Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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PORFLOW Simulations Supporting Saltstone Disposal Unit Design Optimization

G. P. Flach

T. Hang

G. A. Taylor

December 2015

SRNL-STI-2015-00671, Revision 0

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Prepared for
U.S. Department of Energy

SRNL-STI-2015-00671
Revision 0

Keywords: *Performance Assessment Z-Area*

Retention: *Permanent*

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EXECUTIVE SUMMARY

SRNL was requested by SRR to perform PORFLOW simulations to support potential cost-saving design modifications to future Saltstone Disposal Units in Z-Area (SRR-CWDA-2015-00120). The design sensitivity cases are defined in a modeling input specification document SRR-CWDA-2015-00133 Rev. 1. A high-level description of PORFLOW modeling and interpretation of results are provided in SRR-CWDA-2015-00169. The present report focuses on underlying technical issues and details of PORFLOW modeling not addressed by the input specification and results interpretation documents. Design checking of PORFLOW modeling is documented in SRNL-L3200-2015-00146.

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LIST OF ABBREVIATIONS

BE	Best estimate
CE	Conservative estimate
NV	Nominal value
SA	Special Analysis
SDF	Saltstone Disposal Facility
SDU	Saltstone Disposal Unit
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation

1.0 Introduction

Figure 1-1 presents an aerial photograph of the Z-Area Saltstone Production and Disposal Facilities taken in May 2015. The indicated Saltstone Disposal Units (SDUs) reflect multiple design changes and improvements since the original rectangular SDU 1 and 4 (Vaults 1 and 4) were constructed in the late 1980's. SDU 2, 3 and 5 are based on a commercial water tank design and adapted to waste grout disposal. SDU 6 (Figure 1-2) is a much larger cylindrical tank design that reduces waste disposal costs through economy-of-scale. Further cost-savings are desired for future SDU 7.

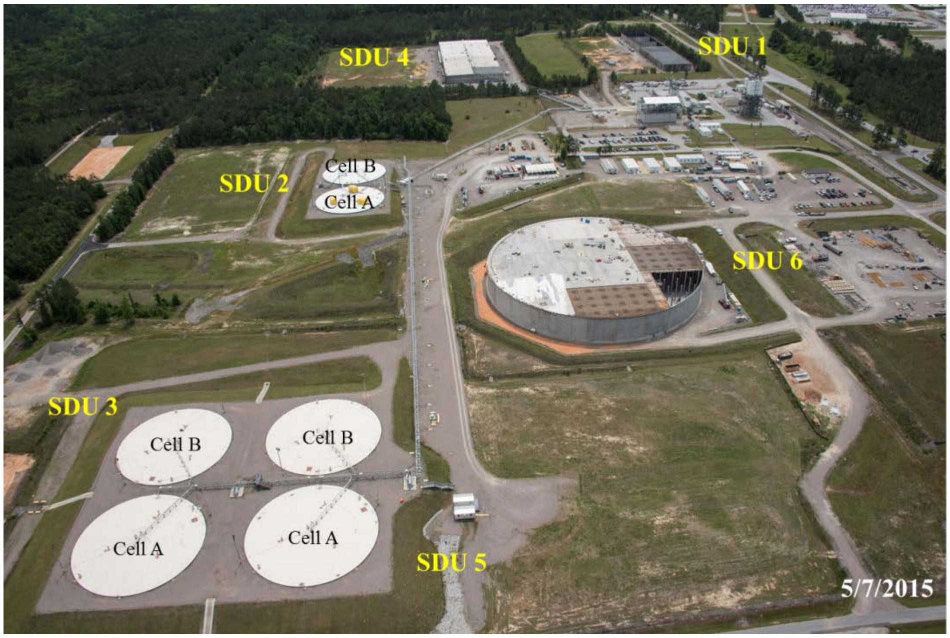


Figure 1-1. Z-Area Saltstone Disposal Units circa May 2015.

Figure 1-2. Saltstone Disposal Unit 6 being constructed in January 2015.

To support a quantitative assessment of potential lower-cost design features, Savannah River Remediation (SRR) requested that SRNL perform a series of PORFLOW model simulations testing the sensitivity of SDU 6 performance to variations in principal design features (SRR-CWDA-2015-00120). Specific input specifications for each modeling case are provided in SRR-CWDA-2015-00133. The reference case for these simulations is the Evaluation Case defined in the FY2014 Saltstone Disposal Facility (SDF) Special Analysis (SA) (SRR-CWDA-2014-00006); in PORFLOW electronic files, this modeling case is referred to as "Case_sa". Unless otherwise indicated, design feature sensitivity case inputs are identical to the FY2014 Evaluation Case.

SRR is producing in parallel a high-level report focused on interpretation of modeling results and SDU 7 design recommendations (SRR-CWDA-2015-00169). The present report complements the results interpretation report by focusing on underlying technical issues and details of PORFLOW modeling. Design checking of PORFLOW electronic files is documented separately in SRNL-L3200-2015-00146 and complements technical review of this report by J. E. Laurinat.

2.0 PORFLOW Modeling

PORFLOW (http://www.acricfd.com/software/porflow/) is a porous-medium flow and solute transport simulation code that was used to model subsurface flow and radionuclide transport for the FY2014 SDF SA (SRNL-STI-2014-00083, Rev. 1). For consistency with the previous Evaluation Case modeling, PORFLOW version 6.30.2 was retained for numerical simulations in this study.

2.1 Transport time step sensitivity

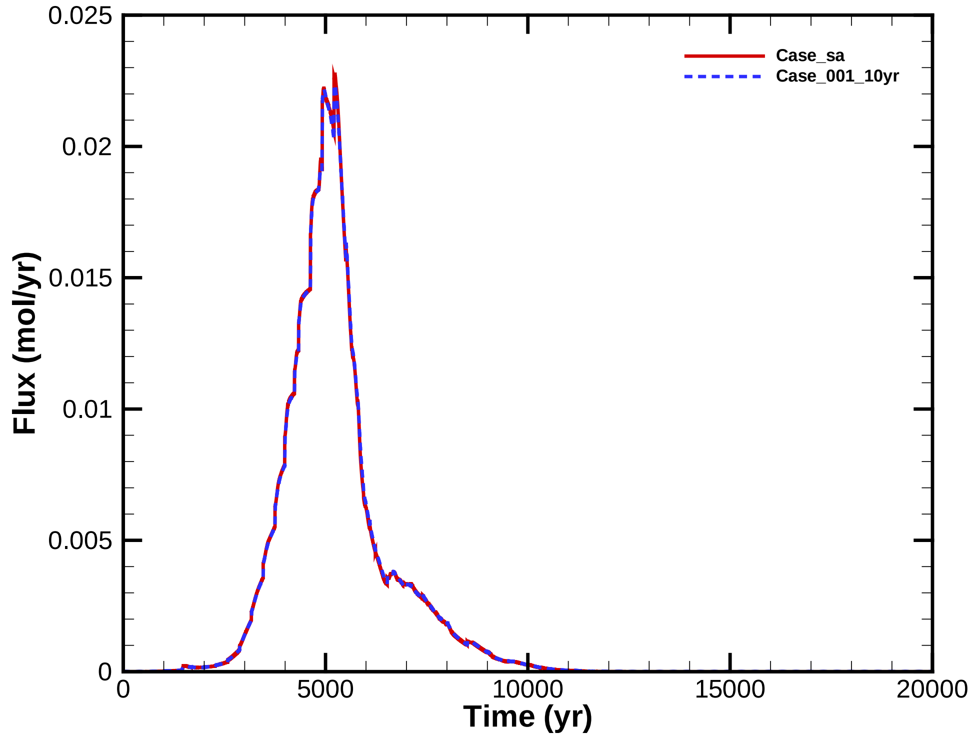
FY2014 SDF SA Evaluation Case simulations were performed with a default time step of one year, a conservative setting to ensure accurate simulation of peak fluxes of mobile species such as I-129 for dose assessment. The interest of the present study is the relative effect of design modifications on dose, and computational efficiency was desired to enable a larger number of sensitivity cases. Figure 2-1 illustrates the I-129 results from a sensitivity study using time steps of 1, 2, 5 and 10 years. The 10-year flux curve generally overlaps the one year reference results (Figure 2-1 (a)) and only minor differences in peak flux are observed (Figure 2-1 (b)). A 10-year time step was thus judged to be adequate for assessing relative design impacts and selected for subsequent design optimization sensitivity runs.

