	104.7	83.5	120.0	129.6	135.0	101.3	0.0
699-38-64	90.4	101.7	50.0	49.2	50.0	37.5	0.0
699-40-67	39.3	78.2	50.0	53.3	60.0	45.0	0.0
699-40-70A	0.0	0.0	0.0	0.0	-130.0	-97.5	0.0
699-42-67	57.3	101.0	50.0	125.0	140.0	105.0	0.0
699-43-67	21.7	47.6	50.0	62.5	70.0	52.5	0.0
699-43-67B	14.5	20.5	20.0	25.4	30.0	22.5	0.0
699-44-67	16.6	36.6	50.0	52.9	60.0	45.0	0.0
699-45-67	28.5	35.4	50.0	47.9	60.0	45.0	0.0
699-45-67B	3.9	33.4	20.0	23.3	25.0	18.8	0.0
699-46-68	41.5	59.2	90.0	90.8	100.0	75.0	0.0
699-47-78	0.0	0.0	0.0	126.7	150.0	112.5	0.0
699-47-78B	0.0	0.0	0.0	125.8	150.0	112.5	0.0
699-47-78C	0.0	0.0	0.0	125.8	150.0	112.5	0.0
699-48-70	0.0	-6.0	-75.0	-87.9	-100.0	-75.0	0.0
699-49-69	20.6	50.2	50.0	46.7	60.0	45.0	0.0

Note: Extraction and injection rates are shown in gallons per minute.

5 Software Applications

MODFLOW-2000-MST, Microsoft® Excel®, PEST, ArcGIS®, and R software programs were used for this calculation. These are Central Plateau Cleanup Company (CPCCo) approved software, managed and used in compliance with the policy regarding software. MODFLOW-2000-MST is approved calculation software and Excel, ArcGIS, and R are approved support software (CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*).

® Microsoft and Excel are registered trademarks of the Microsoft Corporation in the United States and other countries.

® ArcGIS is a registered trademark, or service mark, of ESRI in the United States, the European Community, or certain other jurisdictions.

MODFLOW-2000-MST, and PEST were executed on the GAIA cluster. The details regarding the cluster are presented below. A copy of the *Software Installation and Checkout Form* for the MODFLOW-2000 and MT3D-MST installation used for this calculation is provided in Appendix A to this ECF.

The GAIA Fate and Transport Modeling Platform consists of 10 Dell® PowerEdge® R740 Servers. Each with dual 28-core Intel® Xeon® Platinum 8180M@2.5GHz, 768GB of RAM. The head node (USDOE Property number WF32991) is running CentOS v.7.4.1708.

The results of acceptance testing (CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*) demonstrate that the MODFLOW-2000/MT3D-MST software is acceptable for its intended use. Installations of the software are operating correctly, as demonstrated by the GAIA Fate and Transport Modeling Platform.

5.1 Approved Software

For approved calculation software used in this calculation, the required descriptions are provided below.

5.1.1 Description

MODFLOW

- Software Title: MODFLOW-2000-MST
- Software Version: CHPRC[1] Build 8 (executable "mf2k-mst-chprc08dpl.x"), double precision compilation
- Hanford Information System Inventory (HISI) Identification Number: 2517 (Safety Software, Level C)
- Authorized Workstation type and property number: GAIA Fate and Transport Modeling Platform, USDOE # WF43109
- Authorized User: Ryan Nell
- CHPRC Software Control Documents:
  - CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
  - CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
  - CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
  - CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
  - CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

5.1.2 Software Installation and Checkout

Copies of the *Software Installation and Checkout Forms* for the authorized users and authorized workstations for software used that requires this documentation are provided in Appendix A to this ECF.

® Dell and PowerEdge are registered trademarks of the Dell Corporation, Round Rock, Texas.

® Intel and Xeon are registered trademarks of the Intel Corporation, Santa Clara, California.

[1] CH2M HILL Plateau Remediation Company (CHPRC) was the contractor at the time the software build was qualified for use.

5.1.3 Statement of Valid Software Application

The preparer of this calculation attest that the software identified above, and used for the calculations described in this calculation, is appropriate for the application and used within the range of intended uses for which it was tested and accepted by CPCCo. Because MODFLOW 2000-MST is graded as Level C software, use of this software is required to be logged in the HISI. Accordingly, this environmental calculation has been logged by the software owner in the HISI under Identification Number 2517.

6 Calculation

MODFLOW simulations of the P2R Model version 8.3 predictive model were executed on the GAIA Fate and Transport Modeling Platform by invoking the installed executable and the input files. Simulation files and results were archived in the Environmental Modeling Management Archive under the document number for this ECF. Output files included the "flow-transport link" file needed to provide the flow field generated by the groundwater flow simulation to the fate and transport simulations.

7 Results/Conclusions

Hydrographs were created for 13 locations throughout the model domain to illustrate the variation in hydraulic head over the simulated temporal domain. Figure 6 shows a map of the locations where hydrographs were placed to illustrate the model results. Hydrographs for these locations are shown in Figures 7 through 19. Due to the length of the simulations and the fact that all of the changes in boundary conditions occur in the first 500 years, the x-axis (time in simulated years) is shown on a log scale to emphasize early time periods. A linear plot is shown as well to focus on the first 1,000-year compliance period. Each plot has a line for each model layer. If the line is not visible it is because it is equal to and thus directly beneath another time-series.

