DOCUMENT RELEASE AND CHANGE FORM

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WMA A-AX Performance Assessment Flow and Transport Process Model Support of the Sensitivity Analysis

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Document Control Approval	Alvarez, Efren	*Alvarez, Efren*	11/04/2020
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RPP-CALC-63164	00	WMA A-AX Performance Assessment Contaminant Fate and Transport Process Model to Evaluate Impacts to Groundwater
RPP-ENV-61497	00	Preliminary Performance Assessment of Waste Management Area A-AX, Hanford Site, Washington
RPP-ENV-62206	00	Analysis of Post-Closure Groundwater Impacts from Hazardous Chemicals in Residual Wastes in Tanks and Ancillary Equipment at Waste Management Area A-AX at the Hanford Site, Southeast Washington
RPP-RPT-60101	00	Model Package Report Flow and Contaminant Transport Numerical Model used in WMA A-AX Performance Assessment and RCRA Closure Analysis

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INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

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Responsible Manager	WRPS	10/05/2020	Rutland, Paul L Approved - IDMS data file att.
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This document provides the basis for evaluation and review of the sensitivity analysis conducted with the process model as part of the Waste Management Area (WMA) A AX performance assessment. This sensitivity analysis also includes cases that support development of the uncertainty analysis. The system model includes the sensitivity and uncertainty case evaluations of radionuclide concentrations in groundwater. Therefore, the process model sensitivity and uncertainty evaluation is limited to providing aqueous flow field results to support the conduct of the vadose and saturated zone sensitivity and uncertainty analysis in the system model.

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By Sarah Harrison at 3:36 pm, Nov 02, 2020

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RPP-CALC- 63248
Rev. 0

WMA A-AX Performance Assessment Flow and Transport Process Model Support of the Sensitivity Analysis

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ENVIRONMENTAL MODEL CALCULATION COVER PAGE

SECTION 1: COMPLETED BY RESPONSIBLE MANAGER OR DESIGNEE

~~Rev 0~~ Draft A WJM 06/12/19
RELEASE/ISSUE

Project: WMA A-AX Performance Assessment

Date: 06/12/2109

Calculation Title and Description: WMA A-AX Performance Assessment Flow and Transport Process Model Support of the Sensitivity Analysis

SECTION 2: COMPLETED BY PREPARER

Calculation No.: RPP-CALC-63248 **Revision No.:** ~~0~~ Draft A WJM 06/12/19

Revision History

Revision No.	Description	Date	Affected Pages
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SECTION 3: COMPLETED BY RESPONSIBLE MANAGER OR DESIGNEE

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Print First and Last Name	Position	Signature	Date
Will Nichols	Training Coordinator	[signature]	12 JUN 2019

Software Installation and Checkout Certified:
Integration Lead:

Print First and Last Name	Position	Signature	Date
Will Nichols	Modeling Team Leader	[signature]	12 JUN 2019

SECTION 5: DOCUMENT REVIEW AND APPROVAL

Role	Print First and Last Name	Position	Signature	Date
Preparer:	W.J. McMahon/N. Hassan	Sr. Eng./Hydrologist	[signatures]	06/12/2019; 06/12/2019
Checker:	Amena Mayenna	Environmental Scientist	[signature]	06/12/2019
Senior Reviewer:	Matt Kozak	Principal Engineer	[signature]	6-12-19
Responsible Manager or Designee:	Robert Hiergesell	Manager	[signature]	6/12/19

A-6006-716 (REV 1)

EXECUTIVE SUMMARY

This environmental model calculation provides the basis for evaluation and review of the sensitivity analysis conducted with the process model as part of the Waste Management Area (WMA) A-AX performance assessment. This sensitivity analysis also includes cases that support development of the uncertainty analysis. The system model includes the sensitivity and uncertainty case evaluations of radionuclide concentrations in groundwater, RPP-CALC-63247, *WMA A-AX Performance Assessment Sensitivity Analysis* and RPP-CALC-62451, *WMA A-AX Performance Assessment Uncertainty Calculation*, respectively. Therefore, the process model sensitivity and uncertainty evaluation is limited to providing aqueous flow field results to support the conduct of the vadose and saturated zone sensitivity and uncertainty analysis in the system model.

This environmental model calculation limits the discussion of input parameters and model development to those items necessary to indicate the changes from the base case parameters and the range of values evaluated in the sensitivity and uncertainty cases. The basis of the model to perform the base case calculations, including inputs, is documented in RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis* and RPP-CALC-63164, *WMA A-AX Performance Assessment Contaminant Fate and Transport Process Model to Evaluate Impacts to Groundwater* as required by the documentation requirements associated with the preparation and issue of environmental calculations. The process model calculations are performed using the Subsurface Transport Over Multiple Phases (STOMP)[1] simulator developed by Pacific Northwest National Laboratory to evaluate vadose and saturated zone flow and contaminant transport, particularly in arid environments (PNNL-12030, *STOMP Subsurface Transport Over Multiple Phases Version 2.0 Theory Guide*). Control of all software used to implement the model is directed by the requirements of PRC-PRO-IRM-309, "Controlled Software Management."

[1] Subsurface Transport Over Multiple Phases (STOMP) is developed and distributed by Battelle Memorial Institute.

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APPENDICES

ATTACHMENT

FIGURES

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TERMS

1-D	one-dimensional
3-D	three-dimensional
ASME	American Society of Mechanical Engineers
CFR	*Code of Federal Regulations*
CHPRC	CH2M HILL Plateau Remediation Company
Ci	curie(s)
cm	centimeter(s)
cm/s	centimeters per second
Cr	chromium
DOE	U. S. Department of Energy
EMCF	environmental model calculation file
EMMA	Environmental Model Management Archive
EPA	U.S. Environmental Protection Agency
FEPs	features, events, and processes
ft	feet
g	gram(s)
h	hour(s)
H1	Hanford formation unit 1
H2	Hanford formation unit 2
H3	Hanford formation unit 3
HISI	Hanford Information System Inventory
HSU	hydrostratigraphic unit
in.	inch
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
m	meter(s)
mg/L	milligrams per liter
mi	mile(s)
mL/g	microliters per gram
mm/yr	millimeters per year
NQA	Nuclear Quality Assurance
pCi/L	picocuries per liter
PA	performance assessment
PNNL	Pacific Northwest National Laboratory
PoCal	point of calculation
RCRA	*Resource Conservation and Recovery Act of 1976*
RETC	RETention Curve (software)
STOMP	Subsurface Transport Over Multiple Phases (software)
TFC	tank farm contractor
VZ	vadose zone
WMA	Waste Management Area
WRPS	Washington River Protection Solutions
yr	year

1.0 PURPOSE

The purpose of the Waste Management Area (WMA) A-AX performance assessment (PA) is to support activities associated with the retrieval of waste and the eventual closure of the tanks and ancillary equipment within WMA A-AX. Process models provide detailed deterministic consideration of specific processes expected to be of importance for the analysis (DOE-STD-5002-2017, *Disposal Authorization Statement and Tank Closure Documentation*). Results from a deterministic process model base case often provide the basis for comparison to demonstrate that the performance objectives identified in Chapter IV of DOE M 435.1-1, *Radioactive Waste Management Manual* are not exceeded (DOE-STD-5002-2017). Although the existing regulations express compliance in terms of comparisons of single values, model results are uncertain because models and approximations of environmental processes are inherently uncertain. Therefore, DOE M 435.1-1 directs that the PA shall include sensitivity and uncertainty analyses as part of a PA.

The sensitivity analysis provides credence to a conclusion that there is a reasonable expectation of meeting the performance objectives by evaluating the uncertainty in models and assumptions in the PA. The sensitivity analysis works in concert with the probabilistic uncertainty analysis, which addresses parameter uncertainty, and also serves to identify those parameters that have the greatest impact on the projected doses and introduce the greatest variability into the results. For the WMA A-AX PA, the system model (RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*) includes an evaluation of the base case and sensitivity and uncertainty analyses. The purpose of the WMA A-AX process model in the sensitivity and uncertainty analysis is therefore limited to providing flow field results for input to the system model.

This environmental model calculation file (EMCF) is intended to read as a standalone document. However, that goal is balanced against duplicating content already contained in the supporting model package report (RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*) and EMCF (RPP-CALC-63164, *WMA A-AX Performance Assessment Contaminant Fate and Transport Process Model to Evaluate Impacts to Groundwater*). Therefore, this EMCF does not intend to provide exhaustive details of the context of the calculation, the background of the model development, or the generation of input data. The supporting model package report includes those items. This EMCF also does not intend to provide exhaustive details of the process model inputs. Instead, the focus is on the changes from the base case necessary to conduct the sensitivity and uncertainty case evaluations. The supporting EMCF includes those items.

One of the functions of this EMCF is to document calculation details for review by an internal checker. The organization of the document may differ from that which may seem more logical in other contexts. Per EMCF requirements, the checker must be familiar with the type of calculations performed, and, in this case, the software structure and syntax of Subsurface Transport Over Multiple Phases (STOMP)[2].

[2] Subsurface Transport Over Multiple Phases (STOMP) is developed and distributed by Battelle Memorial Institute.

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2.0 BACKGROUND

For the WMA A-AX PA sensitivity and uncertainty analysis, the process model evaluation is limited to providing aqueous flow field results to the system model to complete the analysis. Flow field abstraction for the sensitivity and uncertainty analysis cases was done using the same abstraction procedure as for the base case flow field, as discussed in Section 4.3.1 of RPP-RPT-60885. The system model includes the sensitivity and uncertainty case evaluations of radionuclide and contaminants of potential concern concentrations in groundwater (RPP-CALC-63247, *WMA A-AX Performance Assessment Sensitivity Analysis* and RPP-CALC-62451, *WMA A-AX Performance Assessment Uncertainty Calculation*, respectively).

2.1 SUMMARY OF WASTE MANAGEMENT AREA A-AX PERFORMANCE ASSESSMENT PROCESS MODEL INPUTS

RPP-RPT-60101 and RPP-CALC-63164 describe and provide the explanation for the process model parameters and values assigned, including boundary and initial conditions. RPP-RPT-60101 contains the description and exposition of the data sources and data quality, and RPP-CALC-63164 includes tables of process model input values structured to mimic the input requirements of STOMP. Section 4.3 of RPP-CALC-63164 contains the process model inputs, with Section 4.3.1 identifying the gridding, zonation and initial conditions, Section 4.3.2 presenting the soil hydraulic properties, Section 4.3.3 defining the boundary conditions, Section 4.3.4 presenting the radionuclide and contaminant transport properties, and Section 4.3.5 summarizing the radionuclide and contaminant source and release. These inputs are not repeated in this document, other than to identify changes involved with the sensitivity and uncertainty cases.

2.1.1 KEY ASSUMPTIONS

Appendix A of RPP-RPT-60101 provides a comprehensive listing of the assumptions relevant to this calculation. No additional assumptions pertinent for this calculation have been identified.

2.1.2 MODEL LIMITATIONS

Section 5.1 of RPP-RPT-60101 provides a discussion of the limitations relevant to this calculation. No additional limitations relevant to this calculation have been identified.

2.2 SUMMARY OF WASTE MANAGEMENT AREA A-AX PERFORMANCE ASSESSMENT PROCESS MODEL RESULTS

The process model analysis evaluates the time-dependent groundwater flow in the vadose and saturated zones, concentrations in groundwater of ^{99}Tc and ^{129}I associated with the individual residual sources, and concentrations in groundwater for the entire WMA. These time-dependent results are used to identify the peak concentration, both for the whole WMA and for each individual source. The process model is also used to identify the point of calculation (PoCal) where the peak concentration occurs (RPP-CALC-63164). This approach is intended to specifically address the requirements of Appendix I of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et. al. 1989) that indicate that the PA needs to evaluate the relative risk of each component compared to the entire WMA performance.

In addition, the process model is used to provide a set of benchmarking or calibration ^{99}Tc and ^{129}I results to assist in the development and evaluation of the system model. This benchmarking assures that the system model produces a reasonable representation of the process model results for selected input parameters. Furthermore, the process model is intended to support the required sensitivity and uncertainty evaluations by providing the flow fields for cases in which a revised flow field is needed.

The three-dimensional (3-D) process model sensitivity analysis consists of evaluating assumptions and parameters that change the aqueous flow results and providing those results to the system model. The system model uses an abstracted version of the 3-D model results as a one-dimensional (1-D) flow field approximation. The system model is then used to evaluate transport of the contaminants through the vadose zone and saturated zone. Therefore, the 3-D process model analysis does not involve evaluating contaminant concentrations in groundwater. The concentrations of ^{99}Tc and ^{129}I in groundwater presented in RPP-CALC-63164 are not reproduced here because they are not relevant to the vadose zone flow sensitivity analysis.

Instead, Figures 2-1 and 2-2 present cross-sections through 241-A and 241-AX Tank Farms that display Darcy flux vectors and moisture content, respectively, for the base case analysis. The direction of the vectors in Figure 2-1 shows the lateral flow diversion occurring at the top of the extant tanks. The distribution of the moisture content displayed in Figure 2-2 indicates that an “umbrella effect” occurs in the results from both tank farms, leading to low moisture contents just below the tanks. With the exception of these dry areas, the moisture content in the farms and surrounding hydrostratigraphic units (HSUs) is fairly uniform, only ranging from about 0.06 to 0.07. The buildup of moisture content within the farm and between the tanks appears to be more pronounced in 241-AX Tank Farm (AX Farm) compared to 241-A Tank Farm (A Farm), which is a consequence of the AX Farm backfill hydraulic properties. In AX Farm the backfill resembles a sand material, whereas in A Farm it resembles a gravel material.

Figure 2-1. Darcy Flux Vectors Around the Representative Tanks and a Neighboring Tank in the 241-AX and 241-A Tank Farms.