2.2 Design optimization sensitivity cases

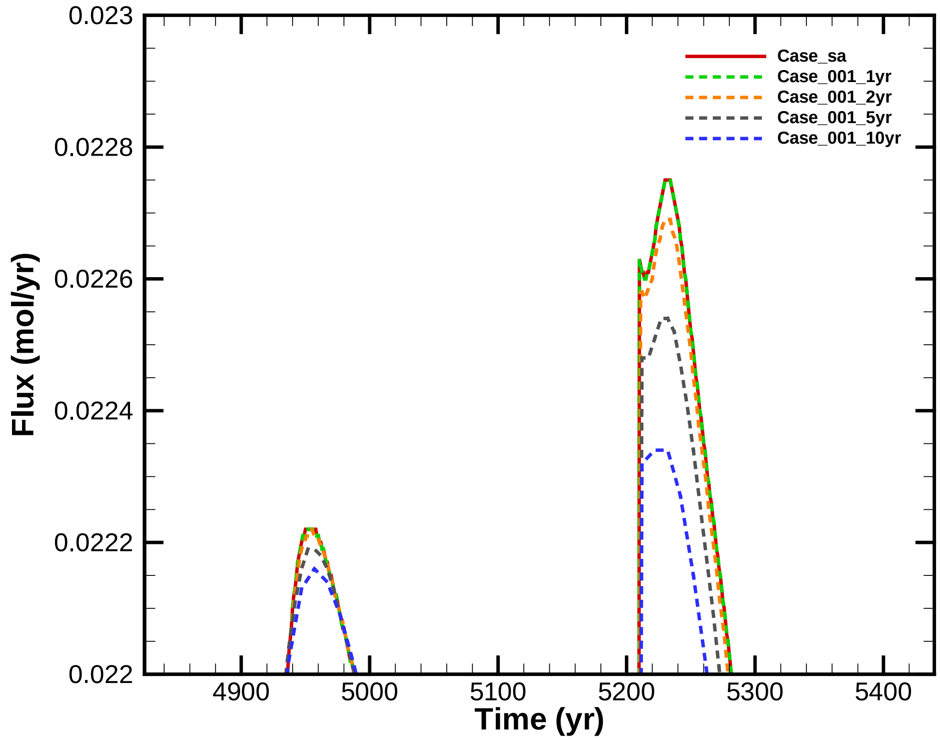
Table 2-1 summarizes PORFLOW sensitivity runs supporting SDU 7 design optimization. The PORFLOW case identification labels generally coincide with the input specification (SRR-CWDA-2015-00133, Rev. 1) and results interpretation report. However, PORFLOW Case_018 and Case_019 are exceptions and correspond to Case_007B and Case_016, respectively, in SRR-CWDA-2015-00169.

2.3 Aquifer source zones

The input specification graphically defines two alternative SDU layouts, which are reproduced in Figure 2-2 and annotated with SDU identification labels. Figure 2-3 illustrates the PORFLOW model approximation of these layouts and the corresponding 100-meter boundaries. The basemap includes an outline of the Evaluation Case layout as a point of reference. Both alternative layouts result in an expansion of the 100-meter perimeter toward the south.



(a)

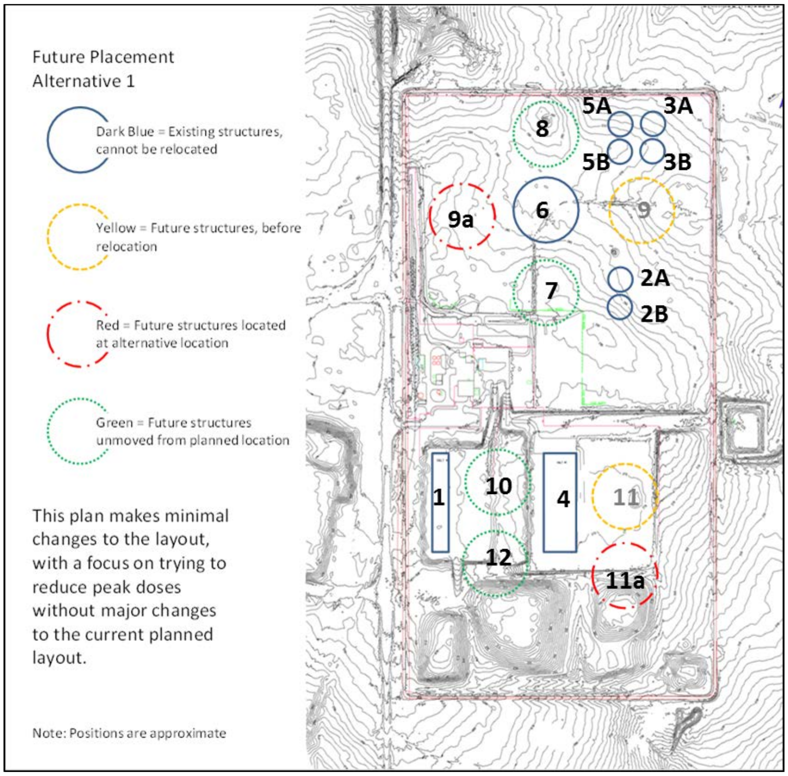


(b)

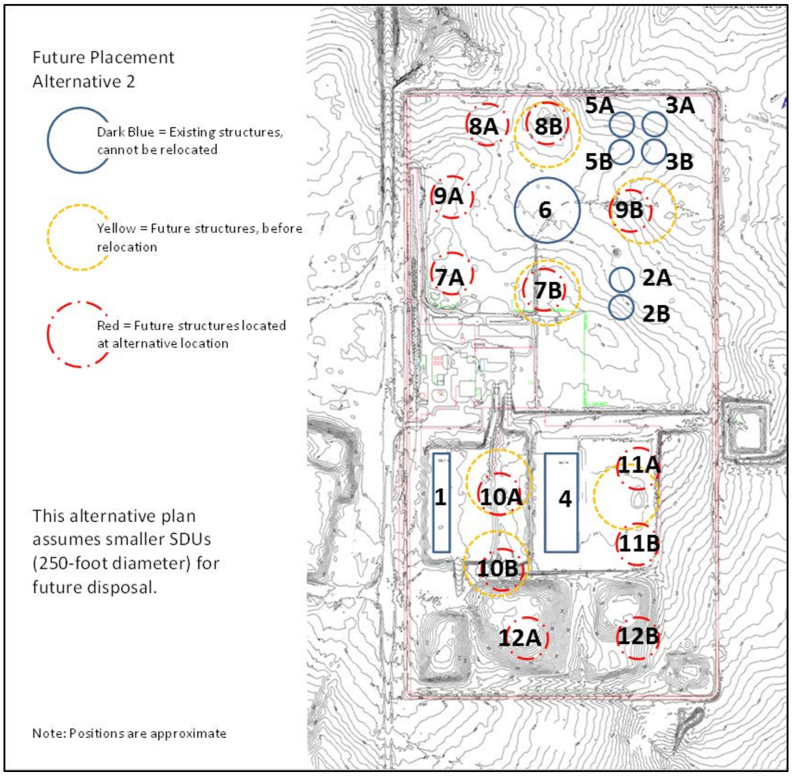
Figure 2-1. I-129 flux to the water table for the SDU 6 Evaluation Case with 1-year (Case_sa) and variable time steps (Case_001): (a) 0 to 20,000 years, (b) peak flux detail.