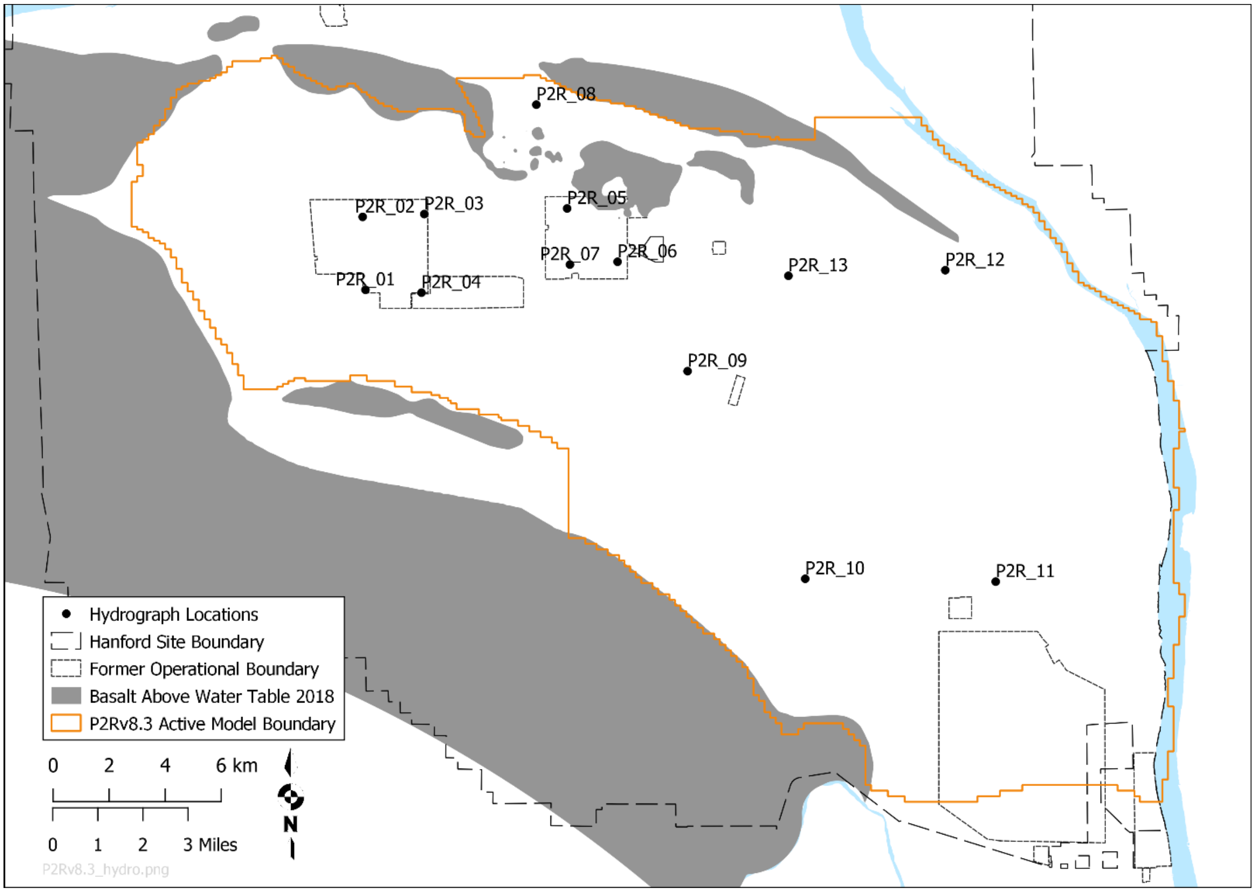

Figure 6. Location of Hydrographs Illustrating the Change in Head Over Time in the Predictive Simulation

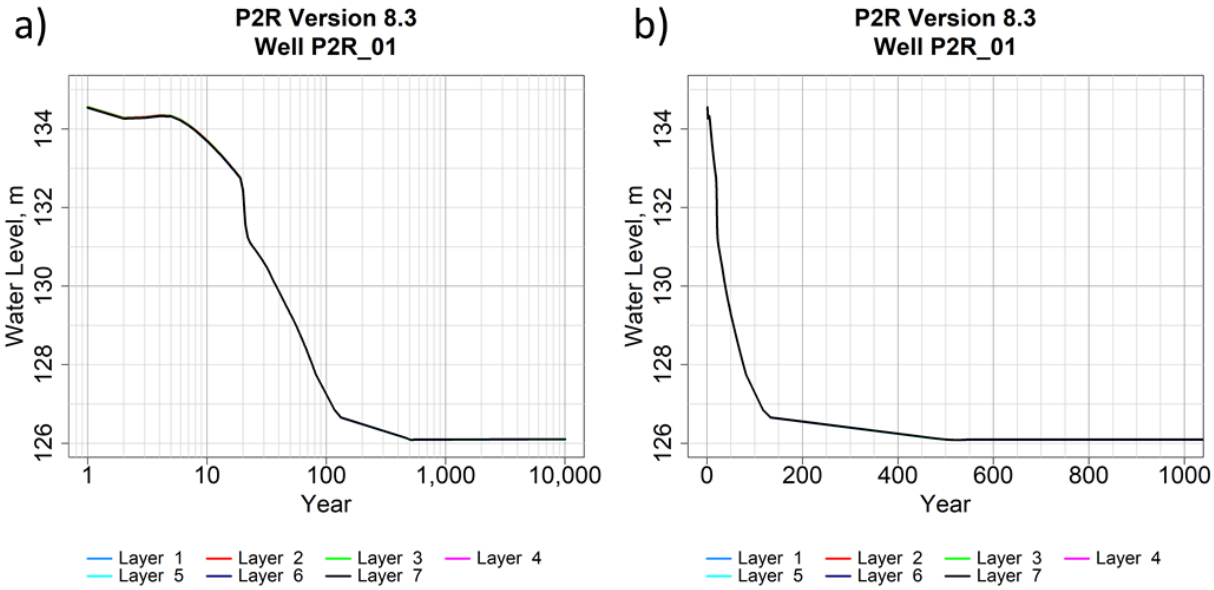

Figure 7. Hydraulic Head at Location P2R_01 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