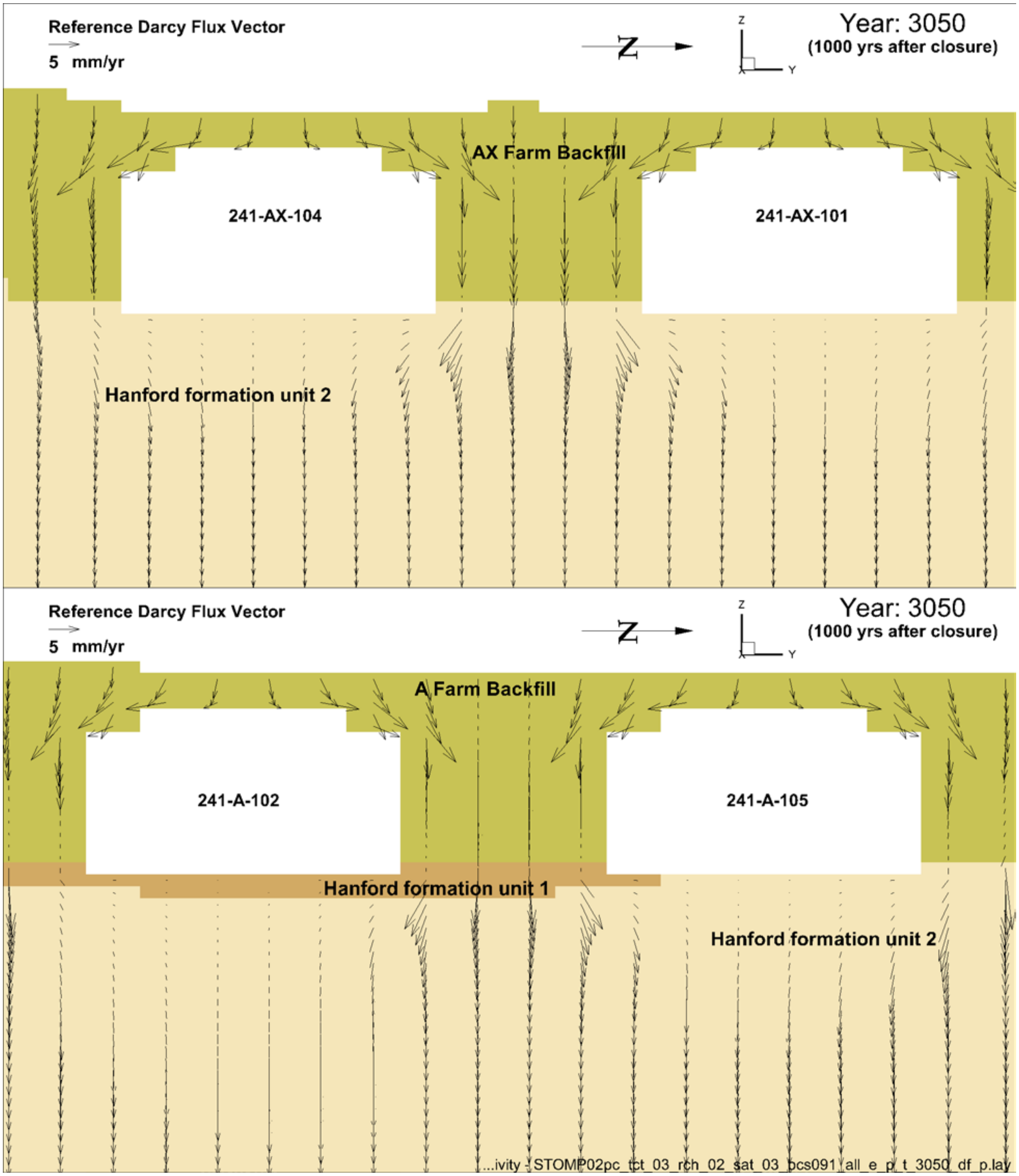
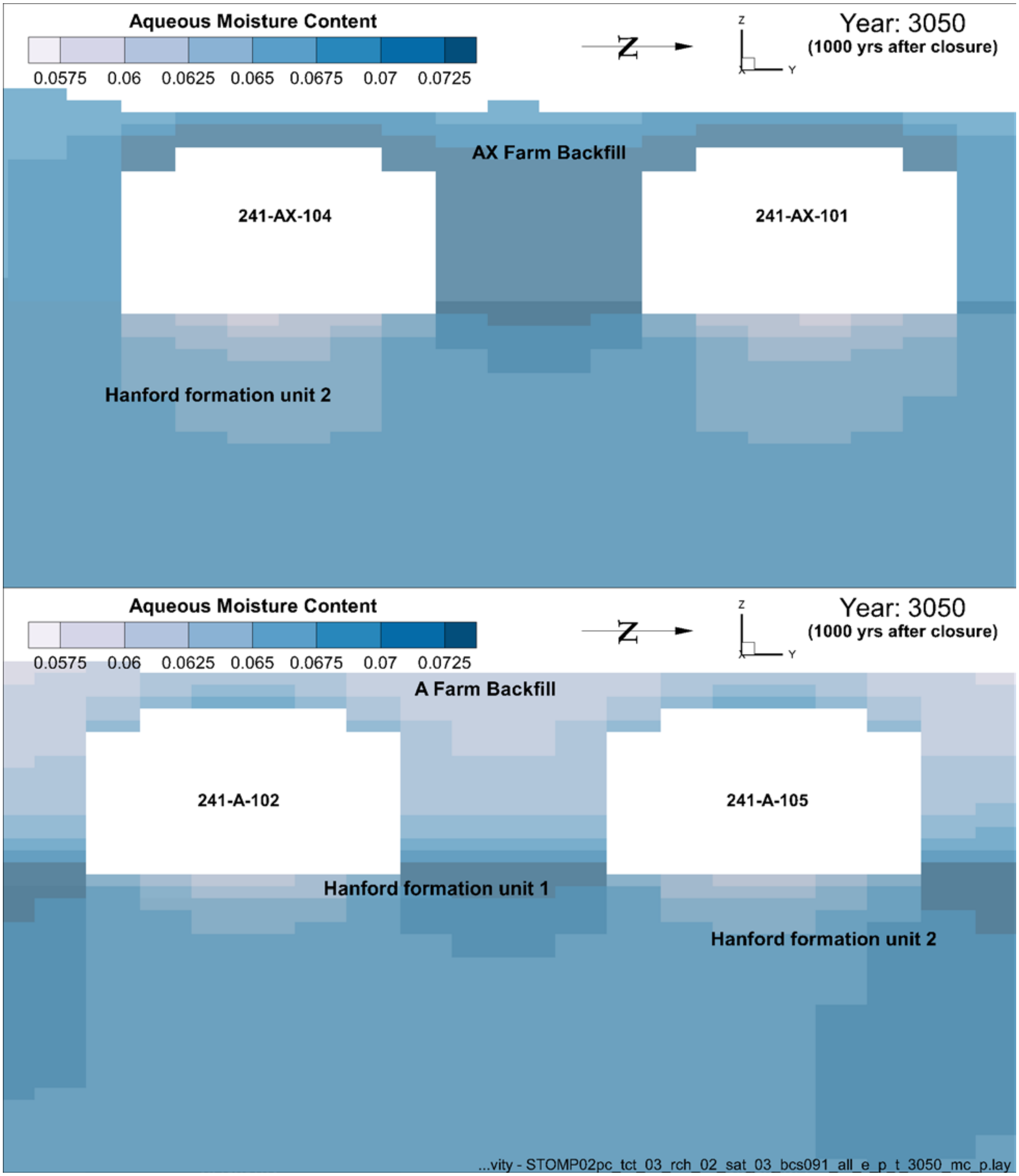


Figure 2-2. Moisture Content Around the Representative Tanks and a Neighboring Tank in the 241-AX and 241-A Tank Farms.



3.0 SUMMARY OF WASTE MANAGEMENT AREA A-AX PERFORMANCE ASSESSMENT VADOSE ZONE FLOW SENSITIVITY ANALYSIS

The set of vadose zone flow sensitivity and uncertainty cases presented in Table 3-1 correspond to the surface barrier and grout categories of safety functions. Each case is assigned a shorthand designator so it can be easily referenced. A brief explanation of each sensitivity and uncertainty case is also provided in the table, to provide insight into the alternative assumptions it is intended to evaluate. The vadose zone flow sensitivity and uncertainty cases presented in this EMCF address the cases that require changes to the base case inputs of the process model.

Table 3-1. Summary of Vadose Zone Flow Sensitivity and Uncertainty Cases.

Surface Barrier Flow Safety Function	
Uncertainty Case Shorthand	**Explanation**
INF-min	All parameters same as base case, except that design and post-design life surface barrier net infiltration equal the minimum values from the range identified in the uncertainty analysis, 0.1 mm/yr and 0.5 mm/yr, respectively.
INF-max	All parameters same as base case, except that design and post-design life surface barrier net infiltration equal the maximum values from the range identified in the uncertainty analysis, 0.9 mm/yr and 5.2 mm/yr, respectively.
Tank Grout Safety Function	
Sensitivity Case Shorthand	**Explanation**
GRT2	All parameters same as base case, except that after 0 years following closure, the grout degrades immediately and the flow properties change to Hanford formation unit 2 (H2) sand values.

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4.0 VADOSE ZONE FLOW SENSITIVITY AND UNCERTAINTY CASES PARAMETERIZATION

The sensitivity and uncertainty cases conducted using the 3-D STOMP model can be considered as changes in net infiltration, or changes in the tank grout performance. The net infiltration uncertainty simulations address the flow safety function of the surface barrier. The analyses evaluate the impacts of changes in recharge rate estimates during both pre- and post-design life performance periods of the surface barrier. The tank grout sensitivity case examines the impacts of the flow safety function of the tank grout. The tank grout sensitivity case is intended to bound the behavior of the system of the grout under potential future degradation scenarios, by assuming that the grout degrades into sand-like material immediately upon closure.

The recharge uncertainty evaluations address the safety function related to surface barrier performance and longevity. For this analysis, the vadose zone and aquifer hydraulic properties remain unchanged from the base case values identified in RPP-CALC-63164. Cases INF-min and INF-max address variability in the design and post-design life surface barrier net infiltration estimates and bracket the low and high end estimates of these parameters (Table 4-1). The recharge estimates included in RPP-RPT-58948, *Model Package Report System Model for the WMA C Performance Assessment and RCRA Closure Analysis Version 1.0* applicable to the WMA C surface barrier are assumed to be applicable to the WMA A-AX surface barrier. Case INF-min involves surface barrier net infiltration rates of 0.1 mm/yr and 0.5 mm/yr for the design and post-design life periods, respectively. Case INF-max involves surface barrier net infiltration rates of 0.9 mm/yr and 5.2 mm/yr for the design and post-design life periods, respectively.

Table 4-1. Recharge Rates Associated with the Surface Barrier Flow Uncertainty Analysis Cases.

Sensitivity Case Shorthand	Pre-WMA A-AX Construction and Undisturbed Ground Recharge Rate (mm/yr)	Recharge Rate of WMA A-AX Ground During Operations (mm/yr)	Design Life Surface Barrier Recharge Rate (mm/yr)[a,b]	Post-Design Life Surface Barrier Recharge Rate (mm/yr)
INF-min	3.5	100	0.1	0.5
INF-max	3.5	100	0.9	5.2

Note: The recharge estimates included in RPP-RPT-58948, *Model Package Report System Model for the WMA C Performance Assessment and RCRA Closure Analysis Version 1.0* are assumed to be applicable to the Waste Management Area (WMA) A-AX surface barrier.

[a]The WMA A-AX surface barrier is expected to cover all of the adjacent A-series double-shell tank farms.

[b]Recharge outside of the surface barrier acquires the base case value of 3.5 mm/yr after WMA A-AX closure.

[c]Post-design recharge begins 100 years after closure.

The tank grout sensitivity case includes the assumption that the grout, tank wall, and base mat degrade immediately upon closure into material that has the same hydraulic parameters as the sand described in RPP-RPT-60101 and RPP-CALC-63164. Since there is no feature, event, and process (FEP) or combination of FEPs that could produce this end state of the concrete and grout materials in the tanks, the selection of properties of for the degraded materials is arbitrary. For the analyses presented in this report, the end state is represented by Hanford formation unit 2 (H2) sand. Other properties could be selected as long as they produce a condition that is bounding compared to any potential realistic behavior of the system under future conditions. The tank grout degradation case involves no changes to the net infiltration rates presented in RPP-CALC-63164, which are 0.5 mm/yr and 3.5 mm/yr for the design and post-design life periods, respectively.

Table 4-2 presents the Rock/Soil Zonation Card listing of the rock/soil numbering in the external zonation file ("wma_aax_postclosure_acm1_ccu_19_deg_tnk.zon") that includes the two representative degraded tanks that are now described as HSUs. The Mechanical Properties Card (Table 4-3) identifies the values applicable to the particle density, porosity, and specific storativity or compressibility, and identifies the tortuosity functions for the two representative degraded tank HSUs. The Hydraulic Properties Card (Table 4-4) identifies the saturated hydraulic conductivity values applicable to the two representative degraded tank HSUs. The Saturation Function Card (Table 4-5) identifies the functional model and associated parameters that relate the aqueous capillary pressure to aqueous saturation for the two representative degraded tank HSUs. The Directional Aqueous Relative Permeability Cards (Table 4-6) identify the functional model and associated parameters that relate the aqueous relative permeability to effective aqueous saturation for the two representative degraded tank HSUs.

Table 4-2. Hydrostratigraphic Distribution of the Finite Difference Cells in the Three-Dimensional Waste Management Area A-AX Flow and Transport Model Domain for Degraded Tanks Sensitivity Case.

Rock/Soil Identifying Number	Post-Closure Period
	zonation file unformatted, wma_aax_postclosure_acm1_ccu_19_deg_tnk.zon
	Hydrostratigraphic Unit
1	Basalt
2	Ringold A Aquifer
3	Ringold LM Aquifer
4	Ringold E Aquifer
5	Cold Creek Gravel Aquifer
6	Ringold A Vadose
7	Ringold LM Vadose
8	Ringold E Vadose
9	Cold Creek Gravel Vadose
10	Cold Creek Silt Vadose
11	H3 Gravelly Sand Vadose
12	H2 Sand
13	H1 Gravelly Sand
14	Eolian
15	A Farm Backfill
16	AX Farm Backfill
17	tank_a_102
18	tank_ax_101

H1 = Hanford formation unit 1 H2 = Hanford formation unit 2 H3 = Hanford formation unit 3

Table 4-3. Soil Hydraulic Properties Identified in the Mechanical Properties Card of the Three-Dimensional Waste Management Area A-AX Flow and Transport Model for Degraded Tanks.