Table 2-1. Design Optimization Sensitivity Cases.

ROUND 1	…/SDUdesignOpt				
Case ID	Case description	Vadose zone geometry	Vadose zone case	Aquifer directory	Comments
N/A	FY2014 SDF SA	…/VadoseSDU1	Case_sa		Repeat of FY2014 SDF SA
N/A	FY2014 SDF SA	…/VadoseSDU2	Case_sa		Repeat of FY2014 SDF SA
N/A	FY2014 SDF SA	…/VadoseSDU4	Case_sa		Repeat of FY2014 SDF SA
N/A	FY2014 SDF SA	…/VadoseSDU6	Case_sa		Repeat of FY2014 SDF SA
Case_001	Case_sa with different time step	…/VadoseSDU7a	Case_001_[1|2|5|10]yr	…/AquiferZ	VadoseSDU7a geometry same as VadoseSDU6
Case_002	WALL* = Soil	…/VadoseSDU7a	Case_002	…/AquiferZ	
Case_003	WALL* = Nominal shotcrete	…/VadoseSDU7a	Case_003	…/AquiferZ	
Case_004	WALL* = Conservative shotcrete	…/VadoseSDU7a	Case_004	…/AquiferZ	
Case_005	WALL* = half thickness	…/VadoseSDU7b	Case_005	…/AquiferZ	
Case_006	WALL* = double thickness	…/VadoseSDU7c	Case_006	…/AquiferZ	
Case_007	ROOF = half thickness	…/VadoseSDU7d	Case_007	…/AquiferZ	Unexpected low flow through SALTSTONE zone
		…/VadoseSDU7d.2	Case_007	…/AquiferZ	Tighter numerical tolerance
		…/VadoseSDU7d.3	Case_007	…/AquiferZ	Drier initial condition to state iteration
	ROOF = full thickness	…/VadoseSDU7d.4	Case_007	…/AquiferZ	Same roof thickness as Case_sa + 2x conductivity
		…/VadoseSDU7d.5	Case_007	…/AquiferZ	Same grid resolution / half grid layers in roof
Case_008	FLOOR = half thickness	…/VadoseSDU7e	Case_008	…/AquiferZ	
Case_009	Smaller diameter	…/VadoseSDU7f	Case_009	N/A (ignore)	
Case_010	Over extension	…/VadoseSDU7g	Case_010	…/AquiferZ	
Case_011	Over extension w/ capillary barrier	…/VadoseSDU7h	Case_011	…/AquiferZ	
Case_012	Umbrella	…/VadoseSDU7i	Case_012	…/AquiferZ	
Case_013	Umbrella w/ capillary barrier	…/VadoseSDU7j	Case_013	…/AquiferZ	
Case_014	Alternate layout 1	N/A	Case_001_10yr	…/AquiferZ_Alt1	
Case_015	Alternate layout 2	N/A	Case_009	…/AquiferZ_Alt2b	
ROUND 2	…/SDUdesignOpt.2				Case_016 aborted preliminary modeling case
Case_017	Case_004 + 005 + 008 + 014	…/VadoseSDU7l	Case_017	…/AquiferZ_Alt1	New geometry
Case_018	…/VadoseSDU7d.4, Case_007	…/VadoseSDU7m	Case_007	…/AquiferZ	Renaming via symbolic link to remove "0.4" suffix
Case_019	Degraded roof columns - backfill	…/VadoseSDU7n	Case_019	…/AquiferZ	Case_016 in input specification



(a)



(b)

Figure 2-2. Alternative SDU layouts from SRR-CWDA-2015-00133 with annotations: (a) Alternative Layout 1, and (b) Alternative Layout 2.

Figure 2-3. PORFLOW representations of the alternative SDU layouts and 100-meter boundaries: (a) Alternative Layout 1, and (b) Alternative Layout 2.

2.4 Degradation times for modified concrete barrier dimensions

Per the input specification document, degradation of wall concrete applied as shotcrete in Case_003 and Case_004 is assumed to occur at the same rate as the FY2014 SDF SA Evaluation Case (Case_sa). Because the concrete dimensions are unaltered, the start and end times for concrete degradation remain the same as Case_sa / Case_001_10yr. Case_005 through Case_008 and Case_017 involve modified thicknesses for certain concrete components, which affect degradation times for the disposal system. Table 2-2 through Table 2-15 summarize revised degradation calculations for these sensitivity cases.

The FY2014 SDF SA Evaluation Case used degradation times from SRNL-STI-2013-00118, Rev. 1. Since then a calculation error of very minor impact was corrected, resulting in issuance of SRNL-STI-2013-00118, Rev. 2. Table 2-4 and Table 2-5 provide the corrected degradation times for the Evaluation Case based on SRNL-STI-2013-00118, Rev. 2. While sensitivity cases not involving changes in concrete thickness use degradation times from SRNL-STI-2013-00118, Rev. 1, the remaining cases use Table 2-4 and Table 2-5 as the starting point for new calculations.

Table 2-2. Estimate of initial wall degradation for Case_005 (half wall).

SDU-7 Half Wall Thickness	*Wall 1*	*Wall 2*	*Wall 3*	*Wall 4*	*Wall 5*		*Note*
thickness, L	11.19	9.54	7.83	6.14	5.16	in	
	28.42	24.23	19.89	15.60	13.11	cm	
initial saturation, S_i	0.73	0.73	0.73	0.73	0.73	mL liquid / mL void	a)
final saturation, S_f	1	1	1	1	1	mL liquid / mL void	
change in saturation, ΔS	0.27	0.27	0.27	0.27	0.27	mL liquid / mL void	
porosity, n	0.11	0.11	0.11	0.11	0.11	mL void / mL total	b)
surface crack depth	1	1	1	1	1	cm	c)
	0.39	0.39	0.39	0.39	0.39	in	
Slow reaction							
penetration fraction	0.27	0.27	0.27	0.27	0.27		
penetration distance, x	7.67	6.54	5.37	4.21	3.54	cm	
total degraded thickness	8.67	7.54	6.37	5.21	4.54	cm	
	3.42	2.97	2.51	2.05	1.79	in	
Fast reaction							
bulk density, ρ_b	2.22	2.22	2.22	2.22	2.22	g/mL	b)
bleedwater concentration, c	150	150	150	150	150	mmol/L	d)
	0.15	0.15	0.15	0.15	0.15	mol/L	
	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	mol/mL	
reaction capacity, R	4.8E-05	4.8E-05	4.8E-05	4.8E-05	4.8E-05	mol/g	e)
	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	mol/mL	
	0.11	0.11	0.11	0.11	0.11	mol/L	
penetration fraction	0.04	0.04	0.04	0.04	0.04		
penetration distance, x	1.18	1.01	0.83	0.65	0.55	cm	
total degraded thickness	2.18	2.01	1.83	1.65	1.55	cm	
	0.86	0.79	0.72	0.65	0.61	in	
Initial damage							
Geometric mean value	4.35	3.89	3.41	2.93	2.65	cm	
	1.71	1.53	1.34	1.15	1.04	in	
Intact wall thickness	24.07	20.34	16.48	12.66	10.46	cm	
	9.48	8.01	6.49	4.99	4.12	in	

Notes:

a) based on 73% average observed in Sappington and Phifer (2005)

b) SRNL-STI-2013-00118, Rev. 0, Table 3-1

c) Page 5 in Levitt, M. Concrete Materials: Problems and Solutions. Taylor & Francis e-Library. 2003.

d) bleedwater taken as the midpoint between feedwater (0.1 mol/L) and porewater (~2x) values; 2x based on SIMCO June 2010 report

e) based on SIMCO March 12 characterization

Table 2-3. Estimate of initial wall degradation for Case_006 (double wall).