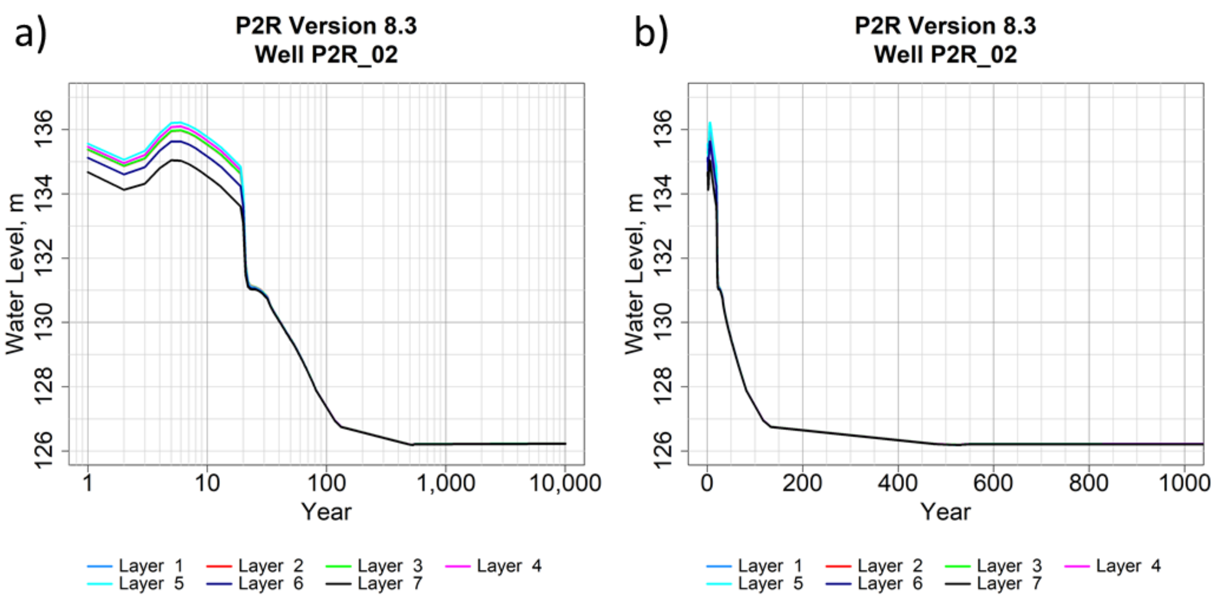

Figure 8. Hydraulic Head at Location P2R_02 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

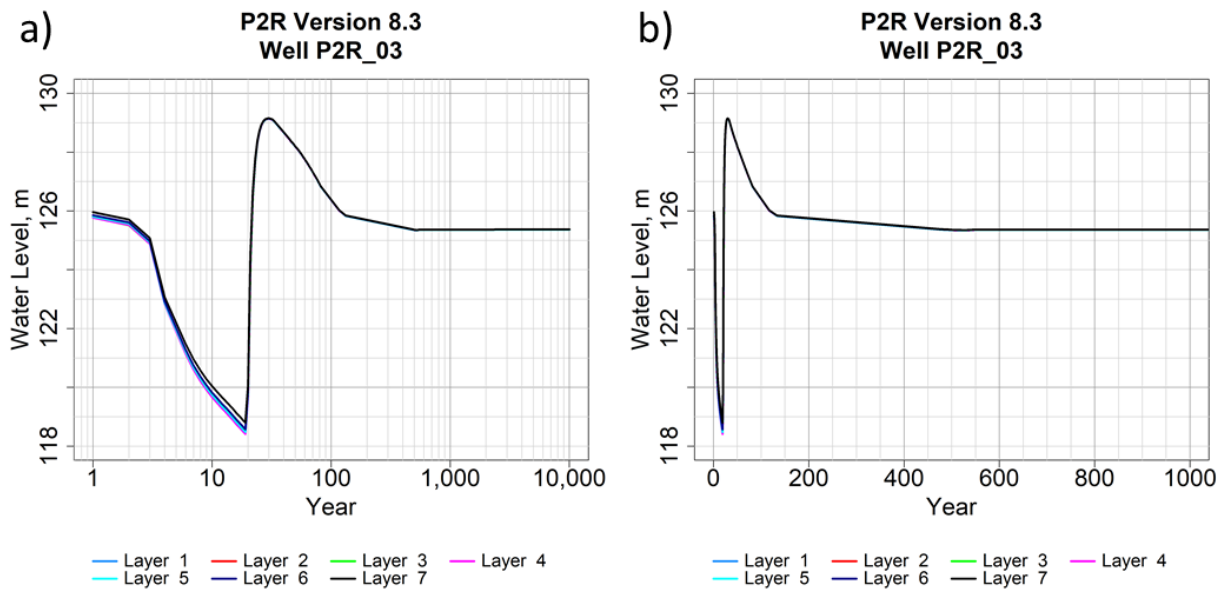

Figure 9. Hydraulic Head at Location P2R_03 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