Hydrostratigraphic Unit	Particle Density[a]	Particle Density Units[a]	Total Porosity[b]	Diffusive Porosity[b]	Specified Compressibility[c]	Compressibility[c]	Compressibility Units[c]	Tortuosity Function[d]
tank_a_102	2.71	g/cm^3	0.384E+00	0.384E+00	Pore	1.00E-07	1/Pa	Millington and Quirk
tank_ax_101	2.71	g/cm^3	0.384E+00	0.384E+00	Pore	1.00E-07	1/Pa	Millington and Quirk

[a]Particle density and particle density units are discussed and described in Section 3.1.4.5.2 of RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis.*

[b]Total and diffusive porosity are discussed and described in Section 3.1.4.3 of RPP-RPT-60101. Note that total and diffusive porosity are assumed to equal the effective saturated moisture content values (θ_s^e) identified in Table 3-2 of RPP-RPT-60101.

[c]Specified compressibility volume and values are discussed and described in Section 3.1.7 of RPP-RPT-60101.

[d]"Millington and Quirk" are input file keywords used to invoke the tortuosity function in Subsurface Transport Over Multiple Phases (STOMP, developed and distributed by Battelle Memorial Institute). The tortuosity function is discussed and described in Section 3.1.4.5.3 of RPP-RPT-60101.

Table 4-4. Soil Hydraulic Properties Identified in the Hydraulic Properties Card of the Three-Dimensional Waste Management Area A-AX Flow and Transport Model for Degraded Tanks.

Hydrostratigraphic Unit	X-Direction Hydraulic Conductivity	Hydraulic Conductivity units	Y-Direction Hydraulic Conductivity	Hydraulic Conductivity units	Z-Direction Hydraulic Conductivity	Hydraulic Conductivity units
tank_a_102	6.20E-03	cm/s	6.20E-03	cm/s	6.16E-03	cm/s
tank_ax_101	6.20E-03	cm/s	6.20E-03	cm/s	6.16E-03	cm/s

Source: Section 3.1.4.4 in RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis.*

Table 4-5. Soil Hydraulic Properties Identified in the Saturation Function Card of the Three-Dimensional Waste Management Area A-AX Flow and Transport Model for Degraded Tanks.

Hydrostratigraphic Unit	Saturation Function Option	van Genuchten α	van Genuchten α Units	van Genuchten n	Residual Saturation*
tank_a_102	Nonhysteretic van Genuchten	6.419E-02	1/cm	1.698E+00	7.552E-02
tank_ax_101	Nonhysteretic van Genuchten	6.419E-02	1/cm	1.698E+00	7.552E-02

*Residual saturation (S_r) is calculated by dividing the effective residual moisture content (θ_r^e) value by the effective saturated moisture content (θ_s^e) value found in Table 3-2 of RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*, i.e., $S_r = \theta_r^e/\theta_s^e$.

Source: Section 3.1.4.3 of RPP-RPT-60101.

Table 4-6. Soil Hydraulic Properties Identified in the Directional Aqueous Relative Permeability Card of the Three-Dimensional Waste Management Area A-AX Flow and Transport Model for Degraded Tanks.

Hydrostratigraphic Unit	Relative Permeability Model X and Y Directions	Pore Scale Parameter*	Relative Permeability Model Z Direction	Pore Scale Parameter*
tank_a_102	Modified Mualem	-0.683	Modified Mualem	0.375
tank_ax_101	Modified Mualem	-0.683	Modified Mualem	0.375

*The pore scale parameter is also known as the tortuosity-connectivity coefficient, and the STOMP default value of 0.5 is applied to all of the aquifer hydrostratigraphic units.

Source: Section 3.1.4.4 of RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*.

Subsurface Transport Over Multiple Phases (STOMP) is developed and distributed by Battelle Memorial Institute.

5.0 SUBSURFACE TRANSPORT OVER MULTIPLE PHASES SOFTWARE

The STOMP software is licensed by CH2M HILL Plateau Remediation Company (CHPRC) for use under the terms of a limited government license from Pacific Northwest National Laboratory (PNNL), which developed the code to meet American Society of Mechanical Engineers (ASME) NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications* and DOE O 414.1C, *Quality Assurance* software requirements. Specifically and currently, PNNL manages STOMP under a Configuration Management Plan [PNNL-SA-92584, *Subsurface Transport Over Multiple Phases (STOMP) Software Configuration Management Plan*] in conjunction with a Software Test Plan (PNNL-SA-92579, *STOMP Software Test Plan*) that detail the procedures used to test, document and archive modifications to the source code. PNNL maintains specific operational modes of STOMP as qualified Safety Software, Level C, per the DOE O 414.1D, *Quality Assurance* definition for safety software and ASME NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications* with NQA-1a-2009 addenda (PNNL-24118, *STOMP/eSTOMP Software Quality Assurance Plan*).

STOMP is used to solve the Richards' equation (the water mass conservation equation in PNNL-12030, *STOMP Subsurface Transport Over Multiple Phases Version 2.0 Theory Guide*) and the advection-dispersion equation (the solute mass conservation equation in PNNL-12030) that govern water flow and solute transport, respectively, under variably saturated conditions in the vadose zone and groundwater. STOMP (PNNL-11216, *STOMP Subsurface Transport Over Multiple Phases Application Guide*; PNNL-12030; PNNL-15782, *STOMP Subsurface Transport Over Multiple Phases Version 4.0 User's Guide*) was selected to simulate the transport of contaminants in the vadose zone of the 200 Area in and around WMA A-AX because STOMP fulfills the following specifications:

- The STOMP simulator operational modes needed for implementation of this model are available free for government use under a limited government-use agreement

- The STOMP simulator solves the necessary governing equations

- The STOMP simulator allows the process model to include the principal FEPs that are relevant (see Section 3.1)

- The STOMP simulator is well documented (PNNL-11216, PNNL-12030, PNNL-15782)

- The STOMP simulator development meets NQA-1-2008 with NQA-1a-2009 addenda software requirements and is compliant with DOE O 414.1D requirements for Safety Software (PNNL-SA-92579; PNNL-SA-92584; PNNL-24122, *Software Requirements Document for STOMP and eSTOMP*)

- The STOMP simulator is distributed with source code, enhancing transparency

- The modeling team implementing this model has expertise in use of this simulator

- There is an extensive history of application of STOMP at Hanford and elsewhere including verification, validation, and benchmarking (DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*)

- Use of STOMP is in keeping with DOE direction for simulation of vadose zone flow and transport at the Hanford Site (06-AMCP-0133, "Contract No. DE-AC06-05RL14655 – Hanford Groundwater Modeling Integration").

5.1 SUBSURFACE TRANSPORT OVER MULTIPLE PHASES SOFTWARE QUALITY ASSURANCE

The use of STOMP to implement the WMA A-AX PA model and perform calculations is performed in a manner that satisfies and complies with environmental quality assurance requirements indicated by Title 10, *Code of Federal Regulations* (CFR), Part 830, "Nuclear Safety Management" (10 CFR 830), Subpart A—Quality Assurance Requirements; DOE O 414.1D; and State and Federal environmental regulations. EM-QA-001, *EM Quality Assurance Program (QAP)*, Attachment G – "Software Quality Requirements" and Attachment H – "Model Development, Use, and Validation" list DOE management expectations for compliance, including configuration control, evaluation, implementation, verification and validation, and operation and maintenance.

Quality assurance project planning for STOMP modeling follows the guidance in EPA/240/R-02/007, *Guide for Quality Assurance Project Plans for Modeling*, EPA QA/G-5M. Model project planning includes documenting specific model development efforts and applications. It addresses as relevant and important all nine "Group A" elements presented in EPA/240/B-01/003, *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5. The nine elements include:

1. Project or task description and organization

2. List of the individuals and their organizations who are involved in the decision-making process

3. Identification of officials responsible for approving the project

4. Problem definition and background

5. Quality objectives and criteria for measurements and data acquisition leading to model inputs and outputs

6. Data validation and usability

7. References, documentation and records management

8. Special training requirements and certifications for modelers

9. Assessments and reports to management.

5.2 SUBSURFACE TRANSPORT OVER MULTIPLE PHASES CONTROLLED CALCULATION SOFTWARE

The following describes the STOMP controlled calculation software and its computational platform.

- Software Title: STOMP-W (a scientific tool for analyzing single- and multiple-phase subsurface flow and transport using the integrated finite volume discretization technique with Newton-Raphson iteration).

- Software Version: STOMP-W was provided by PNNL on January 30, 2013, and was tested and approved for use by CHPRC as "CHPRC Build 4." The specific executable file used for the calculations is stomp-w-cgst-chprc04l.x, which refers to the Conjugate Gradient Stabilized Solver.

- Hanford Information System Inventory Identification Number: 2471 (Safety Software S3, graded Level C).

- Computational Platform: <u>Tellus Subsurface Modeling Platform</u> (Tellus) hosted by Mission Support Alliance for CHPRC:

    - Server Chassis: Dell PowerEdge®[3] M1000e Blade Enclosure

    - Compute Nodes: 16 Dell PowerEdge® M610 Blade Servers

    - Intel Xeon® X5670 CPU (x2), 6 Cores/CPU, 2.93 GHz, 12MB Cache

    - 96 GB RAM; DDR3; 1,333 MHz

    - 10Gbps Ethernet Mezzanine Card – Dual Port – X520DA2 x 2

    - Storage: internal hard drives on management (frontend) server includes 4 SAMSUNG 830 Series MZ-7PC512D/AM 2.5" SATAIII MLC Internal Solid State Drives

    - Operating System and Version

        - Red Hat Enterprise Linux®[4] 5 (Tikanga), Release 5.8

[3] Dell® and PowerEdge® are registered trademarks of Dell Products, Inc.
[4] Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

        - Rocks Cluster/Ganglia open source software operating system

- Olive hosted by INTERA Incorporated for CHPRC

    - Server Chassis: Dell PowerEdge R530

        - Two Intel Xeon® E5-2680 v3 12-core processors @ 2.50GHz
        - 128 GB RAM; RDIMM, 2133 MT/s Dual Rank

    - Storage: 26 TB RAID-5 disk array

    - Operating System and Version

        - Linux 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86_64 x86_64 GNU/Linux.

- Approved Users: W. J. (Bill) McMahon and N. Hasan.

5.3 SOFTWARE INSTALLATION AND CHECKOUT

After receipt of the STOMP source code from PNNL, CHPRC commits the code to the MKS Integrity™[5] configuration management system that ensures traceability and precludes loss of information. Successful acceptance and installation includes confirming that the software is operating correctly by benchmarking results produced on the local computer system to those presented for selected problems from the STOMP Application Guide (PNNL-11216). The CHPRC software owner maintains the configuration-managed copies in MKS Integrity™ and grants access to the executable files to users upon request in accordance with the approved software installation and checkout forms.

Receipt of the current STOMP source code occurred January 2013, and testing of CHPRC Build 4 on Tellus successfully concluded April 2013. Approved users are registered in the Hanford Information System Inventory for safety software, which identifies W. J. (Bill) McMahon as an authorized user of STOMP on the Tellus Platform as of May 6, 2013. The software installation and checkout form for STOMP is provided in Attachment 1 to this EMCF.

5.4 STATEMENT OF VALID SOFTWARE APPLICATION

The WMA A-AX PA requires calculations of the potential long-term impact on groundwater of post-retrieval single-shell tank waste residuals and waste left in ancillary equipment, including pipelines. STOMP was developed for these type of applications, among others, and is used to solve the Richards equation and the Advection-Dispersion equation that govern water flow and solute transport, respectively, under variably saturated conditions in the vadose zone and

[5] MKS Integrity is a trademark of MKS, Incorporated.

groundwater. The WMA A-AX PA implementation of STOMP to perform calculations satisfies and complies with environmental quality assurance requirements indicated by 10 CFR 830 and Subpart A; DOE O 414.1D; and State and Federal environmental regulations. Successful acceptance and installation of STOMP on Tellus concluded in April 2013, and the Hanford Information System Inventory for safety software lists W. J. (Bill) McMahon as an authorized user of Build 4 of STOMP on the Tellus Platform.

The quality assurance project planning for STOMP modeling follows the guidance in EPA/240/R-02/007, and the conduct of implementation is shown to comply with DOE management expectations for compliance. Therefore, for this application STOMP is an appropriate software code to use, using it to implement the WMA A-AX PA model described in this report is consistent with STOMP's intended use, and its use is shown to comply with applicable quality assurance requirements.

CHPRC-00176, *STOMP Software Management Plan* requires that a "STOMP Options Analysis" be prepared and reported to identify all invoked options in a STOMP input file and the Nuclear Quality Assurance (NQA)-1 testing status of options reported by the software vendor, PNNL, to ensure that only NQA-1 qualified options of the STOMP code are used in a quality-affecting calculation. The STOMP Options Analysis for this EMCF is provided in Attachment 2, and indicates no unqualified options were used in this calculation.

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6.0 VADOSE ZONE FLOW SENSITIVITY AND UNCERTAINTY CASES RESULTS AND ANALYSIS

This model package focuses on the 3-D numerical flow sensitivity and uncertainty calculations. The 3-D process model sensitivity analysis consists of evaluating assumptions and parameters that change the aqueous flow results and providing those results to the system model to complete the analysis. The sensitivity and uncertainty evaluations of the radionuclides and their transport and impacts to groundwater occur within the system model.

6.1 NET INFILTRATION FLOW UNCERTAINTY RESULTS

The purpose of the net infiltration uncertainty cases is to develop a regression equation between recharge rate and flow field (Darcy velocity and volumetric moisture content). At long times when the flow rate is at steady state, and far from any subsurface obstruction, simple mass balance indicates that the Darcy flow rate in the vadose zone should equal the recharge rate. However, the presence of the tanks in the subsurface causes a diversion of flow, such that the representative flow rate below the tanks abstracted for the GoldSim©[6] model differs from the recharge rate. Furthermore, the amount of diversion that occurs is dependent on the anisotropy, which itself is dependent on the moisture content. The result is that at higher recharge rates that produce a higher moisture content, the Darcy flux under the tanks is somewhat higher than the recharge rate. At low recharge rates that produce a lower moisture content, the flux is somewhat lower than the recharge rate. As discussed in RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*, a linear relationship between both the vertical Darcy flux and the moisture content and the recharge rate is adequate to approximate these effects in the GoldSim© model. This linear relationship was developed as follows.