SDU-7 Double Wall Thick.	*Wall 1*	*Wall 2*	*Wall 3*	*Wall 4*	*Wall 5*		*Note*
thickness, L	44.74	38.15	31.31	24.56	20.62	in	
	113.64	96.90	79.53	62.38	52.37	cm	
initial saturation, S_i	0.73	0.73	0.73	0.73	0.73	mL liquid / mL void	a)
final saturation, S_f	1	1	1	1	1	mL liquid / mL void	
change in saturation, ΔS	0.27	0.27	0.27	0.27	0.27	mL liquid / mL void	
porosity, n	0.11	0.11	0.11	0.11	0.11	mL void / mL total	b)
surface crack depth	1	1	1	1	1	cm	c)
	0.39	0.39	0.39	0.39	0.39	in	
Slow reaction							
penetration fraction	0.27	0.27	0.27	0.27	0.27		
penetration distance, x	30.68	26.16	21.47	16.84	14.14	cm	
total degraded thickness	31.68	27.16	22.47	17.84	15.14	cm	
	12.47	10.69	8.85	7.02	5.96	in	
Fast reaction							
bulk density, ρ_b	2.22	2.22	2.22	2.22	2.22	g/mL	b)
bleedwater concentration, c	150	150	150	150	150	mmol/L	d)
	0.15	0.15	0.15	0.15	0.15	mol/L	
	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	mol/mL	
reaction capacity, R	4.8E-05	4.8E-05	4.8E-05	4.8E-05	4.8E-05	mol/g	e)
	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	mol/mL	
	0.11	0.11	0.11	0.11	0.11	mol/L	
penetration fraction	0.04	0.04	0.04	0.04	0.04		
penetration distance, x	4.73	4.03	3.31	2.60	2.18	cm	
total degraded thickness	5.73	5.03	4.31	3.60	3.18	cm	
	2.26	1.98	1.70	1.42	1.25	in	
Initial damage							
Geometric mean value	13.47	11.69	9.84	8.01	6.94	cm	
	5.30	4.60	3.87	3.15	2.73	in	
Intact wall thickness	100.17	85.21	69.69	54.37	45.44	cm	
	39.44	33.55	27.44	21.41	17.89	in	

Notes:

a) based on 73% average observed in Sappington and Phifer (2005)

b) SRNL-STI-2013-00118, Rev. 0, Table 3-1

c) Page 5 in Levitt, M. Concrete Materials: Problems and Solutions. Taylor & Francis e-Library. 2003.

d) bleedwater taken as the midpoint between feedwater (0.1 mol/L) and porewater (~2x) values;
2x based on SIMCO June 2010 report

e) based on SIMCO March 12 characterization

Table 2-4. Degradation times for Evaluation Case slightly revised per SRNL-STI-2013-00118, Rev. 2 -- part 1.

SDU-7 (same as SDU-6 Design Case+noCleanCap)																						
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**							
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
Roof delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
FloorUMM delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	8.73	22.17	14.3	7.85	17.2	4.93	21	1.19	0.027	0.021	0.011	533	815	1933	0.27	0.17	0.0271	533	815	1933	5
Wall delay+degradation			0		0		0					533	**815**	1933				533	**815**	1933	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	10.45	26.54	17.1	9.39	20.7	5.85	25.2	1.31	0.027	0.021	0.011	639	979	2324	0.27	0.17	0.0271	639	979	2324	5
Wall delay+degradation			0		0		0					639	**979**	2324				639	**979**	2324	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	13.46	34.19	22.1	12.1	26.7	7.53	32.7	1.49	0.027	0.021	0.011	822	1261	3012	0.27	0.17	0.0271	822	1261	3012	5
Wall delay+degradation			0		0		0					822	**1261**	3012				822	**1261**	3012	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	16.50	41.91	27.1	14.8	32.7	9.23	40.3	1.65	0.027	0.021	0.011	1008	1546	3708	0.27	0.17	0.0271	1008	1546	3708	5
Wall delay+degradation			0		0		0					1008	**1546**	3708				1008	**1546**	3708	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	19.45	49.4	31.9	17.5	38.5	10.9	47.6	1.79	0.027	0.021	0.011	1188	1822	4385	0.27	0.17	0.0271	1188	1822	4385	5
Wall delay+degradation			0		0		0					1188	**1822**	4385				1188	**1822**	4385	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	1135	**1413**	2717	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		1369	**1996**	32000	

* Use degradation time for successive column segments

Table 2-5. Degradation times for Evaluation Case slightly revised per SRNL-STI-2013-00118, Rev. 2 -- part 2.

SDU-7 (same as SDU-6 Design Case+noCleanCap)

Degradation mechanism:	**Decalcification**									**Limiting**						
	Thickness:		**A (cm/√yr)**			**Time (yr)**			**max δ**	**NV**		**Initial thickness**		**t=0 thickness**		**Times:**
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)		(in)	(cm)	(in)	(cm)	(yr)
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	12	30.48			0.021			358791	5	Roof						
Roof delay+degradation								360191		**1413**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**						
FloorUMM degradation	12	30.48			0.021			358791	5	FloorUMM						
FloorUMM delay+degradation								360191		**1413**						
Wall delay					*HDPE:*			900		**0**						**-151**
Wall degradation	8.73	22.17			0.021			261020	5	Wall	⑤	10.35	26.3	8.73	22.2	Wall
Wall delay+degradation								261920		**815**						**815**
Wall delay					*HDPE:*			900		**0**						**-171**
Wall degradation	10.45	26.54			0.021			312447	5	Wall	④	12.28	31.2	10.45	26.5	Wall
Wall delay+degradation								313347		**979**						**979**
Wall delay					*HDPE:*			900		**0**						**-206**
Wall degradation	13.46	34.19			0.021			402444	5	Wall	③	15.66	39.8	13.46	34.2	Wall
Wall delay+degradation								403344		**1261**						**1261**
Wall delay					*HDPE:*			900		**0**						**-241**
Wall degradation	16.5	41.91			0.021			493338	5	Wall	②	19.07	48.4	16.5	41.9	Wall
Wall delay+degradation								494238		**1546**						**1546**
Wall delay					*HDPE:*			900		**0**						**-274**
Wall degradation	19.45	49.4			0.021			581540	5	Wall	①	22.37	56.8	19.45	49.4	Wall
Wall delay+degradation								582440		**1822**						**1822**
Grout delay			**A_U (cm/yr)**			1135	1413	2717		**1413**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44933	**439398**	4382571		**439398**						
Column delay										**1413**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1996**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	1413	1997	grout21
grout2	1997	2581	grout20
grout3	2581	3165	grout19
grout4	3165	3749	grout18
grout5	3749	4333	grout17
grout6	4333	4917	grout16
grout7	4917	5501	grout15
grout8	5501	6085	grout14
grout9	6085	6669	grout13
grout10	6669	7253	grout12
grout11	7253	7837	grout11

Table 2-6. Degradation times for Case_005 (half wall) -- part 1.