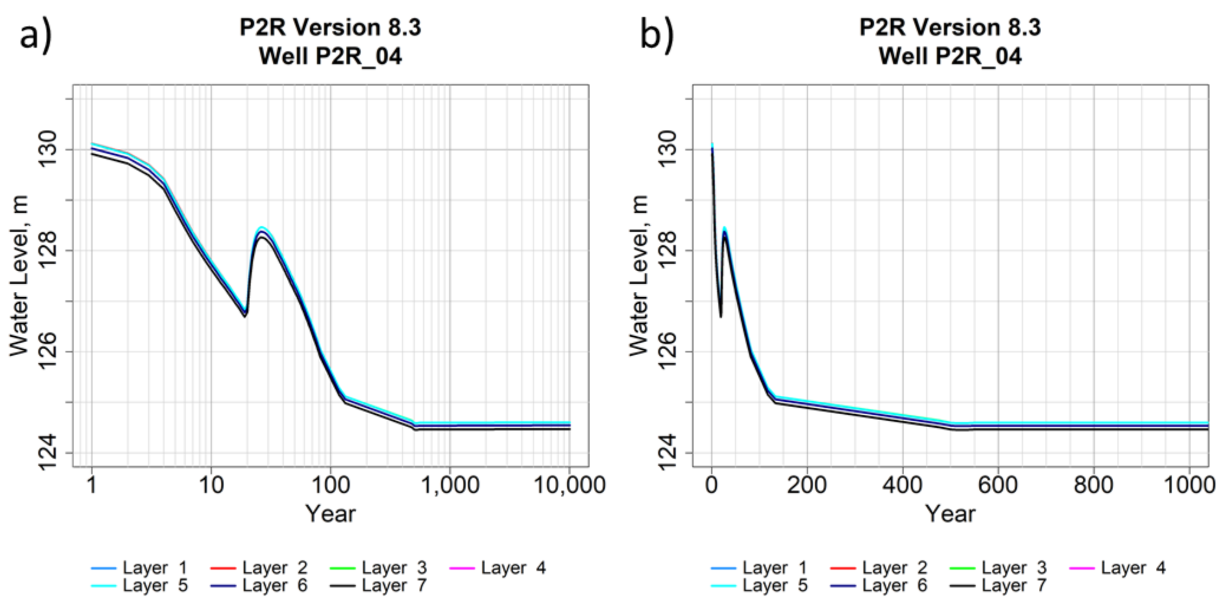

Figure 10. Hydraulic Head at Location P2R_04 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

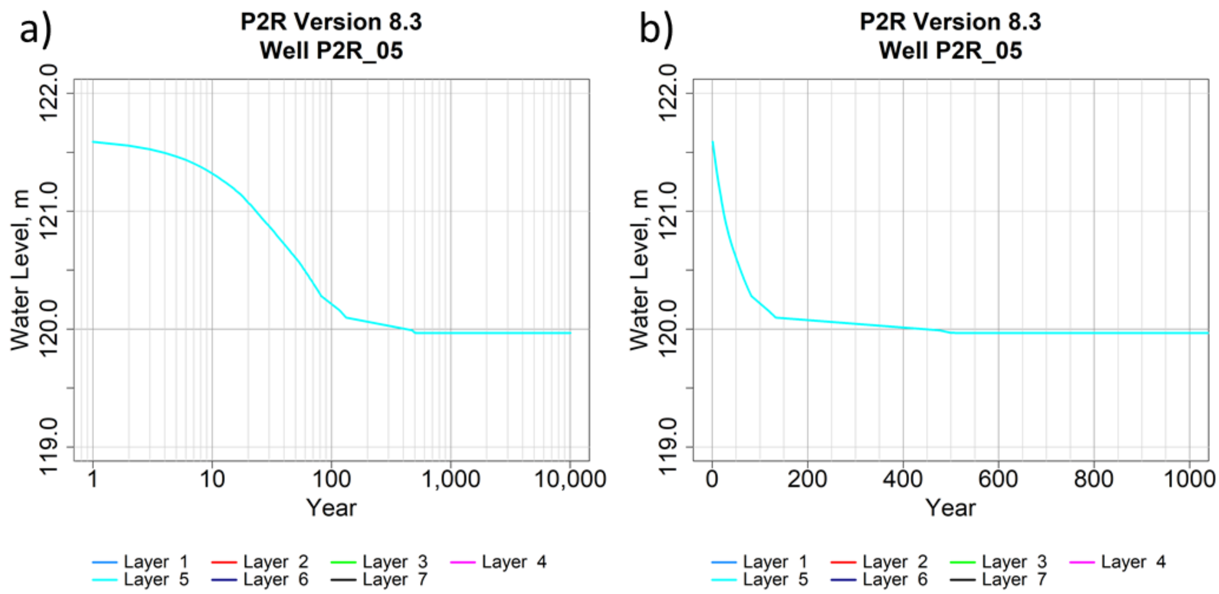

Figure 11. Hydraulic head at location P2R_05 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