- Vertical Darcy flux and volumetric moisture content values were abstracted from STOMP model nodes that correspond to the GoldSim© 1-D discretization. This was done for Calendar Year 2300 (to represent the post-closure time period from Calendar Year 2020 to 2520 while the surface cover is intact), and at Calendar Year 5050 (to represent the late post-closure period beyond Calendar Year 2520 following surface barrier degradation).

- The extracted vertical Darcy flux and volumetric moisture content for layer 69 (representing the middle of the H2 unit) in the STOMP model were normalized by dividing by the values obtained from the base case recharge flow field.

- The normalization factors were evaluated by linear regression against recharge rate.

- These normalization factors are then multiplied by the base case Darcy flux and moisture content for any value of recharge rate to produce the corresponding vadose zone flow rate and moisture content in the representative GoldSim© column.

[6] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

The regression analyses for the early period in the analysis, when the surface barrier is intact, are presented in Figure 6-1 and Figure 6-2. The regression analyses for the later period in the analysis, when the surface barrier is degraded, are shown in Figure 6-3 and Figure 6-4. The flow field generated from the process flow model includes the spatial and temporal variability in imposed recharge rates that produces spatial and temporal variability in flow underneath the tanks.

6.2 TANK DEGRADATION FLOW SENSITIVITY RESULTS

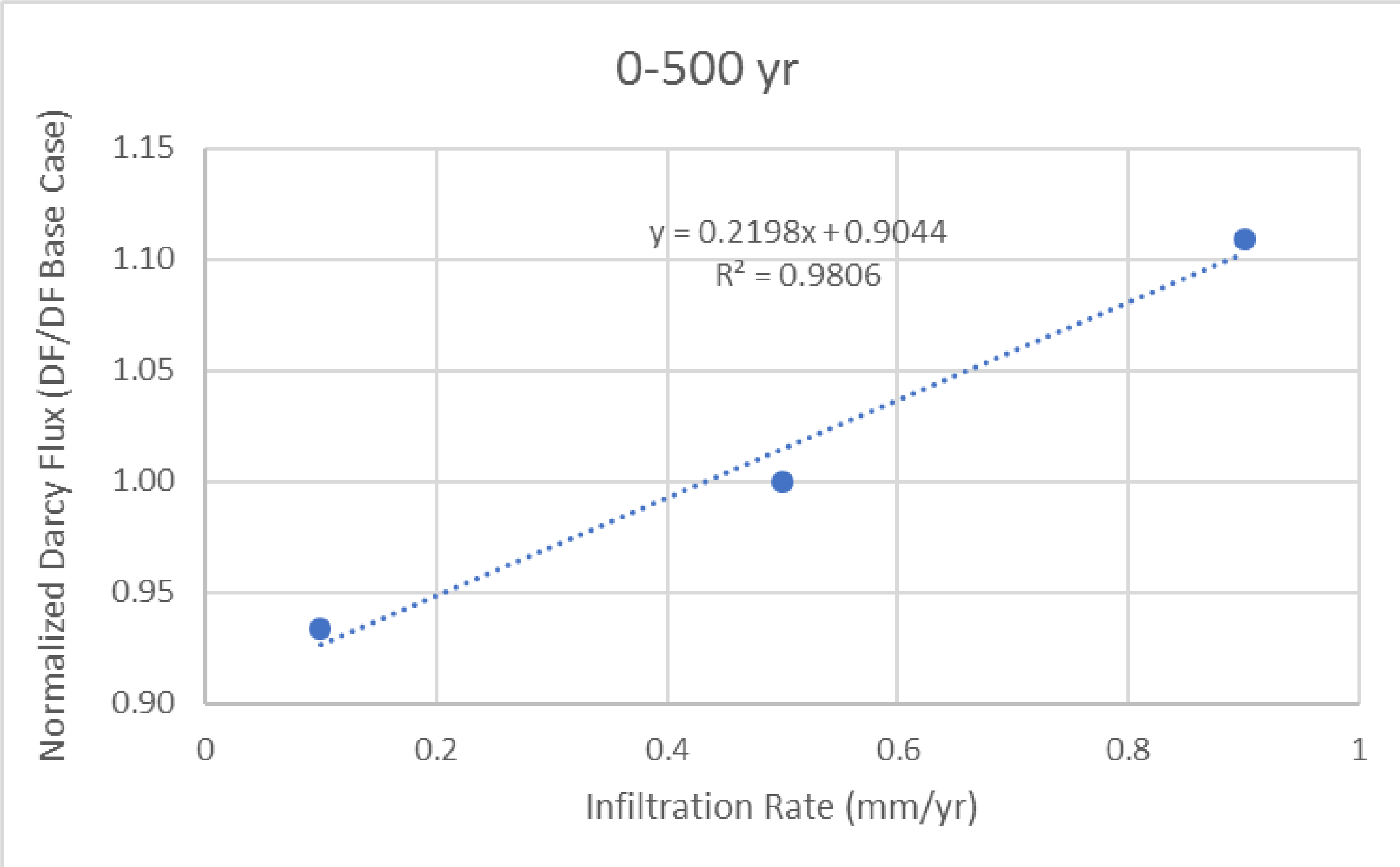
The infill grout material presents a relatively impermeable barrier to flow that diverts flow around the tank, as long as the grout is not physically degraded. If the infill grout material is assumed to degrade into sand material, then the tanks do not provide as effective a barrier to flow. Figures 6-5 and 6-6 present cross-sections through A Farm and AX Farm that display Darcy flux vectors and the moisture content, respectively, around the degraded tank and a neighboring intact tank in each farm.

As indicated in Figure 6-5, the vectors between tanks 241-AX-104 and 241-AX-101 include a slight horizontal component oriented toward tank 241-AX-101 associated with flow diversion around the intact tank 241-AX-104. At AX Farm, the assumed degraded infill material, approximated as H2 sand, is the same as the assumed properties for the backfill. Therefore, the flow through the degraded tank occurs as readily as it does through the backfill material. The vectors additionally acquire the slight horizontal component, and the flux under the degraded tank exceeds the flux near the bottom of the vadose zone, because of the water diverting around the intact neighboring tanks. The vectors under tank 241-AX-101 do not appear to exhibit a horizontal component (Figure 6-5). The lines of vectors between tanks 241-AX-101 and 241-AX-104 orient almost directly downward, which indicates that any flow diverted around tank 241-AX-104 does not affect the vectors under tank 241-AX-101.

By contrast to the behavior in the modeled AX Farm system, in A Farm there is some diversion to the flow. The reason for this is that the assumed degraded infill material, assigned properties for sand, is finer than the gravel tank farm backfill. The contrast between the properties of these two materials leads to preferential flow through the backfill material. The vectors under the right side of tank 241-A-102 do appear to exhibit a horizontal component, but that appears to be caused by the diversion around the tank itself (Figure 6-5). One of the lines of vectors between tanks 241-A-102 and 241-A-105 orients almost directly downward, which indicates that flow diverted around tank 241-A-105 does not appear to affect the vectors under tank 241-A-102.

The distribution of the moisture content displayed in Figure 6-6 indicates that the range of moisture content values in the two farms and adjoining HSUs only ranges from about 0.06 to 0.07. Flow diversion occurs above and under tank 241-AX-104 in the AX Farm results, with the diverted moisture entering the neighboring degraded tank 241-AX-101. Since the properties of tank 241-AX-101 have been assumed to be the same as the backfill material, there is no flow diversion, and the flow passes through the degraded tank.

Figure 6-1. Regression Equation for Ratio of Darcy Flux to the Base Case Darcy Flux as a Function of Recharge Rate: Intact Surface Barrier.



DF = Darcy Flux

Figure 6-2. Regression Equation for Ratio of Moisture Content to the Base Case Moisture Content as a Function of Recharge Rate: Intact Surface Barrier.

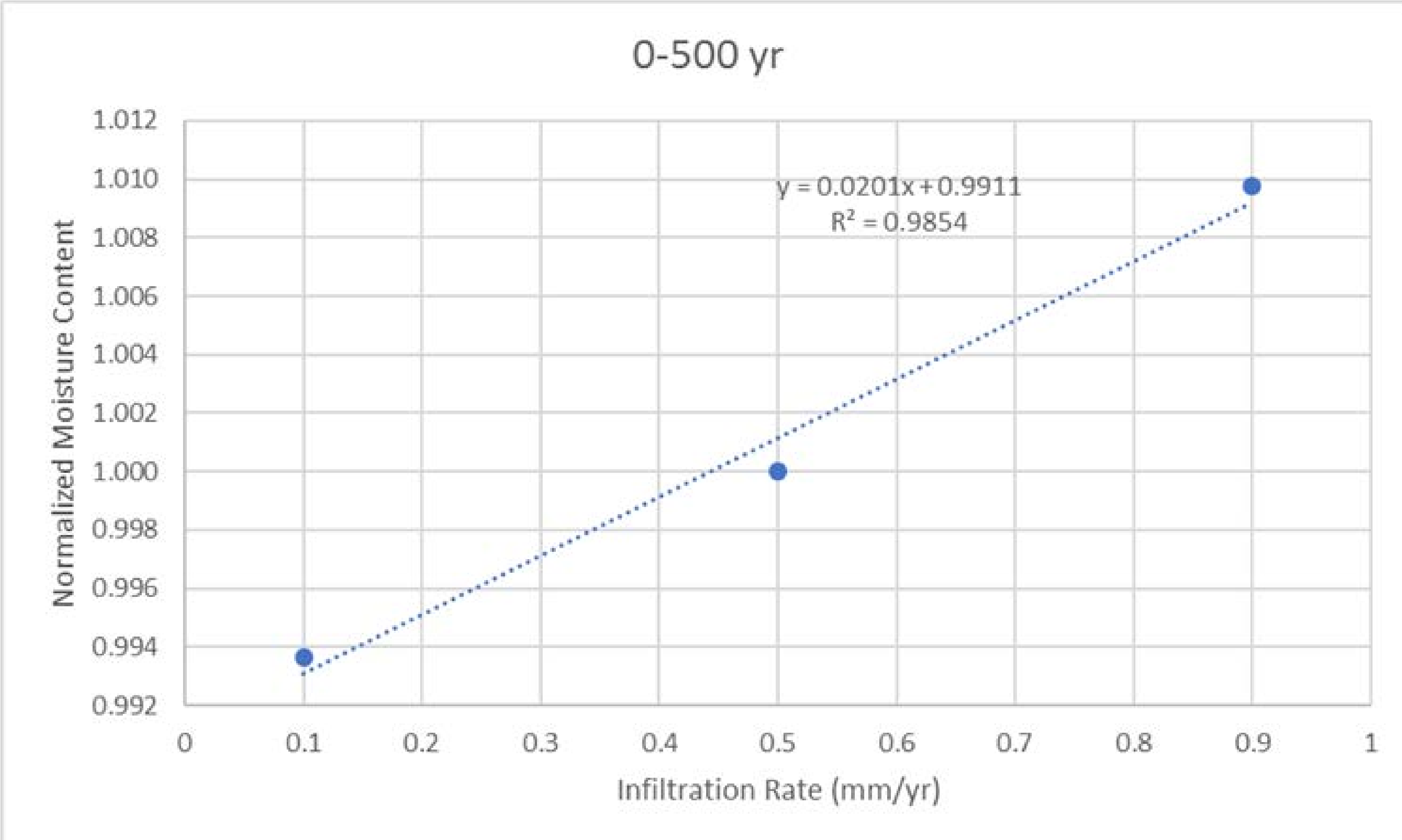
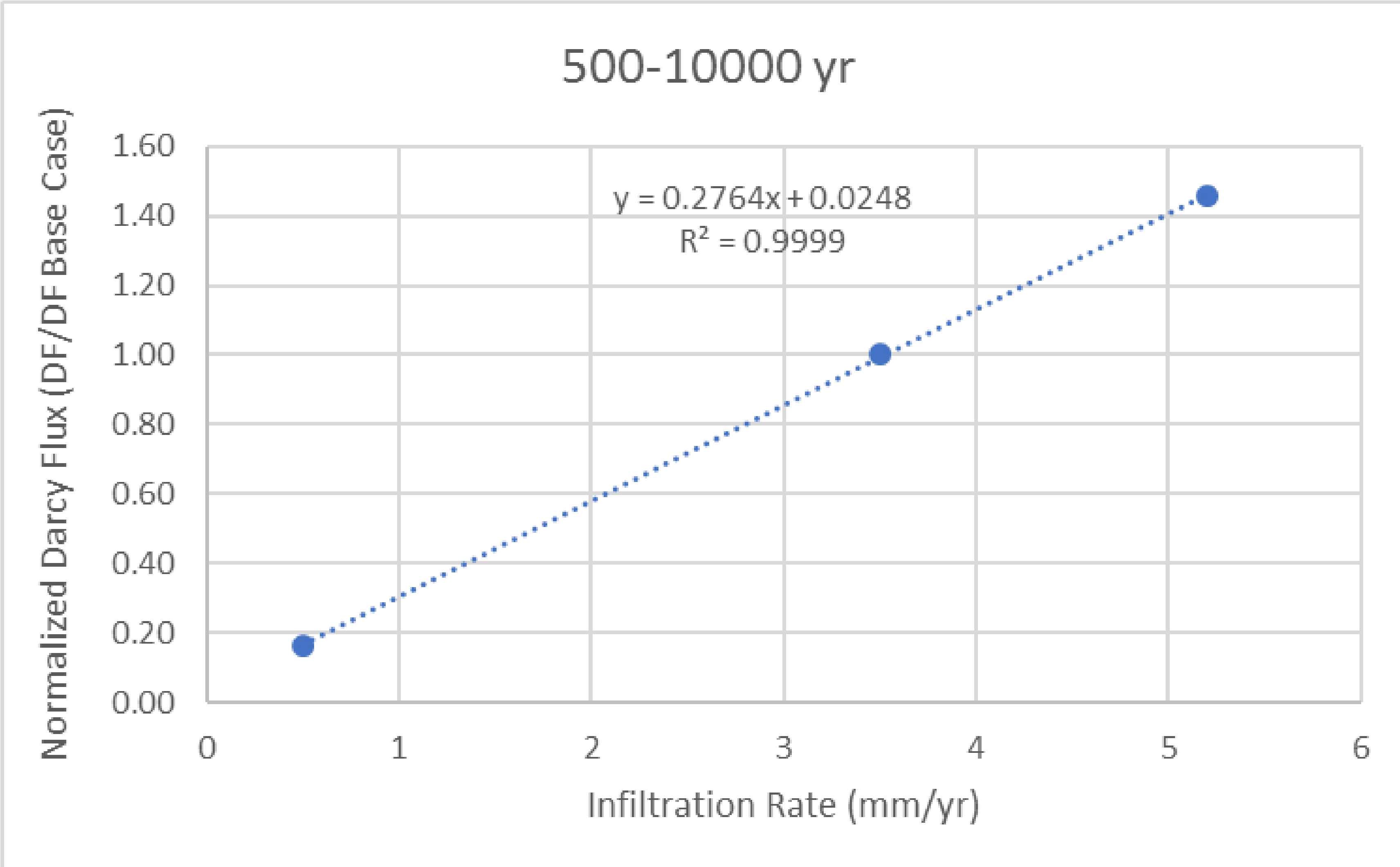


Figure 6-3. Regression Equation for Ratio of Darcy Flux to the Base Case Darcy Flux as a Functions of Recharge Rate: Degraded Surface Barrier.