SDU-7 Half Wall																					
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**						
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
Roof delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
FloorUMM delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	4.12	10.46	6.31	4.16	7.26	3.2	9.66	0.81	0.027	0.021	0.011	235	343	889	0.27	0.17	0.0271	235	343	889	5
Wall delay+degradation			0		0		0					235	**343**	889				235	**343**	889	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	4.99	12.67	7.99	4.68	9.09	3.58	11.8	0.89	0.027	0.021	0.011	298	430	1085	0.27	0.17	0.0271	298	430	1085	5
Wall delay+degradation			0		0		0					298	**430**	1085				298	**430**	1085	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	6.49	16.48	10.7	5.83	12.3	4.17	15.5	1.02	0.027	0.021	0.011	397	582	1424	0.27	0.17	0.0271	397	582	1424	5
Wall delay+degradation			0		0		0					397	**582**	1424				397	**582**	1424	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	8.01	20.35	13.1	7.2	15.6	4.7	19.2	1.14	0.027	0.021	0.011	489	740	1769	0.27	0.17	0.0271	489	740	1769	5
Wall delay+degradation			0		0		0					489	**740**	1769				489	**740**	1769	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	9.48	24.08	15.6	8.52	18.8	5.3	22.8	1.24	0.027	0.021	0.011	579	888	2103	0.27	0.17	0.0271	579	888	2104	5
Wall delay+degradation			0		0		0					579	**888**	2103				579	**888**	2104	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	1135	**1413**	2717	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		1369	**1996**	32000	

* Use degradation time for successive column segments

Table 2-7. Degradation times for Case_005 (half wall) -- part 2.

SDU-7 Half Wall																
Degradation mechanism:			**Decalcification**							**Limiting**		**Initial thickness**		**t=0 thickness**		
	Thickness:		**A (cm/√yr)**				**Time (yr)**		**max δ**	**NV**						**Times:**
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)		(in)	(cm)	(in)	(cm)	(yr)
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	12	30.48			0.021			358791	5	Roof						
Roof delay+degradation								360191		**1413**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**						
FloorUMM degradation	12	30.48			0.021			358791	5	FloorUMM						
FloorUMM delay+degradation								360191		**1413**						
Wall delay					*HDPE:*			900		**0**						**-87**
Wall degradation	4.12	10.46			0.021			123185	5	Wall	⑤	5.16	13.1	4.12	10.5	Wall
Wall delay+degradation								124085		**343**						**343**
Wall delay					*HDPE:*			900		**0**						**-99**
Wall degradation	4.99	12.67			0.021			149197	5	Wall	④	6.14	15.6	4.99	12.7	Wall
Wall delay+degradation								150097		**430**						**430**
Wall delay					*HDPE:*			900		**0**						**-120**
Wall degradation	6.49	16.48			0.021			194046	5	Wall	③	7.83	19.9	6.49	16.5	Wall
Wall delay+degradation								194946		**582**						**582**
Wall delay					*HDPE:*			900		**0**						**-141**
Wall degradation	8.01	20.35			0.021			239493	5	Wall	②	9.54	24.2	8.01	20.3	Wall
Wall delay+degradation								240393		**740**						**740**
Wall delay					*HDPE:*			900		**0**						**-160**
Wall degradation	9.48	24.08			0.021			283445	5	Wall	①	11.19	28.4	9.48	24.1	Wall
Wall delay+degradation								284345		**888**						**888**
Grout delay			**A_U (cm/yr)**			1135	1413	2717		**1413**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44933	**439398**	4382571		**439398**						
Column delay										**1413**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1996**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	1413	1997	grout21
grout2	1997	2581	grout20
grout3	2581	3165	grout19
grout4	3165	3749	grout18
grout5	3749	4333	grout17
grout6	4333	4917	grout16
grout7	4917	5501	grout15
grout8	5501	6085	grout14
grout9	6085	6669	grout13
grout10	6669	7253	grout12
grout11	7253	7837	grout11

Table 2-8. Degradation times for Case_006 (double wall) -- part 1.

SDU-7 Double Wall																					
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**						
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
Roof delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
FloorUMM delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	17.89	45.44	29.4	16.1	35.4	10	43.7	1.72	0.027	0.021	0.011	1093	1676	4027	0.27	0.17	0.0271	1093	1676	4027	5
Wall delay+degradation			0		0		0					1093	**1676**	4027				1093	**1676**	4027	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	21.41	54.38	35.1	19.2	42.4	12	52.5	1.88	0.027	0.021	0.011	1308	2006	4835	0.27	0.17	0.0271	1308	2006	4835	5
Wall delay+degradation			0		0		0					1308	**2006**	4835				1308	**2006**	4835	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	27.44	69.7	45	24.7	54.3	15.4	67.6	2.14	0.027	0.021	0.011	1677	2570	6223	0.27	0.17	0.0271	1677	2570	6223	5
Wall delay+degradation			0		0		0					1677	**2570**	6223				1677	**2570**	6223	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	33.55	85.22	55.1	30.2	66.4	18.8	82.9	2.37	0.027	0.021	0.011	2050	3143	7631	0.27	0.17	0.0271	2050	3143	7631	5
Wall delay+degradation			0		0		0					2050	**3143**	7631				2050	**3143**	7631	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	39.44	100.2	64.7	35.5	78.1	22.1	97.6	2.57	0.027	0.021	0.011	2410	3695	8990	0.27	0.17	0.0271	2410	3695	8990	5
Wall delay+degradation			0		0		0					2410	**3695**	8990				2410	**3695**	8990	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	1135	**1413**	2717	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		1369	**1996**	32000	
* Use degradation time for successive column segments																					

Table 2-9. Degradation times for Case_006 (double wall) -- part 2.

SDU-7 Double Wall																
Degradation mechanism:			**Decalcification**							**Limiting**						
	Thickness:		**A (cm/√yr)**			**Time (yr)**			**max δ**	**NV**						
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)						
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	12	30.48			0.021			358791	5	Roof						
Roof delay+degradation								360191		**1413**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**		**Initial**		**t=0**		
FloorUMM degradation	12	30.48			0.021			358791	5	FloorUMM		**thickness**		**thickness**		**Times:**
FloorUMM delay+degradation								360191		**1413**		(in)	(cm)	(in)	(cm)	(yr)
Wall delay					*HDPE:*			900		**0**						**-256**
Wall degradation	17.89	45.44			0.021			534898	5	Wall	⑤	20.62	52.4	17.89	45.4	Wall
Wall delay+degradation								535798		**1676**						**1676**
Wall delay					*HDPE:*			900		**0**						**-295**
Wall degradation	21.41	54.38			0.021			640143	5	Wall	④	24.56	62.4	21.41	54.4	Wall
Wall delay+degradation								641043		**2006**						**2006**
Wall delay					*HDPE:*			900		**0**						**-363**
Wall degradation	27.44	69.7			0.021			820435	5	Wall	③	31.31	79.5	27.44	69.7	Wall
Wall delay+degradation								821335		**2570**						**2570**
Wall delay					*HDPE:*			900		**0**						**-431**
Wall degradation	33.55	85.22			0.021			1003120	5	Wall	②	38.15	96.9	33.55	85.2	Wall
Wall delay+degradation								1004020		**3143**						**3143**
Wall delay					*HDPE:*			900		**0**						**-496**
Wall degradation	39.44	100.2			0.021			1179226	5	Wall	①	44.74	113.6	39.44	100.2	Wall
Wall delay+degradation								1180126		**3695**						**3695**
Grout delay			**A_U (cm/yr)**			1135	1413	2717		**1413**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44933	**439398**	4382571		**439398**						
Column delay										**1413**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1996**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	1413	1997	grout21
grout2	1997	2581	grout20
grout3	2581	3165	grout19
grout4	3165	3749	grout18
grout5	3749	4333	grout17
grout6	4333	4917	grout16
grout7	4917	5501	grout15
grout8	5501	6085	grout14
grout9	6085	6669	grout13
grout10	6669	7253	grout12
grout11	7253	7837	grout11