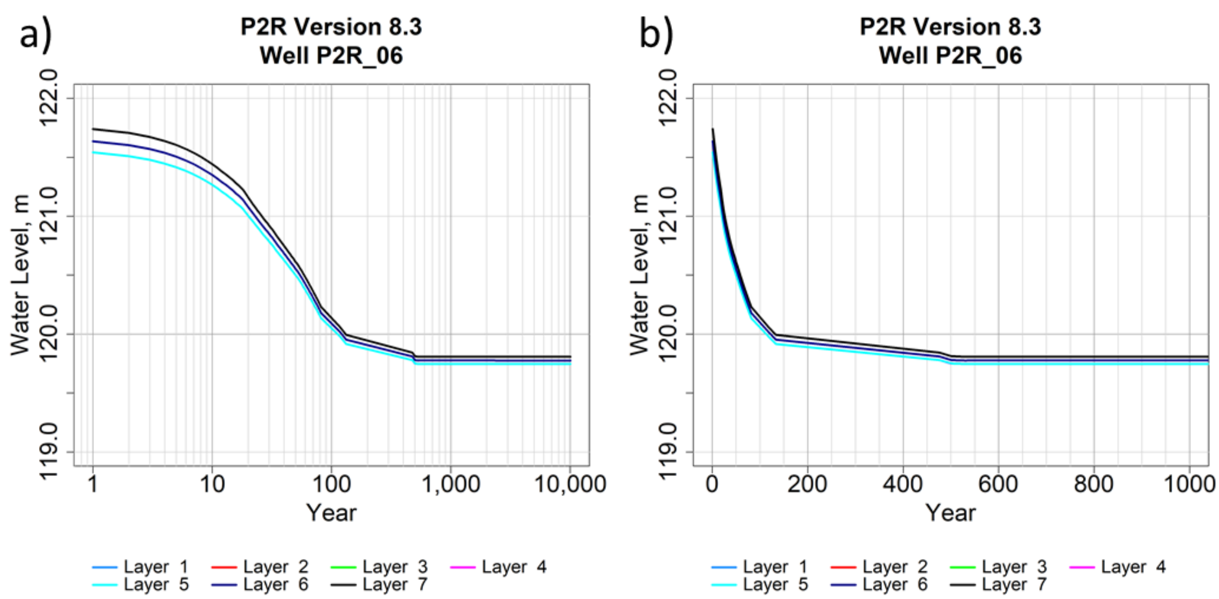

Figure 12. Hydraulic Head at Location P2R_06 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

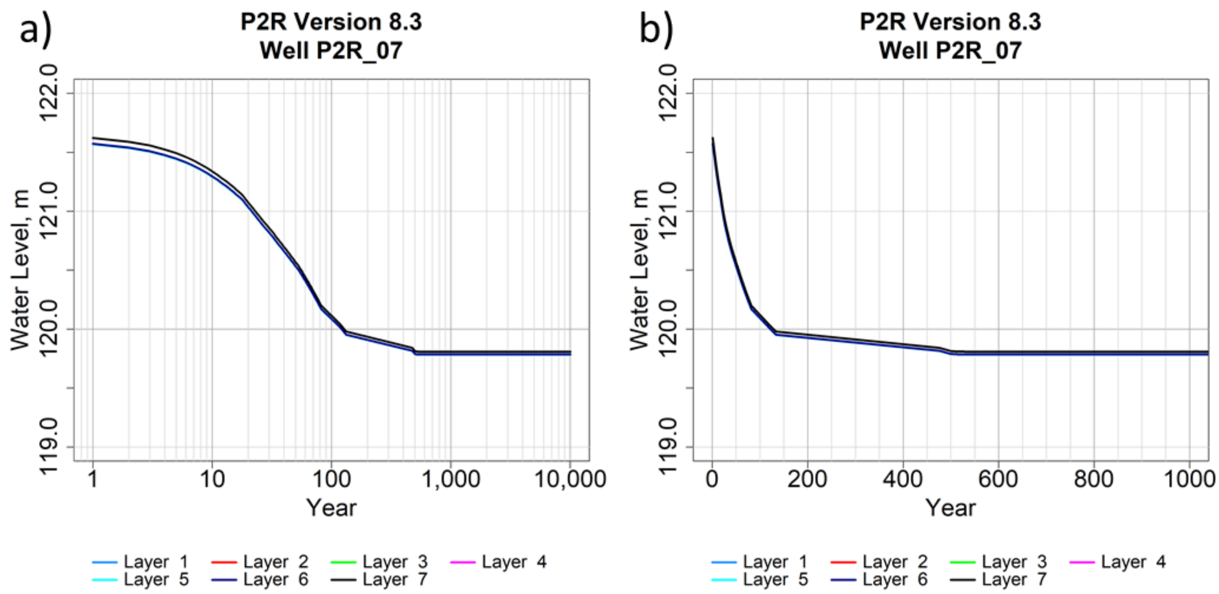

Figure 13. Hydraulic Head at Location P2R_07 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