DF = Darcy Flux

Figure 6-4. Regression Equation for Ratio of Moisture Content to the Base Case Moisture Content as a Function of Recharge Rate: Degraded Surface Barrier.

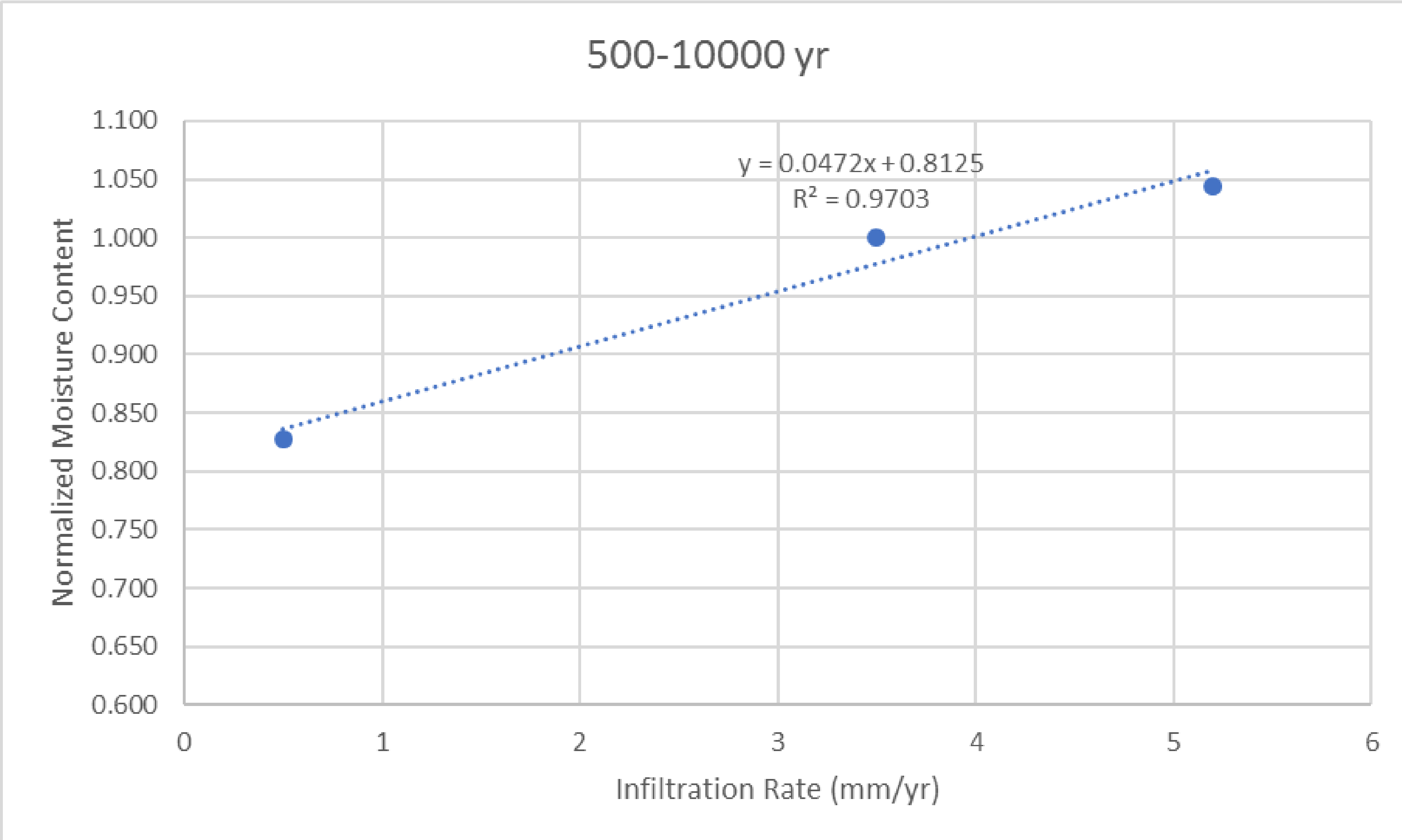
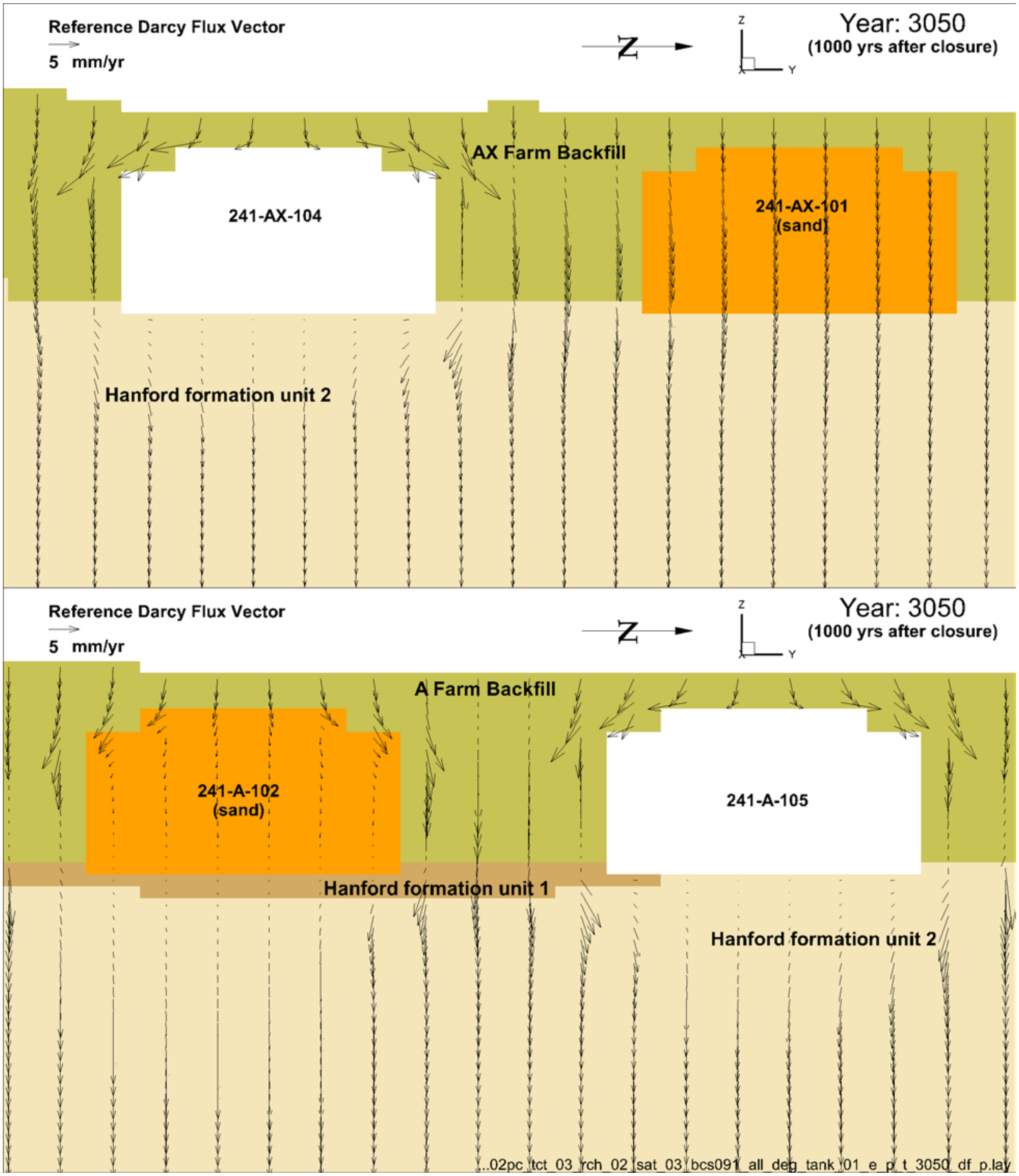
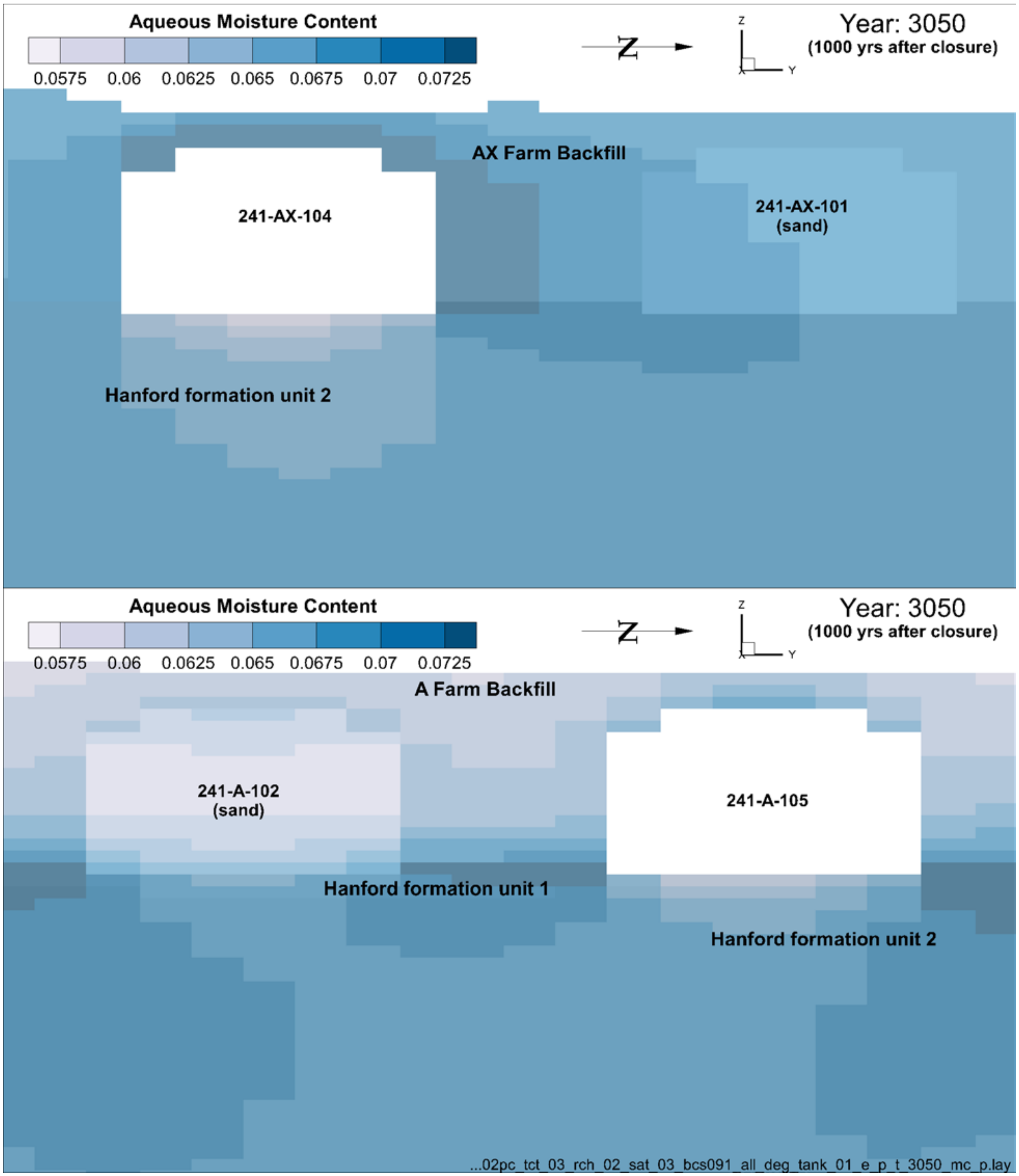


Figure 6-5. Darcy Flux Vectors Around the Representative Tanks with Degraded Fill Material and a Neighboring Extant Tank in the 241-AX and 241-A Tank Farms.



The distribution of the moisture content displayed in Figure 6-6 shows the flow diversion above and under both tanks in the A Farm results, although the effect is much less prominent for the tank with degraded properties. This occurs because the degraded tank grout material contrasts with the tank farm backfill and the Hanford formation unit 1 (H1) sand in A Farm. This contrast in the hydraulic property values causes lateral movement of water, such that flow remains preferentially in the backfill.

Figure 6-6. Moisture Content Around the Representative Tanks with Degraded Fill Material and a Neighboring Extant Tank in the 241-AX and 241-A Tank Farms.



Flow field abstraction for the degraded tank case was done using the same abstraction procedure for the base case flow field, as discussed in Section 4.3.1 of RPP-RPT-60885. The vertical Darcy flux and moisture content were extracted from the STOMP model simulation for each of the vertical layers corresponding to the system model discretization below tanks 241-A-102 and 241-AX-101. The flow field for all the planar nodes (I, J) under each tank were extracted from the STOMP model "plot" files, and the geometric mean of the values was calculated for each layer (K nodes). Table 6-1 through Table 6-4 presents the calculated flow field for the degraded tank flow sensitivity case.