Table 2-10. Degradation times for Case_007 (half roof) -- part 1.

SDU-7 Half Roof																					
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**						
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	6	15.24	15.2	0	15.2	0	15.2	0.03	0.027	0.021	0.011	567	721	1401	0.27	0.17	0.0271	0	0	1	5
Roof delay+degradation			-833		-679		0					567	**721**	1401				1400	**1400**	1401	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
FloorUMM delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	8.73	22.17	14.3	7.85	17.2	4.93	21	1.19	0.027	0.021	0.011	533	815	1933	0.27	0.17	0.0271	533	815	1933	5
Wall delay+degradation			0		0		0					533	**815**	1933				533	**815**	1933	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	10.45	26.54	17.1	9.39	20.7	5.85	25.2	1.31	0.027	0.021	0.011	639	979	2324	0.27	0.17	0.0271	639	979	2324	5
Wall delay+degradation			0		0		0					639	**979**	2324				639	**979**	2324	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	13.46	34.19	22.1	12.1	26.7	7.53	32.7	1.49	0.027	0.021	0.011	822	1261	3012	0.27	0.17	0.0271	822	1261	3012	5
Wall delay+degradation			0		0		0					822	**1261**	3012				822	**1261**	3012	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	16.50	41.91	27.1	14.8	32.7	9.23	40.3	1.65	0.027	0.021	0.011	1008	1546	3708	0.27	0.17	0.0271	1008	1546	3708	5
Wall delay+degradation			0		0		0					1008	**1546**	3708				1008	**1546**	3708	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	19.45	49.4	31.9	17.5	38.5	10.9	47.6	1.79	0.027	0.021	0.011	1188	1822	4385	0.27	0.17	0.0271	1188	1822	4385	5
Wall delay+degradation			0		0		0					1188	**1822**	4385				1188	**1822**	4385	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	567	**720.8**	1401	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		801	**1305**	30684	

* Use degradation time for successive column segments

Table 2-11. Degradation times for Case_007 (half roof) -- part 2.

SDU-7 Half Roof

Degradation mechanism:			**Decalcification**							**Limiting**						
	Thickness:		**A (cm/√yr)**			**Time (yr)**			**max δ**	**NV**						
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)						
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	6	15.24			0.021			179396	5	Roof						
Roof delay+degradation								180796		**721**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**		**Initial**		**t=0**		
FloorUMM degradation	12	30.48			0.021			358791	5	FloorUMM		**thickness**		**thickness**		**Times:**
FloorUMM delay+degradation								360191		**1413**		(in)	(cm)	(in)	(cm)	(yr)
Wall delay					*HDPE:*			900		**0**						**-151**
Wall degradation	8.73	22.17			0.021			261020	5	Wall	⑤	10.35	26.3	8.73	22.2	Wall
Wall delay+degradation								261920		**815**						**815**
Wall delay					*HDPE:*			900		**0**						**-171**
Wall degradation	10.45	26.54			0.021			312447	5	Wall	④	12.28	31.2	10.45	26.5	Wall
Wall delay+degradation								313347		**979**						**979**
Wall delay					*HDPE:*			900		**0**						**-206**
Wall degradation	13.46	34.19			0.021			402444	5	Wall	③	15.66	39.8	13.46	34.2	Wall
Wall delay+degradation								403344		**1261**						**1261**
Wall delay					*HDPE:*			900		**0**						**-241**
Wall degradation	16.5	41.91			0.021			493338	5	Wall	②	19.07	48.4	16.5	41.9	Wall
Wall delay+degradation								494238		**1546**						**1546**
Wall delay					*HDPE:*			900		**0**						**-274**
Wall degradation	19.45	49.4			0.021			581540	5	Wall	①	22.37	56.8	19.45	49.4	Wall
Wall delay+degradation								582440		**1822**						**1822**
Grout delay			**A_U (cm/yr)**			567	721	1401		**721**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44366	**438706**	4381256		**438706**						
Column delay										**721**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1305**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	721	1305	grout21
grout2	1305	1889	grout20
grout3	1889	2473	grout19
grout4	2473	3057	grout18
grout5	3057	3641	grout17
grout6	3641	4225	grout16
grout7	4225	4809	grout15
grout8	4809	5393	grout14
grout9	5393	5977	grout13
grout10	5977	6561	grout12
grout11	6561	7145	grout11

Table 2-12. Degradation times for Case_008 (half floor) -- part 1.

SDU-7 Half Floor																					
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**						
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
Roof delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	6	15.24	15.2	0	15.2	0	15.2	0.03	0.027	0.021	0.011	567	721	1401	0.27	0.17	0.0271	0	0	1	5
FloorUMM delay+degradation			-833		-679		0					567	**721**	1401				1400	**1400**	1401	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	8.73	22.17	14.3	7.85	17.2	4.93	21	1.19	0.027	0.021	0.011	533	815	1933	0.27	0.17	0.0271	533	815	1933	5
Wall delay+degradation			0		0		0					533	**815**	1933				533	**815**	1933	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	10.45	26.54	17.1	9.39	20.7	5.85	25.2	1.31	0.027	0.021	0.011	639	979	2324	0.27	0.17	0.0271	639	979	2324	5
Wall delay+degradation			0		0		0					639	**979**	2324				639	**979**	2324	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	13.46	34.19	22.1	12.1	26.7	7.53	32.7	1.49	0.027	0.021	0.011	822	1261	3012	0.27	0.17	0.0271	822	1261	3012	5
Wall delay+degradation			0		0		0					822	**1261**	3012				822	**1261**	3012	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	16.50	41.91	27.1	14.8	32.7	9.23	40.3	1.65	0.027	0.021	0.011	1008	1546	3708	0.27	0.17	0.0271	1008	1546	3708	5
Wall delay+degradation			0		0		0					1008	**1546**	3708				1008	**1546**	3708	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	19.45	49.4	31.9	17.5	38.5	10.9	47.6	1.79	0.027	0.021	0.011	1188	1822	4385	0.27	0.17	0.0271	1188	1822	4385	5
Wall delay+degradation			0		0		0					1188	**1822**	4385				1188	**1822**	4385	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	567	**720.8**	1401	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		801	**1305**	30684	
* Use degradation time for successive column segments																					

Table 2-13. Degradation times for Case_008 (half floor) -- part 2.