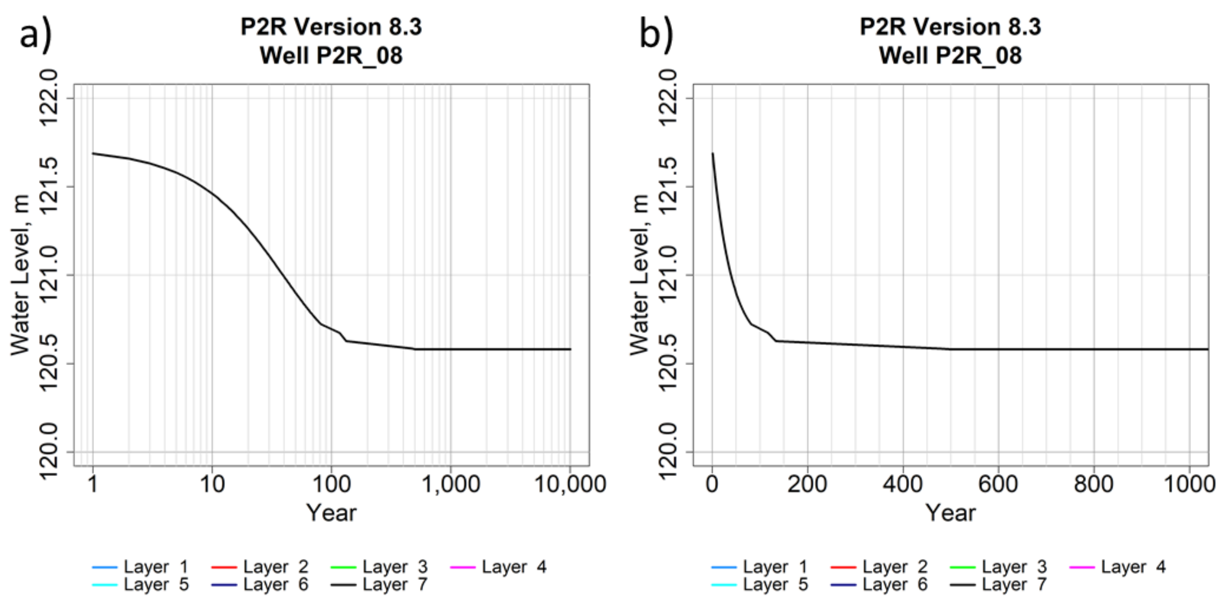

Figure 14. Hydraulic Head at Location P2R_08 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

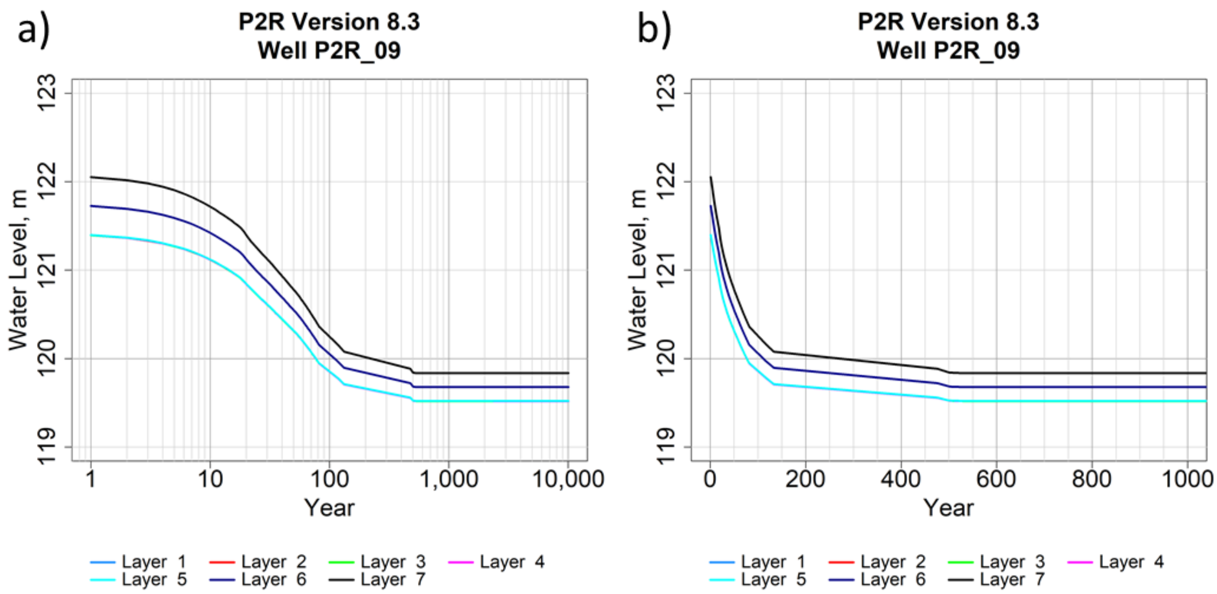

Figure 15. Hydraulic Head at Location P2R_09 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

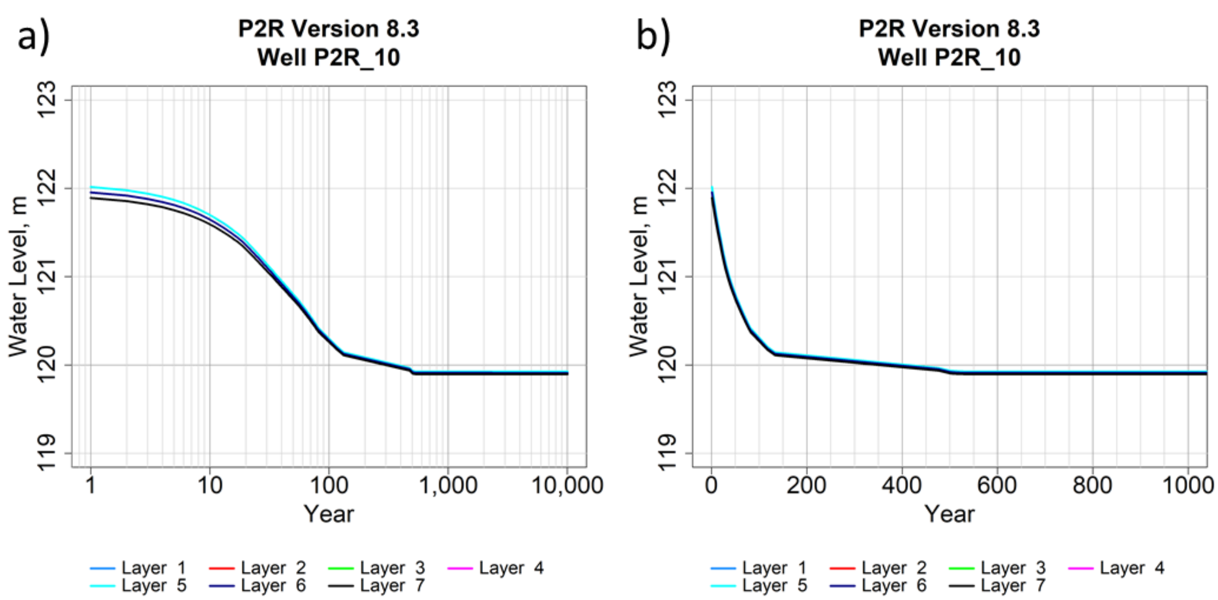

Figure 16. Hydraulic Head at Location P2R_10 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