Table 6-1. Moisture Contents (dimensionless) versus Time (years after closure) for the Degraded Tank Condition in 241-A Tank Farm. (2 sheets)

Time (years)	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	0.0854	0.2561	0.0951	0.1052	0.1056	0.1051	0.1049	0.1046
0.1	0.0854	0.2561	0.0951	0.1052	0.1056	0.1051	0.1049	0.1046
0.5	0.0854	0.2561	0.0951	0.1052	0.1056	0.1051	0.1049	0.1045
1	0.0854	0.2561	0.0951	0.1052	0.1056	0.1046	0.1042	0.1038
2	0.0854	0.2561	0.0951	0.1052	0.1056	0.1016	0.1009	0.1001
3	0.0854	0.2561	0.0951	0.1052	0.1055	0.0979	0.0971	0.0962
5	0.0854	0.2560	0.0950	0.1051	0.1042	0.0919	0.0910	0.0901
7	0.0853	0.2555	0.0948	0.1045	0.1016	0.0877	0.0869	0.0859
10	0.0848	0.2524	0.0937	0.1023	0.0976	0.0833	0.0825	0.0816
15	0.0833	0.2441	0.0911	0.0978	0.0922	0.0787	0.0779	0.0771
20	0.0819	0.2362	0.0887	0.0940	0.0884	0.0756	0.0749	0.0741
25	0.0808	0.2297	0.0866	0.0910	0.0855	0.0734	0.0728	0.0720
30	0.0800	0.2244	0.0849	0.0885	0.0832	0.0717	0.0711	0.0704
40	0.0789	0.2161	0.0822	0.0848	0.0798	0.0691	0.0686	0.0680
50	0.0781	0.2101	0.0801	0.0820	0.0772	0.0673	0.0668	0.0662
70	0.0772	0.2019	0.0770	0.0780	0.0737	0.0648	0.0644	0.0639
100	0.0766	0.1946	0.0739	0.0740	0.0702	0.0625	0.0622	0.0618
130	0.0762	0.1902	0.0717	0.0713	0.0678	0.0611	0.0608	0.0605
160	0.0760	0.1873	0.0701	0.0693	0.0661	0.0602	0.0600	0.0597
200	0.0758	0.1847	0.0685	0.0673	0.0643	0.0594	0.0593	0.0591
250	0.0757	0.1825	0.0670	0.0654	0.0627	0.0589	0.0588	0.0586
300	0.0756	0.1811	0.0658	0.0639	0.0615	0.0586	0.0585	0.0584
400	0.0755	0.1794	0.0642	0.0617	0.0599	0.0583	0.0583	0.0582
500	0.0755	0.1784	0.0631	0.0603	0.0589	0.0582	0.0582	0.0581
500.5	0.0755	0.1784	0.0631	0.0603	0.0589	0.0582	0.0582	0.0581

Table 6-1. Moisture Contents (dimensionless) versus Time (years after closure) for the Degraded Tank Condition in 241-A Tank Farm. (2 sheets)

Time (years)	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
501	0.0755	0.1784	0.0631	0.0602	0.0589	0.0582	0.0582	0.0581
502	0.0755	0.1783	0.0631	0.0602	0.0589	0.0582	0.0582	0.0581
503	0.0755	0.1783	0.0631	0.0602	0.0588	0.0582	0.0582	0.0581
505	0.0755	0.1783	0.0631	0.0602	0.0588	0.0582	0.0582	0.0581
507	0.0755	0.1783	0.0630	0.0602	0.0588	0.0582	0.0582	0.0581
510	0.0755	0.1783	0.0630	0.0601	0.0588	0.0582	0.0582	0.0581
515	0.0755	0.1782	0.0630	0.0601	0.0588	0.0582	0.0582	0.0582
520	0.0755	0.1782	0.0629	0.0600	0.0587	0.0583	0.0584	0.0584
525	0.0755	0.1782	0.0629	0.0600	0.0587	0.0585	0.0587	0.0590
530	0.0754	0.1781	0.0628	0.0599	0.0587	0.0590	0.0595	0.0599
540	0.0754	0.1781	0.0628	0.0598	0.0586	0.0610	0.0618	0.0624
550	0.0754	0.1780	0.0627	0.0597	0.0585	0.0637	0.0644	0.0649
570	0.0754	0.1779	0.0625	0.0595	0.0584	0.0677	0.0679	0.0678
600	0.0754	0.1777	0.0623	0.0592	0.0583	0.0695	0.0694	0.0691
630	0.0754	0.1776	0.0622	0.0590	0.0583	0.0699	0.0697	0.0694
660	0.0754	0.1775	0.0620	0.0588	0.0605	0.0699	0.0697	0.0694
700	0.0754	0.1774	0.0618	0.0585	0.0681	0.0699	0.0697	0.0694
800	0.0756	0.1819	0.0677	0.0682	0.0698	0.0699	0.0697	0.0694
900	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
1,000	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
1,200	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
1,400	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
1,600	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
1,800	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
2,000	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
2,200	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
2,400	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
2,600	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
2,800	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
3,000	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694
10,000	0.0759	0.1862	0.0698	0.0695	0.0698	0.0699	0.0697	0.0694

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Table 6-2. Darcy Velocities (millimeters per year) versus Time (years after closure) for the Degraded Tank Condition in 241-A Tank Farm. (2 sheets)

Time (years)	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	102.6181	102.4126	103.8248	104.7201	107.5327	102.8177	100.6020	97.4752
0.1	102.6181	102.4126	103.8248	104.7201	107.5327	102.8177	100.6020	97.4752
0.5	102.6176	102.4125	103.8248	104.7201	107.5327	102.5949	100.2583	96.9709
1	102.6179	102.4125	103.8248	104.7201	107.5327	98.3963	95.1819	91.0051
2	102.6181	102.4125	103.8248	104.7201	107.5049	77.7671	73.3706	68.2279
3	102.6179	102.4120	103.8237	104.7168	106.7962	58.2580	54.1562	49.5166
5	102.5253	102.2095	103.5185	104.1406	97.0978	35.5615	32.6507	29.3840
7	101.1247	99.8975	100.4979	99.7682	80.3528	24.5079	22.3893	19.9895
10	92.5752	88.9650	87.9575	85.0837	58.9610	16.2079	14.7548	13.0799
15	70.7918	65.9357	63.9958	60.6115	38.3028	10.0571	9.1361	8.0471
20	53.6951	49.4292	47.6096	44.7972	27.5217	7.1770	6.5184	5.7230
25	42.1609	38.6528	37.0938	34.8230	21.1590	5.5400	5.0349	4.4139
30	34.2446	31.3593	30.0329	28.1725	17.0326	4.4965	4.0910	3.5846
40	24.3082	22.2949	21.3101	19.9860	12.0398	3.2480	2.9635	2.5983
50	18.4860	17.0132	16.2514	15.2489	9.1837	2.5401	2.3254	2.0427
70	12.1380	11.2600	10.7601	10.1123	6.1069	1.7857	1.6465	1.4543
100	7.7298	7.2486	6.9404	6.5404	3.9770	1.2765	1.1896	1.0602
130	5.5423	5.2423	5.0305	4.7536	2.9144	1.0348	0.9737	0.8750
160	4.2634	4.0600	3.9039	3.6987	2.2887	0.9021	0.8558	0.7744
200	3.2220	3.0896	2.9778	2.8308	1.7762	0.8038	0.7690	0.7009
250	2.4418	2.3566	2.2767	2.1732	1.3915	0.7409	0.7140	0.6546
300	1.9526	1.8934	1.8328	1.7567	1.1519	0.7092	0.6866	0.6317
400	1.3848	1.3520	1.3128	1.2687	0.8823	0.6834	0.6645	0.6134
500	1.0772	1.0567	1.0287	1.0031	0.7488	0.6757	0.6580	0.6081
500.5	1.0760	1.0555	1.0276	1.0020	0.7483	0.6757	0.6579	0.6081
501	1.0749	1.0544	1.0265	1.0010	0.7478	0.6756	0.6579	0.6081
502	1.0726	1.0522	1.0244	0.9991	0.7469	0.6756	0.6579	0.6080
503	1.0703	1.0500	1.0223	0.9971	0.7460	0.6756	0.6579	0.6080
505	1.0657	1.0456	1.0180	0.9931	0.7441	0.6755	0.6578	0.6080
507	1.0612	1.0413	1.0139	0.9892	0.7423	0.6754	0.6578	0.6081

Table 6-2. Darcy Velocities (millimeters per year) versus Time (years after closure) for the Degraded Tank Condition in 241-A Tank Farm. (2 sheets)

Time (years)	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
510	1.0545	1.0348	1.0077	0.9835	0.7397	0.6757	0.6587	0.6101
515	1.0436	1.0243	0.9976	0.9741	0.7354	0.6808	0.6693	0.6282
520	1.0330	1.0141	0.9877	0.9649	0.7312	0.7045	0.7089	0.6838
525	1.0227	1.0041	0.9781	0.9560	0.7272	0.7674	0.8000	0.7946
530	1.0126	0.9944	0.9688	0.9473	0.7233	0.8915	0.9595	0.9675
540	0.9932	0.9757	0.9508	0.9306	0.7160	1.3592	1.4736	1.4568
550	0.9747	0.9579	0.9337	0.9147	0.7091	2.0223	2.1015	1.9972
570	0.9404	0.9248	0.9018	0.8853	0.6968	3.1215	3.0484	2.7875
600	0.8948	0.8809	0.8596	0.8463	0.6818	3.7259	3.5595	3.2233
630	0.8554	0.8429	0.8231	0.8128	0.6943	3.8360	3.6516	3.3013
660	0.8214	0.8100	0.7915	0.7841	1.2436	3.8521	3.6648	3.3123
700	0.7831	0.7732	0.7563	0.7540	3.3917	3.8545	3.6668	3.3139
800	2.0920	2.4574	2.7816	3.4415	3.9375	3.8546	3.6669	3.3141
900	3.7582	3.7532	3.7501	3.8458	3.9386	3.8546	3.6669	3.3141
1,000	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
1,200	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
1,400	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
1,600	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
1,800	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
2,000	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
2,200	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
2,400	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
2,600	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
2,800	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
3,000	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141
10,000	3.7641	3.7568	3.7522	3.8466	3.9386	3.8546	3.6669	3.3141

Table 6-3. Moisture Contents (dimensionless) versus Time (years after closure) for the Degraded Tank Grout in 241-AX Tank Farm. (1 of 2 sheets)

Time (years)	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
0	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1059	0.1061	0.1062	0.1063	0.1063	0.1063	0.1063	0.1062
0.1	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1059	0.1061	0.1062	0.1063	0.1063	0.1063	0.1063	0.1062
0.5	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1059	0.1061	0.1062	0.1063	0.1063	0.1063	0.1063	0.1062
1	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1059	0.1061	0.1062	0.1062	0.1062	0.1062	0.1061	0.1061
2	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1058	0.1056	0.1054	0.1050	0.1048	0.1046	0.1042	0.1038
3	0.0871	0.2588	0.0831	0.0895	0.0978	0.1053	0.1047	0.1037	0.1031	0.1024	0.1020	0.1015	0.1010	0.1004
5	0.0871	0.2588	0.0830	0.0894	0.0977	0.1045	0.1006	0.0987	0.0978	0.0968	0.0963	0.0957	0.0951	0.0945
7	0.0870	0.2583	0.0828	0.0889	0.0970	0.1025	0.0966	0.0945	0.0935	0.0925	0.0920	0.0914	0.0908	0.0902
10	0.0866	0.2558	0.0816	0.0871	0.0946	0.0988	0.0919	0.0897	0.0888	0.0878	0.0873	0.0868	0.0863	0.0857
15	0.0853	0.2485	0.0790	0.0833	0.0899	0.0934	0.0865	0.0844	0.0836	0.0827	0.0822	0.0817	0.0813	0.0808
20	0.0841	0.2417	0.0766	0.0802	0.0861	0.0895	0.0828	0.0809	0.0801	0.0792	0.0788	0.0784	0.0779	0.0775
25	0.0833	0.2362	0.0748	0.0777	0.0830	0.0865	0.0801	0.0782	0.0775	0.0767	0.0763	0.0759	0.0755	0.0751
30	0.0826	0.2319	0.0733	0.0756	0.0805	0.0842	0.0779	0.0762	0.0754	0.0747	0.0743	0.0739	0.0736	0.0732
40	0.0818	0.2257	0.0710	0.0725	0.0768	0.0806	0.0747	0.0731	0.0724	0.0717	0.0714	0.0710	0.0707	0.0703
50	0.0812	0.2214	0.0692	0.0702	0.0740	0.0780	0.0724	0.0708	0.0702	0.0695	0.0692	0.0689	0.0686	0.0683
70	0.0806	0.2161	0.0668	0.0669	0.0701	0.0744	0.0692	0.0677	0.0671	0.0665	0.0663	0.0660	0.0657	0.0655
100	0.0801	0.2118	0.0645	0.0637	0.0663	0.0709	0.0661	0.0647	0.0642	0.0637	0.0635	0.0632	0.0630	0.0628
130	0.0799	0.2093	0.0629	0.0615	0.0637	0.0685	0.0639	0.0627	0.0623	0.0618	0.0616	0.0614	0.0613	0.0611
160	0.0797	0.2078	0.0617	0.0598	0.0617	0.0666	0.0624	0.0613	0.0609	0.0605	0.0603	0.0602	0.0600	0.0599
200	0.0796	0.2064	0.0604	0.0581	0.0597	0.0647	0.0609	0.0599	0.0596	0.0593	0.0592	0.0591	0.0590	0.0589
250	0.0795	0.2053	0.0593	0.0565	0.0578	0.0630	0.0596	0.0588	0.0585	0.0583	0.0583	0.0582	0.0582	0.0582
300	0.0794	0.2046	0.0584	0.0553	0.0564	0.0617	0.0587	0.0581	0.0579	0.0578	0.0577	0.0577	0.0578	0.0578
400	0.0794	0.2039	0.0573	0.0537	0.0546	0.0601	0.0578	0.0574	0.0573	0.0573	0.0573	0.0573	0.0574	0.0575
500	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0575	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
500.5	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0575	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
501	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0575	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
502	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0575	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
503	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
505	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
507	0.0793	0.2035	0.0566	0.0528	0.0535	0.0592	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574

Table 6-3. Moisture Contents (dimensionless) versus Time (years after closure) for the Degraded Tank Grout in 241-AX Tank Farm. (2 of 2 sheets)