SDU-7 Half Floor																
Degradation mechanism:	**Decalcification**									**Limiting**						
	Thickness:		**A (cm/√yr)**			**Time (yr)**			**max δ**	**NV**		**Initial thickness**		**t=0 thickness**		**Times:**
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)		(in)	(cm)	(in)	(cm)	(yr)
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	12	30.48			0.021			358791	5	Roof						
Roof delay+degradation								360191		**1413**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**						
FloorUMM degradation	6	15.24			0.021			179396	5	FloorUMM						
FloorUMM delay+degradation								180796		**721**						
Wall delay					*HDPE:*			900		**0**						**-151**
Wall degradation	8.73	22.17			0.021			261020	5	Wall	⑤	10.35	26.3	8.73	22.2	Wall
Wall delay+degradation								261920		**815**						**815**
Wall delay					*HDPE:*			900		**0**						**-171**
Wall degradation	10.45	26.54			0.021			312447	5	Wall	④	12.28	31.2	10.45	26.5	Wall
Wall delay+degradation								313347		**979**						**979**
Wall delay					*HDPE:*			900		**0**						**-206**
Wall degradation	13.46	34.19			0.021			402444	5	Wall	③	15.66	39.8	13.46	34.2	Wall
Wall delay+degradation								403344		**1261**						**1261**
Wall delay					*HDPE:*			900		**0**						**-241**
Wall degradation	16.5	41.91			0.021			493338	5	Wall	②	19.07	48.4	16.5	41.9	Wall
Wall delay+degradation								494238		**1546**						**1546**
Wall delay					*HDPE:*			900		**0**						**-274**
Wall degradation	19.45	49.4			0.021			581540	5	Wall	①	22.37	56.8	19.45	49.4	Wall
Wall delay+degradation								582440		**1822**						**1822**
Grout delay			**A_U (cm/yr)**			567	721	1401		**721**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44366	**438706**	4381256		**438706**						
Column delay										**721**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1305**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	721	1305	grout21
grout2	1305	1889	grout20
grout3	1889	2473	grout19
grout4	2473	3057	grout18
grout5	3057	3641	grout17
grout6	3641	4225	grout16
grout7	4225	4809	grout15
grout8	4809	5393	grout14
grout9	5393	5977	grout13
grout10	5977	6561	grout12
grout11	6561	7145	grout11

Table 2-14. Degradation times for Case_017 (half wall and floor) -- part 1.

SDU-7 Half Wall+HalfFloor																					
Degradation mechanism:			*SA*	*Carb*	*SA*	*Carb*	*SA*	*Carb*	**Sulfate attack**						**Carbonation**						
	Thickness:		CE	CE	NV	NV	BE	BE	**A_L (cm/yr)**			**Time (yr)**			**A (cm/√yr)**			**Time (yr)**			**max δ**
Component	(in)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	CE	NV	BE	CE	NV	BE	CE	NV	BE	CE	NV	BE	(cm)
Roof delay											*clean grout:*	0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
Roof degradation	12	30.48	30.5	0	29.9	0.61	29.5	0.98	0.027	0.021	0.011	1135	1413	2717	0.27	0.17	0.0271	0	13	1317	5
Roof delay+degradation			-265		0		0					1135	**1413**	2717				1400	**1413**	2717	
FloorUMM delay												0	**0**	0			*HDPE-GCL:*	1400	1400	1400	
FloorUMM degradation	6	15.24	15.2	0	15.2	0	15.2	0.03	0.027	0.021	0.011	567	721	1401	0.27	0.17	0.0271	0	0	1	5
FloorUMM delay+degradation			-833		-679		0					567	**721**	1401				1400	**1400**	1401	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	4.12	10.46	6.31	4.16	7.26	3.2	9.66	0.81	0.027	0.021	0.011	235	343	889	0.27	0.17	0.0271	235	343	889	5
Wall delay+degradation			0		0		0					235	**343**	889				235	**343**	889	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	4.99	12.67	7.99	4.68	9.09	3.58	11.8	0.89	0.027	0.021	0.011	298	430	1085	0.27	0.17	0.0271	298	430	1085	5
Wall delay+degradation			0		0		0					298	**430**	1085				298	**430**	1085	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	6.49	16.48	10.7	5.83	12.3	4.17	15.5	1.02	0.027	0.021	0.011	397	582	1424	0.27	0.17	0.0271	397	582	1424	5
Wall delay+degradation			0		0		0					397	**582**	1424				397	**582**	1424	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	8.01	20.35	13.1	7.2	15.6	4.7	19.2	1.14	0.027	0.021	0.011	489	740	1769	0.27	0.17	0.0271	489	740	1769	5
Wall delay+degradation			0		0		0					489	**740**	1769				489	**740**	1769	
Wall delay												0	**0**	0			*no HDPE:*	0	**0**	0	
Wall degradation	9.48	24.08	15.6	8.52	18.8	5.3	22.8	1.24	0.027	0.021	0.011	579	888	2103	0.27	0.17	0.0271	579	888	2104	5
Wall delay+degradation			0		0		0					579	**888**	2103				579	**888**	2104	
Grout delay																					
Grout degradation	516	1311																			
Grout delay+degradation																					
Column delay																	*Roof or floor min:*	567	**720.8**	1401	
Column degradation*	24	60.96													1.1	0.72	0.10	234	***584***	29283	5
Column delay+degradation																		801	**1305**	30684	

* Use degradation time for successive column segments

Table 2-15. Degradation times for Case_017 (half wall and floor) -- part 2.

SDU-7 Half Wall+HalfFloor																
Degradation mechanism:			**Decalcification**							**Limiting**						
	Thickness:		**A (cm/√yr)**			**Time (yr)**			**max δ**	**NV**		**Initial thickness**		**t=0 thickness**		**Times:**
Component	(in)	(cm)	CE	NV	BE	CE	NV	BE	(cm)	(yr)		(in)	(cm)	(in)	(cm)	(yr)
Roof delay					*HDPE-GCL:*			1400		**0**						
Roof degradation	12	30.48			0.021			358791	5	Roof						
Roof delay+degradation								360191		**1413**						
FloorUMM delay					*HDPE-GCL:*			1400		**0**						
FloorUMM degradation	6	15.24			0.021			179396	5	FloorUMM						
FloorUMM delay+degradation								180796		**721**						
Wall delay					*HDPE:*			900		**0**						**-87**
Wall degradation	4.12	10.46			0.021			123185	5	Wall	⑤	5.16	13.1	4.12	10.5	Wall
Wall delay+degradation								124085		**343**						**343**
Wall delay					*HDPE:*			900		**0**						**-99**
Wall degradation	4.99	12.67			0.021			149197	5	Wall	④	6.14	15.6	4.99	12.7	Wall
Wall delay+degradation								150097		**430**						**430**
Wall delay					*HDPE:*			900		**0**						**-120**
Wall degradation	6.49	16.48			0.021			194046	5	Wall	③	7.83	19.9	6.49	16.5	Wall
Wall delay+degradation								194946		**582**						**582**
Wall delay					*HDPE:*			900		**0**						**-141**
Wall degradation	8.01	20.35			0.021			239493	5	Wall	②	9.54	24.2	8.01	20.3	Wall
Wall delay+degradation								240393		**740**						**740**
Wall delay					*HDPE:*			900		**0**						**-160**
Wall degradation	9.48	24.08			0.021			283445	5	Wall	①	11.19	28.4	9.48	24.1	Wall
Wall delay+degradation								284345		**888**						**888**
Grout delay			**A_U (cm/yr)**			567	721	1401		**721**						
Grout degradation	516	1311	3.0E-02	3.0E-03	3.0E-04	43799	437985	4379855		Grout						
Grout delay+degradation						44366	**438706**	4381256		**438706**						
Column delay										**721**						
Column degradation*	24	60.96								Column						
Column delay+degradation										**1305**						