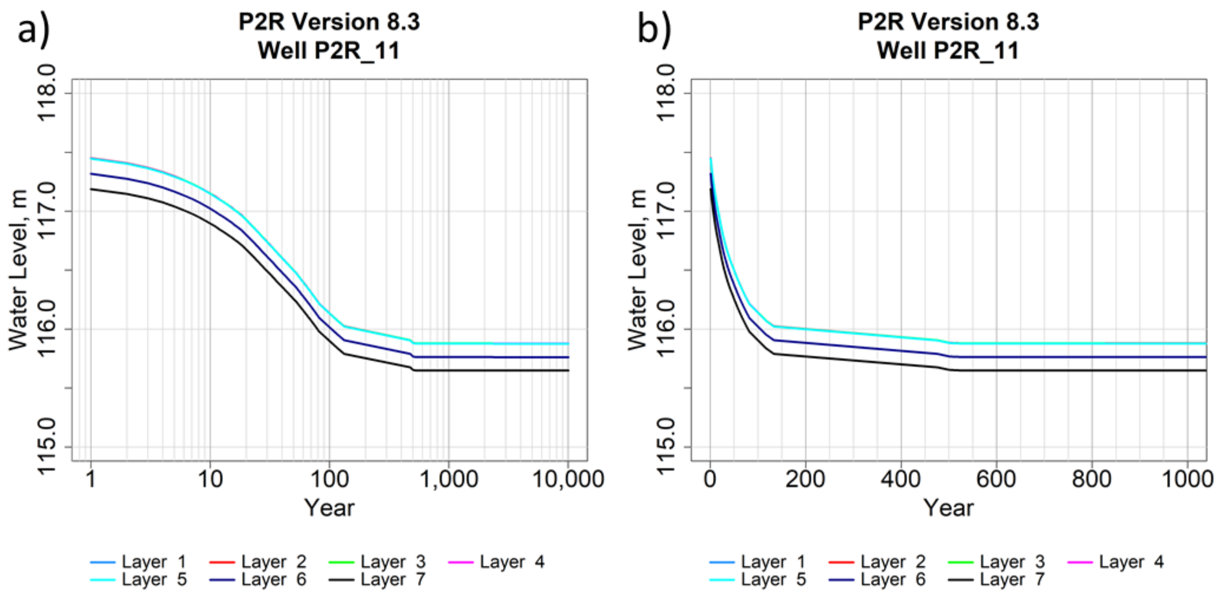

Figure 17. Hydraulic Head at Location P2R_11 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

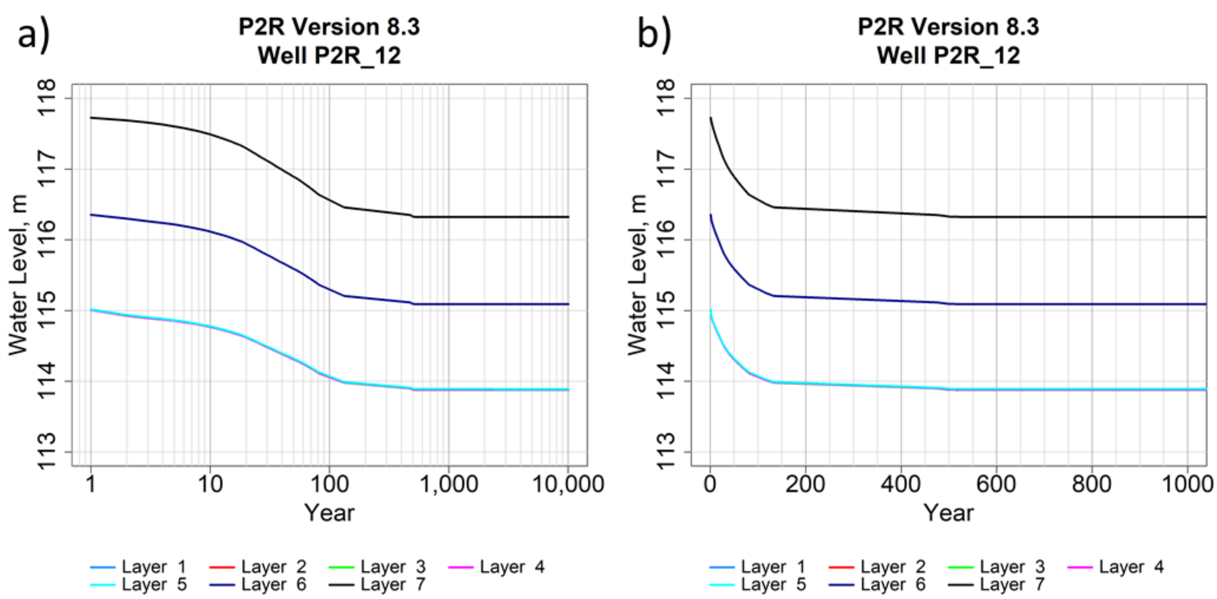

Figure 18. Hydraulic Head at Location P2R_12 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