Time (years)	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
510	0.0793	0.2034	0.0566	0.0527	0.0534	0.0592	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
515	0.0793	0.2034	0.0565	0.0527	0.0534	0.0591	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
520	0.0793	0.2034	0.0565	0.0527	0.0534	0.0591	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
525	0.0793	0.2034	0.0565	0.0526	0.0533	0.0591	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
530	0.0793	0.2034	0.0565	0.0526	0.0533	0.0591	0.0574	0.0572	0.0571	0.0571	0.0572	0.0572	0.0573	0.0574
540	0.0793	0.2034	0.0564	0.0526	0.0532	0.0590	0.0574	0.0572	0.0571	0.0572	0.0572	0.0574	0.0575	0.0578
550	0.0793	0.2034	0.0564	0.0525	0.0531	0.0590	0.0574	0.0572	0.0572	0.0574	0.0577	0.0581	0.0587	0.0595
570	0.0793	0.2033	0.0563	0.0524	0.0530	0.0589	0.0574	0.0579	0.0590	0.0610	0.0623	0.0637	0.0650	0.0661
600	0.0793	0.2033	0.0562	0.0523	0.0529	0.0588	0.0600	0.0652	0.0670	0.0682	0.0687	0.0691	0.0695	0.0698
630	0.0793	0.2032	0.0561	0.0521	0.0527	0.0587	0.0667	0.0688	0.0692	0.0695	0.0697	0.0698	0.0700	0.0701
660	0.0793	0.2032	0.0561	0.0520	0.0526	0.0591	0.0687	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
700	0.0793	0.2031	0.0560	0.0520	0.0526	0.0640	0.0690	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
800	0.0795	0.2052	0.0600	0.0587	0.0607	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
900	0.0796	0.2066	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
1,000	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
1,200	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
1,400	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
1,600	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
1,800	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
2,000	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
2,200	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
2,400	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
2,600	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
2,800	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
3,000	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702
10,000	0.0796	0.2067	0.0610	0.0593	0.0613	0.0687	0.0691	0.0693	0.0695	0.0697	0.0698	0.0699	0.0700	0.0702

Table 6-4. Darcy Velocities (millimeters per year) versus Time (years after closure) for the Degraded Tank Grout of 241-AX Tank Farm. (1 of 2 sheets)

Time (years)	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
0	102.6966	102.2017	102.8496	103.0401	103.2019	105.7000	110.5905	111.9893	112.4895	112.8327	112.8858	112.8076	112.5364	111.9666
0.1	102.6966	102.2017	102.8496	103.0401	103.2019	105.7000	110.5905	111.9893	112.4895	112.8327	112.8858	112.8076	112.5364	111.9666
0.5	102.6945	102.2013	102.8496	103.0401	103.2019	105.7000	110.5905	111.9891	112.4889	112.8306	112.8819	112.8002	112.5229	111.9418
1	102.6955	102.2014	102.8496	103.0401	103.2019	105.7000	110.5784	111.8925	112.2785	112.3890	112.2513	111.9085	111.2739	110.2098
2	102.6963	102.2016	102.8496	103.0400	103.2018	105.6953	108.8077	106.8741	105.0348	102.2747	100.4603	98.2932	95.7089	92.6089
3	102.6964	102.2014	102.8478	103.0351	103.1957	105.4747	100.1337	92.6682	88.5488	83.7244	81.0260	78.1118	74.9457	71.4626
5	102.6162	102.0585	102.4434	102.3038	102.3684	99.8018	73.9802	63.6428	59.1962	54.6078	52.2568	49.8536	47.3708	44.7553
7	101.3242	100.1869	98.8673	97.2763	96.9829	85.9330	54.2106	45.4380	41.9097	38.3931	36.6362	34.8693	33.0697	31.1917
10	93.0332	90.2581	85.4030	81.7334	81.0146	64.6904	36.8090	30.4499	27.9781	25.5616	24.3729	23.1901	21.9965	20.7552
15	71.1952	67.6118	61.3788	57.2870	56.5432	42.3427	22.8420	18.7847	17.2387	15.7472	15.0226	14.3086	13.5945	12.8529
20	53.8477	50.8093	45.4530	41.9395	41.3418	30.3592	16.0859	13.2070	12.1209	11.0813	10.5803	10.0901	9.6033	9.0986
25	42.1422	39.7318	35.3484	32.3872	31.9113	23.2551	12.2131	10.0212	9.2001	8.4191	8.0452	7.6816	7.3229	6.9518
30	34.1414	32.2242	28.6067	26.0748	25.6874	18.6546	9.7434	7.9925	7.3405	6.7237	6.4302	6.1463	5.8681	5.5809
40	24.1743	22.9132	20.3338	18.3871	18.1133	13.1215	6.8055	5.5810	5.1296	4.7069	4.5079	4.3175	4.1332	3.9441
50	18.4132	17.5314	15.5807	14.0030	13.7962	9.9927	5.1582	4.2294	3.8902	3.5753	3.4287	3.2898	3.1570	3.0217
70	12.2395	11.7402	10.4766	9.3301	9.1965	6.6711	3.4213	2.8058	2.5845	2.3828	2.2908	2.2054	2.1259	2.0462
100	7.9597	7.6918	6.9052	6.0922	6.0087	4.3689	2.2336	1.8376	1.6986	1.5754	1.5212	1.4725	1.4292	1.3873
130	5.7644	5.5983	5.0520	4.4258	4.3663	3.1835	1.6369	1.3571	1.2616	1.1798	1.1453	1.1159	1.0915	1.0691
160	4.4407	4.3288	3.9238	3.4176	3.3721	2.4692	1.2876	1.0801	1.0116	0.9555	0.9334	0.9159	0.9032	0.8926
200	3.3464	3.2740	2.9830	2.5826	2.5486	1.8824	1.0109	0.8650	0.8196	0.7855	0.7739	0.7666	0.7637	0.7630
250	2.5284	2.4818	2.2739	1.9585	1.9336	1.4502	0.8180	0.7197	0.6923	0.6751	0.6716	0.6720	0.6765	0.6831
300	2.0258	1.9931	1.8353	1.5762	1.5574	1.1911	0.7108	0.6427	0.6263	0.6197	0.6210	0.6260	0.6349	0.6457
400	1.4710	1.4516	1.3479	1.1566	1.1458	0.9174	0.6124	0.5772	0.5726	0.5764	0.5825	0.5919	0.6048	0.6192
500	1.1957	1.1818	1.1049	0.9508	0.9448	0.7928	0.5783	0.5573	0.5572	0.5648	0.5725	0.5834	0.5975	0.6130
500.5	1.1947	1.1809	1.1040	0.9501	0.9441	0.7924	0.5782	0.5573	0.5572	0.5648	0.5725	0.5834	0.5975	0.6130
501	1.1937	1.1799	1.1031	0.9493	0.9434	0.7920	0.5781	0.5572	0.5571	0.5648	0.5725	0.5833	0.5975	0.6130
502	1.1917	1.1780	1.1014	0.9479	0.9419	0.7911	0.5779	0.5571	0.5570	0.5647	0.5724	0.5833	0.5974	0.6129
503	1.1898	1.1760	1.0997	0.9464	0.9405	0.7903	0.5778	0.5570	0.5570	0.5647	0.5724	0.5833	0.5974	0.6129
505	1.1859	1.1722	1.0962	0.9436	0.9377	0.7887	0.5774	0.5568	0.5568	0.5646	0.5723	0.5832	0.5973	0.6129
507	1.1821	1.1685	1.0929	0.9407	0.9350	0.7870	0.5770	0.5566	0.5567	0.5645	0.5722	0.5831	0.5973	0.6128

Table 6-4. Darcy Velocities (millimeters per year) versus Time (years after closure) for the Degraded Tank Grout of 241-AX Tank Farm. (2 of 2 sheets)

Time (years)	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
510	1.1764	1.1629	1.0879	0.9366	0.9309	0.7847	0.5765	0.5563	0.5565	0.5643	0.5721	0.5830	0.5972	0.6127
515	1.1673	1.1539	1.0798	0.9298	0.9243	0.7809	0.5757	0.5559	0.5561	0.5641	0.5719	0.5828	0.5971	0.6127
520	1.1584	1.1452	1.0719	0.9232	0.9179	0.7772	0.5749	0.5555	0.5558	0.5639	0.5717	0.5828	0.5971	0.6130
525	1.1497	1.1368	1.0643	0.9169	0.9118	0.7736	0.5741	0.5551	0.5556	0.5638	0.5719	0.5833	0.5984	0.6157
530	1.1414	1.1285	1.0569	0.9107	0.9058	0.7702	0.5735	0.5548	0.5555	0.5644	0.5732	0.5861	0.6039	0.6262
540	1.1254	1.1128	1.0429	0.8990	0.8944	0.7638	0.5722	0.5550	0.5580	0.5742	0.5915	0.6195	0.6637	0.7300
550	1.1103	1.0981	1.0296	0.8879	0.8836	0.7578	0.5715	0.5611	0.5780	0.6360	0.6977	0.7966	0.9467	1.1562
570	1.0827	1.0710	1.0053	0.8678	0.8641	0.7472	0.5846	0.7386	1.0207	1.5538	1.9036	2.2811	2.6580	3.0031
600	1.0469	1.0358	0.9739	0.8419	0.8391	0.7343	1.1948	2.6134	3.1374	3.5436	3.7088	3.8543	3.9812	4.0812
630	1.0169	1.0064	0.9478	0.8206	0.8185	0.7298	2.9600	3.5935	3.7543	3.9012	3.9750	4.0503	4.1243	4.1850
660	0.9921	0.9821	0.9265	0.8039	0.8027	0.8093	3.5071	3.7313	3.8275	3.9386	4.0014	4.0688	4.1373	4.1940
700	0.9709	0.9617	0.9141	0.8075	0.8133	2.0475	3.5899	3.7483	3.8360	3.9428	4.0043	4.0708	4.1386	4.1949
800	2.3829	2.4694	2.9508	3.0579	3.1083	3.3855	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
900	3.5278	3.5096	3.4704	3.2630	3.2739	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
1,000	3.5316	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
1,200	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
1,400	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
1,600	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
1,800	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
2,000	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
2,200	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
2,400	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
2,600	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
2,800	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
3,000	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949
10,000	3.5317	3.5128	3.4716	3.2634	3.2742	3.3885	3.5953	3.7494	3.8365	3.9430	4.0045	4.0709	4.1387	4.1949

7.0 MODEL CONFIGURATION MANAGEMENT

All inputs and outputs for the development of WMA A-AX PA models are submitted to the CHPRC Environmental Model Management Archive (EMMA) to maintain and preserve models, input and output files under configuration management. Inputs include the input files used in the STOMP simulations and the auxiliary files called by the input files such as the zonation and boundary node list files. Basis information (that information collected to form the basis for model input parameterization) is also stored in the EMMA for traceability purposes. Use of the STOMP software for implementing the model described in this report is consistent with its intended use for CHPRC, as indicated in Section 5.4 "Statement of Valid Software Application."

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APPENDIX A

SELECTION OF TECHNICAL STAFF

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APPENDIX A
SELECTION OF TECHNICAL STAFF

The following staff performed the identified functions on the basis of their expertise and experience.

A.1 Project Management

Robert A. Hiergesell, Senior Scientist, Washington River Protection Solutions, LCC (WRPS).

M.S., Hydrogeology, University of Nebraska-Lincoln
B.S., Geology, Virginia Polytechnic Institute

Mr. Hiergesell has over 30 years of experience is in the areas of subsurface flow and transport simulation, groundwater monitoring, environmental remediation and performance assessment for low-level radioactive waste disposal. Prior to joining WRPS, Mr. Hiergesell was employed at the U.S. Department of Energy Savannah River National Laboratory where he was the lead technical investigator for numerous environmental restoration and waste management projects.

A.2 Originators

William J. McMahon, Senior Engineer, CH2M HILL Plateau Remediation Company (CHPRC).

M.S., Agricultural Engineering, Texas A&M University
B.S., Agricultural Engineering, University of California, Davis

Mr. McMahon specializes in hydrologic data collection, analysis, and interpretation, and groundwater and vadose zone numerical modeling to support groundwater and vadose remedial projects. He has experience with a number of vadose zone and groundwater modeling packages. Mr. McMahon has been one of the principal investigators in several performance assessments, focusing on the vadose and saturated flow and transport modeling using STOMP and eSTOMP[7] code, groundwater pathway compliance calculations, sensitivity analysis, and document preparation. His other duties include directing hydrologic data collection efforts, analyzing and interpreting hydrologic data, assessing the effectiveness of groundwater remedial actions, developing work plans for data collection and interpretation, and performing numerical modeling to predict facility impacts to the aquifer to support remediation and construction decisions.

Nazmul Hassan, Hydrologist, Professional Engineer, INTERA, Inc.

M.S., Environmental Engineering, Washington State University
B.S., Civil Engineering, Bangladesh University of Engineering & Technology

[7] Subsurface Transport Over Multiple Phases (STOMP) and extreme scale Subsurface Transport Over Multiple Phases (eSTOMP) are developed and distributed by Battelle Memorial Institute.

Mr. Hasan is a hydrologist with 11 years of experience in numerical modeling of groundwater in the saturated and unsaturated zones, model calibration, groundwater management, geostatistics analysis, and programming in and application of multiple languages and codes including FORTRAN, MODFLOW[8], MT3DMS[9], MODPATH[10], PEST[11], STOMP, ArcGIS[12], GoldSim©[13], Groundwater Vistas[14], RETC[15], R[16], and TecPlot®[17].

A.3 Checkers

Amena Mayenna, Environmental Scientist, Professional Engineer, INTERA, Inc.

M.S., Environmental Engineering, Washington State University
B.S., Civil Engineering, Bangladesh University of Engineering & Technology

Ms. Mayenna has 11 years of experience in numerical modeling of groundwater in the vadose and saturated zones, model calibration, groundwater management, and geostatistics analysis. She is an experienced programmer and has applied multiple languages and modeling codes including Fortran, MODFLOW, MT3D, MODPATH, PEST, Groundwater Vistas, STOMP, ArcGIS, and Leapfrog® Hydro[18].

A.4 Senior Reviewers

Matthew W. Kozak, Principal Scientist, INTERA, Inc.