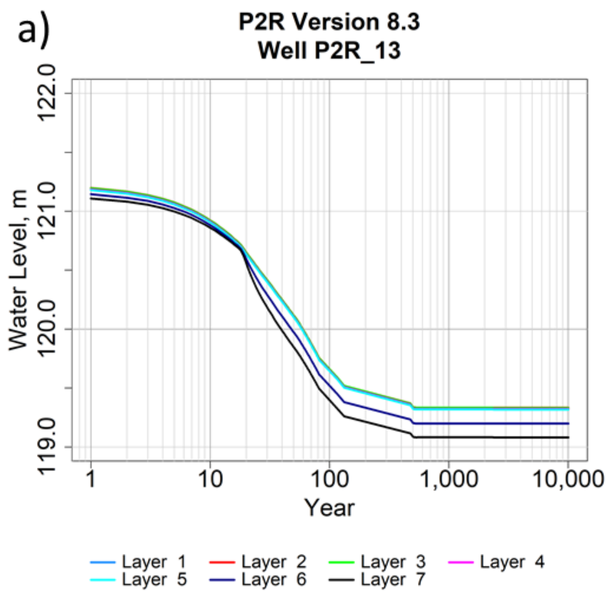

Figure 19. Hydraulic Head at Location P2R_13 (a) Over Entire Predictive Flow Simulation and (b) First 1,000 Years

8 References

CHPRC-00257, 2010, *MODFLOW and Related Codes Functional Requirements Document*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00258, 2015, *MODFLOW and Related Codes Software Management Plan*, Rev. 4, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00259, 2014, *MODFLOW and Related Codes Software Test Plan*, Rev. 3, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00260, 2015, *MODFLOW and Related Codes Requirements Traceability Matrix*, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00261, 2015, *MODFLOW and Related Codes Acceptance Test Report*, CHPRC Build 8, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.

CP-57037, 2020, *Model Package Report: Plateau to River Groundwater Model, Version 8.3*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

ECF-200IA1-20-0108, 2021, *Determination of Preliminary Remediation Goals for 200-IA-1 Source Operable Unit*, Central Plateau Cleanup Company, Richland, Washington.

ECF-HANFORD-15-0019, 2019, *Hanford Site-Wide Natural Recharge Boundary Conditions for Groundwater Models*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

ECF-HANFORD-20-0049, *Groundwater Pump and Treat (P&T) Report*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

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Appendix A

Software Installation and Checkout Form

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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: MODFLOW and Related Codes   Software Version No.: Bld 8

EXECUTABLE INFORMATION:

2. Executable Name (include path):

```
Following executable files in directory: /state/partition1/bin on compute-0-9 node only

MD5 Signature (unique ID)          Executable File Name    Code
--------------------------------   ---------------------   ---------------------------
8b0b28c5e102e63df95de542d83d013b   mf2k-chprc08spl.x       MODFLOW-2000 single precision
2fade33e27978063a9a70ff8605e4c0c   mf2k-chprc08dpl.x       MODFLOW-2000 double precision
d879defafdc5ad25be51a484d73ea65d   mf2k-mst-chprc08spl.x   MODFLOW-2000-MST single precis.
80d670658425653bf5bcbb97ad2a2730   mf2k-mst-chprc08dpl.x   MODFLOW-2000-MST double precis.
8b0b28c5e102e63df95de542d83d013b   mf2k-chprc08spl.x       MT3DMS single precision
2fade33e27978063a9a70ff8605e4c0c   mf2k-chprc08dpl.x       MT3DMS double precision
2d0a8a4c480318763b6aaaa0f880348a   mt3d-mst-chprc08spl.x   MT3DMS-MST single precision
1e468c4409ac913843ce783aabed819c   mt3d-mst-chprc08dpl.x   MT3DMS-MST double precision
```

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

COMPILATION INFORMATION:

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

   INTERA Austin Linux(R) Cluster

5. Operating System (include version number):

   Linux head.cluster 2.6.32-358.11.1.el6.centos.plus.x86_64 #1 SMP Wed Jun 12 19:12:17 UTC 2013 x86 64 x86 64 x86 64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

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

   Gaia

7. Operating System (include version number):

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

TEST CASE INFORMATION:

9. Directory/Path:

   /state/partition1/test/modflow/build-8-a on compute node 9

10. Procedure(s):

    CHPRC-00259 Rev. 3, MODFLOW and Related Codes Software Test Plan

11. Libraries:

    N/A (static linking)

12. Input Files:

    Per CHPRC-00259 Rev. 3

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes — Software Version No.: Bld 8

13. Output Files:

Found in test subdirectories

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW); run both single & double precision
MT-ITC-1 run for single and double precision, multiple solvers

15. Test Case Results:

All PASS, All Tests, on compute-0-9 node only of Gaia

16. Test Performed By: WE Nichols

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

18. Disposition (include HISI update):

This is a retest of the installation following replacement of failed RAM modules. All tests pass in the revised configuration.

Prepared By:

19. WILLIAM NICHOLS (Affiliate) Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2020.04.01 14:31:11 -07'00'

Software Owner (Signature)	Print	Date
WILLIAM NICHOLS (Affiliate)	WE Nichols	

20. Test Personnel:

Sign	Print	Date
	WE Nichols	

Approved By:

21.

Software SME (Signature)	Print	Date
	N/R (CHPRC-00258 Rev. 3)	

A-6005-149 (REV 0)