Ph.D., Chemical Engineering, University of Washington
B.S., Chemical Engineering, Cleveland State University

Dr. Kozak has more than 30 years of experience in the areas of performance assessment of near-surface and geological radioactive waste repositories, regulatory development, dose assessment for residual contamination of soils and buildings, toxic materials risk assessment, and

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[8] MODFLOW software has been developed and distributed by the U.S. Geological Survey, Washington, D.C.

[9] MT3DMS© model software is copyrighted by The University of Alabama, Tuscaloosa, Alabama.

[10] MODPATH software has been developed and distributed by the U.S. Geological Survey, Washington, D.C.

[11] PEST (Parameter ESTimation) is an open-source, freely-available software tool currently distributed by S. S. Papadopoulos & Associates, Inc., Bethesda, Maryland.

[12] ArcGIS® is a registered trademark of Environmental Systems Research Institute, Inc., Redlands, California.

[13] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

[14] Groundwater Vistas is a product of Environmental Simulations, Inc., Leesport, Pennsylvania.

[15] RETC (RETention Curve) was developed by the U.S. Department of Agriculture, Agricultural Research Service for the U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C.

[16] R is a programming language and free software environment created by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand.

[17] Tecplot® is a registered trademark of Tecplot, Inc., 3535 Factoria Blvd. SE, Bellevue, Washington.

[18] Leapfrog® is a registered trademark of ARANZ Geo Limited, Christchurch, New Zealand.

mixed waste issues. He is the author of over 100 publications on these topics. He has supported national programs in the U.S. and countries in Europe, Asia, and Africa to site, develop, construct, and analyze facilities for disposal of radioactive waste.

He has participated in a number of international research programs, including the International Atomic Energy Agency's Coordinated Research Program on Improvement of Safety Assessment Methodologies, and its successor programs: Application of Safety Assessment Methodologies, Practical Illustration and Use of the Safety Case Concept in the Management of Near-Surface Disposal, and most recently Modelling and Data for Radiological Impact Assessments.

He is a principle investigator for the WMA A-AX PA.

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ATTACHMENT 1

SOFTWARE INSTALLATION AND CHECKOUT FORMS

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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: eSTOMP (Parallel - Subsurf. Trans. Over Mult. Phases) Software Version No.: Bld 6

EXECUTABLE INFORMATION:

2. Executable Name (include path):

```
Test: [redacted]estomp-w-petsc-chprc06i.x
Production:[redacted]estomp-w-petsc-chprc06i.x
MD5 file signature: c4429b6a23dd26537f59d15594e5fc3f
```

3. Executable Size (bytes): 12824187

COMPILATION INFORMATION:

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

   Tellus Subsurface Modeling Platform

5. Operating System (include version number):

   [redacted] 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):

   Tellus Subsurface Modeling Platform

7. Operating System (include version number):

   [redacted]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

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

TEST CASE INFORMATION:

9. Directory/Path:

   [redacted]build-06 estomp

10. Procedure(s):

    CHPRC-00211 Rev. 3, "STOMP Software Test Plan"

11. Libraries:

    [redacted]

12. Input Files:

    [redacted]

13. Output Files:

    [redacted]

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: eSTOMP (Parallel - Subsurf. Trans. Over Mult. Phases) Software Version No.: Bld 6

14. Test Cases:

ATC-STOMP-1 (Water Mode with Transport) only

15. Test Case Results:

Pass

16. Test Performed By: WJ McMahon

17. Test Results: ◉ Satisfactory, Accepted for Use ○ Unsatisfactory

18. Disposition (include HISI update):

Accepted; Installation noted in HISI for users WE Nichols, TJ Budge, WJ McMahon, S Mehta

Prepared By:

19. [signature] Software Owner (Signature)	WE Nichols Print	1 OCT 2018 Date
20. Test Personnel: [signature] Sign	WJ McMahon Print	10/01/18 Date
Sign	Print	Date
Sign	Print	Date

Approved By:

21. Software SME (Signature)	N/R (per CHPRC-00211, Rev. 3) Print	Date

 A-6005-149 (REV 0)

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 6

EXECUTABLE INFORMATION:

2. Executable Name (include path):

```
All executable files installed in directory[redacted]
--------------------------------  ---------------------------
MD5 File Signature                Executable File Name
--------------------------------  ---------------------------
2aed5deebf96f2acd085ee5b8c035107  estomp-w-bcgs-chprc06i.x
```

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

COMPILATION INFORMATION:

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

Olive Linux Cluster

5. Operating System (include version number):

Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86 64 x86 64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

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

Olive Linux Cluster

7. Operating System (include version number):

Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86 64 x86 64 GNU/Linux

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

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]

10. Procedure(s):

CHPRC-00211 Rev 1, STOMP Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

Input files for ATC-eSTOMP-1
(Baseline for comparison are results files from ATC-eSTOMP-1 prepared on Green Linux Cluster during acceptance testing)

13. Output Files:

plot.* files produced by eSTOMP in testing

14. Test Cases:

ATC-eSTOMP-1

1
2

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: STOMP (Subsurface Transport Over Multiple Phases) Software Version No.: Bld 6

15. Test Case Results:

Pass for the executable file 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.

Prepared By:

	Software Owner (Signature)	Print	Date
19.	[signature]	WE Nichols	17 APR 2018

20. Test Personnel:

Sign	Print	Date
[signature]	WE Nichols	19 APR 2018

Approved By:

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

ATTACHMENT 2

STOMP OPTIONS ANALYSIS

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STOMP Option NQA-1 Status Check

Input Files: "input_pc_tct_03_rch_02_sat_03_bcs091_ccu_18_e_p_t" and "input_pc_tct_03_rch_02_sat_03_bcs091_ccu_18_deg_tank_01_e_p_t"
(McMahon; Water Only / Process Model and Degraded Tank Material / Post-Closure Input Files)
Input Files: " input_pc_tct_03_rch_02p000_sat_03_bcs091_ccu_18_e_p_t" and " input_pc_tct_03_rch_02p100_sat_03_bcs091_ccu_18_e_p_t"
(Hasan; Water Only / Minimum and Maximum Surface Barrier Net Infiltration / Post-Closure Input Files)

Option status check by: WJ McMahon, 05/01/2019

Input Card	Input Parameter	Input Option	NQA-1 Tested?	Comment
Simulation Title	Simulation Title	—	Yes	
Simulation Title	Simulation Documentation Information	—	Yes	
Solution Control	Execution Mode Option	restart file w/petsc, ./restart, 1.0E-12, 1.0E-25,	Yes	
Solution Control	Operational Mode Options	Water	Yes	
Solution Control	Interfacial Averaging Options	Default (all)	Yes	
Grid	Method of Grid Input	(Non-uniform) Cartesian	Yes	
Grid	Grid Spacing Specification Option	Count and Cell Size	Yes	
Rock/Soil Zonation	Method of Zonation	External File	Yes	
Inactive Nodes	Declaration of Inactive Nodes	External File	Yes	
Mechanical Properties	Compressibility Option	Pore Compressibility	Yes	
Mechanical Properties	Tortuosity Function	Millington and Quirk	Yes	
Hydraulic Properties	Method of Hydraulic Property Input	Hydraulic Conductivity	Yes	

Saturation Function	Saturation Function Option	Nonhysteretic van Genuchten	Yes	"Nonhysteretic" is no longer a recognized keyword and is ignored according to the output files. The description the van Genuchten (1980) retention function presented on the STOMP User Guide page is nonhysteretic.
Aqueous Relative Permeability	Relative Permeability Option	Modified Mualem	Yes	
Initial Conditions	Initial Aqueous Pressure	Aqueous Pressure-Gas Pressure	Yes	
Initial Conditions	Method of Initial Condition Input	Restart	Yes	
Boundary Conditions	Method of Boundary Node Identification	External File	N/A	Neither method of Boundary Node Identification, Explicit or External File, is identified as NQA-1 tested, although the boundary condition types, Neumann and Dirichlet Outflow, are.
Boundary Conditions	Aqueous Boundary Condition Options	Neumann	Yes	
Boundary Conditions	Aqueous Boundary Condition Options	Seepage Face	Yes	Boundary Conditions
Boundary Conditions	Aqueous Boundary Condition Options	Initial Condition	Yes	Boundary Conditions
Output Control	Reference Node Output	Aqueous Saturation	Yes	

Output Control	Reference Node Output	Aqueous Pressure	Yes	
Output Control	Reference Node Output	Aqueous Moisture Content	Yes	
Output Control	Reference Node Output	XNC Aqueous Volumetric Flux	Yes	
Output Control	Reference Node Output	ZNC Aqueous Volumetric Flux	Yes	
Output Control	Plot File Output	Final Restart	N/A	Final Restart is not included in the list of variables. Final Restart is not a variable but a flag indicating that a restart file is only created at the end of the simulation. All other specified variables are identified as NQA-1 tested.
Output Control	Plot File Output	Rock/Soil type	Yes	
Output Control	Plot File Output	Aqueous Saturation	Yes	
Output Control	Plot File Output	Aqueous Pressure	Yes	
Output Control	Plot File Output	Aqueous Moisture Content	Yes	
Output Control	Plot File Output	XNC Aqueous Volumetric Flux	Yes	
Output Control	Plot File Output	YNC Aqueous Volumetric Flux	Yes	
Output Control	Plot File Output	ZNC Aqueous Volumetric Flux	Yes	
Surface Flux	Surface Output File Options	Multiple Surface Output Files	Yes	
Surface Flux	Defining Surfaces for the Output Fluxes	Range of Node Indices	Yes	
Surface Flux	Surface Output Flux Types	Aqueous Volumetric Flux	Yes	

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ATTACHMENT 3

EMCF CHECK LOG

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EMCF CHECK LOG: FURTHER CHECKS

Additional checks performed and results:

CHECKER LOG FOR PROCESS MODELS					
Project and Environmental Model Calculation Specific Information:					
Project: WMA A-AX Performance Assessment					
Responsible Manager or Designee, and Position: Bob Hiergesell/Sr. Scientist (WRPS)					
Originating Group or Department: Closure and Interim Measures				Date: 05/29/2019	
Environmental Model Calculation File Report and Revision No.: RPP-CALC-63248, DRAFT A					
Environmental Model Calculation File Title: WMA A-AX PA F&T Process Model Support Calculation					
Check: Environmental Model Calculation File Document Elements					
	List where Information is Described *(EMCF Section Number)*	Is the Description Correct and Sufficient?			Checker Signature
		Yes	No	If No, describe deficiency:	
Purpose	1	◉	○		[signature]
Calculation Approach	3 and 4	◉	○		[signature]
Assumptions	4	◉	○		[signature]
Inputs *(reference detailed checklist below as well)*	4	◉	○		[signature]
Equations used	2.1 cited MPR (RPP-RPT-60101)	◉	○		[signature]
Conclusions	6, 6.1 and 6.2	◉	○		[signature]
References	8	◉	○		[signature]
Check: Controlled Software Use					
	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met?			Checker Signature
		Yes	No	If No, describe deficiency:	
Software used in the calculation is appropriate for application	5.4	◉	○		[signature]
Software use is approved and properly validated in accordance with approved software management plan	5.1	◉	○		[signature]
Software use is properly documented	5	◉	○		[signature]
Verify data was input correctly to approved software or spreadsheets	5	◉	○		[signature]
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy		○	◉	No spreadsheet mentioned in the EMCF	[signature]
Check: Perform Calculation to Verify Free of Errors					
	Describe how calculation was performed	List any discrepancies encountered *(If none, enter "None")*			Checker Signature
Perform the environmental model calculation as described to verify it is free of errors	Calculation was performed independently by the	Little discrepancy in one time step was found but acceptable.			[signature]

CHECKER LOG FOR PROCESS MODELS (Continued)

	Describe how calculation was performed	List any discrepancies encountered *(If none, enter "None")*	Checker Signature
	checker and verified with the results presented (Table 6-1 through Table 6-4) in the EMCF.		

Check: Process Model Parameterization ***(Specify Values and Units in Each Column)***

Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Simulation duration: Historic	No historic simulation	Not applicable	Not applicable
Simulation duration: Predictive	2020-5050 (Section 6.1)		
Boundary conditions: Recharge	(Table 4.1) INF-min: Design life surface barrier, 0.1 mm/yr; Post-design life, 0.5 mm/yr. INF-max: Design life surface barrier, 0.9 mm/yr; Post-design life, 5.2 mm/yr.	Yes	Yes
Boundary conditions: River	Not applicable	Not applicable	Not applicable
Boundary conditions: Head Dependent	Cited RPP CALC-63164	RPP CALC-63164	Yes
Boundary Conditions: Specified Flux	Cited RPP CALC-63164	RPP CALC-63164	Yes
Initial Conditions: Hydraulic	Cited RPP CALC-63164	RPP CALC-63164	Yes
Initial Conditions: Contaminant	Cited RPP CALC-63164	RPP CALC-63164	Yes
Sources and Sinks: Aqueous Mass	No transport simulation	Not applicable	Not applicable
Sources and Sinks: Contaminant Mass	No transport simulation	Not applicable	Not applicable
Hydraulic Properties: Conductivity	Table 4-4	RPP-RPT-60101 (Section 3.1.4.4)	Yes
Hydraulic Properties: Porosity	Table 4-3	RPP-RPT-60101 (Section 3.1.4.3)	Yes
Hydraulic Properties: Water Retention *(Vadose Only)*	Table 4-5, Table 4-6	RPP-RPT-60101 (Section 3.1.4.3, Section 3.1.4.4)	Yes
Hydraulic Properties: Formation Density	Table 4-3	RPP-RPT-60101 (Section 3.1.4.5.2)	
Transport Properties: Diffusion	No transport simulation	Not applicable	Not applicable
Transport Properties: Dispersivity	No transport simulation	Not applicable	Not applicable
Transport Properties:	No transport	Not applicable	Not applicable

CHECKER LOG FOR PROCESS MODELS (Continued)

Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Sorption *(typically K_d)*	simulation		
Transport Properties: Radioactive Decay Rate	No transport simulation	Not applicable	Not applicable
Check: Further Checks ***(Record additional checks performed and results)***			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Inventory: Radiological Decay Correction. Does the inventory *(source term)* include radionuclides, and if so, is it decay-corrected to the appropriate date for inclusion as a source?	No transport simulation	Not applicable	Not applicable

1
2

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