* Use degradation time for successive column segments

segment	**start (yr)**	**end (yr)**	**segment**
grout1	721	1305	grout21
grout2	1305	1889	grout20
grout3	1889	2473	grout19
grout4	2473	3057	grout18
grout5	3057	3641	grout17
grout6	3641	4225	grout16
grout7	4225	4809	grout15
grout8	4809	5393	grout14
grout9	5393	5977	grout13
grout10	5977	6561	grout12
grout11	6561	7145	grout11

2.5 Case_007 (half roof) flow behavior

Case_007, involving a half-thickness roof, exhibited unexpected flow behavior as indicated by Figure 2-4. The upper left figure is total flow (cm^3/yr) through the saltstone monolith. The lower left figure is average Darcy velocity or volumetric flux (cm/s). The average downward flux component is shown in the upper right. Horizontal Darcy velocity through the sand drainage layer above the roof is plotted in the lower right. Case_007 exhibits significantly lower flow through saltstone, and water is shunted laterally through the sand drain layer. This behavior was unexpected.

No errors were detected in Case_007 inputs so additional simulations were performed for diagnostic purposes. Case_007.2 involved a tighter convergence tolerance on numerical iterations. Case_007.3 used a different initial condition to test for potential non-uniqueness and/or incomplete convergence. Case_007.4 retained the original roof thickness, but increased the conductivity by two-fold to match the vertical leakance coefficient of a half-thickness roof. The *leakance coefficient* (or *leakance*) of a layer is derived from Darcy's Law by collecting hydraulic conductivity (K_v) and thickness (Δz) into a single parameter (L_v) reflecting the combined influence of conductivity and thickness on vertical flow (V) for a given hydraulic head difference (Δh):

$$V = K_v \frac{\Delta h}{\Delta z} = \frac{K_v}{\Delta z} \Delta h \equiv L_v \Delta h$$

The same leakance coefficient results whether thickness is halved or conductivity is doubled. Case_007.5 halved the number of grid layers in the half-thickness roof to preserve grid resolution in that component.

Figure 2-5 presents flow results for these cases. All of the diagnostic cases except Case_007.4 produced essentially the same flow behavior as Case_007. Case_007.4 produced the qualitative behavior expected for Case_007: slightly higher flow through saltstone due to earlier degradation of roof leading to earlier degradation of saltstone. For aquifer transport simulations, Case_007.4 was renamed to Case_018 in PORFLOW modeling to avoid confusion with Case_007. In the results interpretation report, this case is referred to as "Case 7B" and "Case_007B". Case_018 / Case 7B was proposed as a surrogate replacement for original Case_007 pending a definitive diagnosis of Case_007 behavior.

Further effort was expended to explain Case_007 flow behavior. Figure 2-6 shows saturation, pressure head, saturation residual error, and mass balance error for the FY2014 SDF SA Evaluation Case (Case_sa), and Figure 2-7 provides the same plots for Case_007. Case_007 exhibits a slightly lower saturation state than the Evaluation Case. The other sensitivity cases generally produced saturation results more similar to the Evaluation Case, as indicated by Figure 2-8. One exception is Case_009 (smaller tank diameter) which allows water to more easily shed off the roof through the sand drainage layer. Figure 2-9 compares saltstone saturation for Case_007 and Case_009 to the results from Figure 2-8.The slightly lower saturation state of saltstone in Case_007 causes a sufficient decrease in relative permeability to reduce saltstone flow by roughly half (Figure 2-4).

The reason for lower saltstone saturation in Case_007 is unclear. Perhaps the closer proximity of the unsaturated sand drainage layer to the saltstone monolith imparts lower saturation on the latter. Further investigation would be needed for a decisive conclusion.

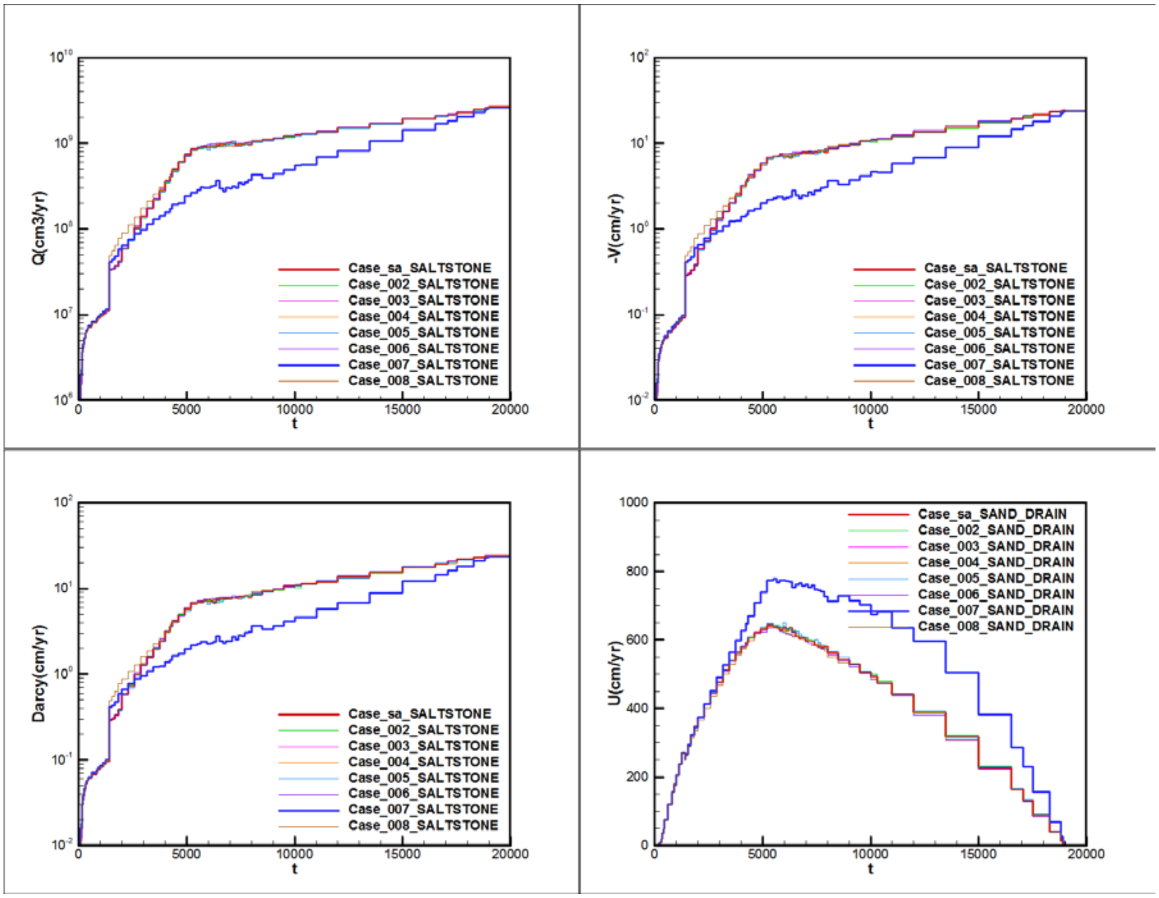


Figure 2-4. Flow through the saltstone monolith for various modeling cases.

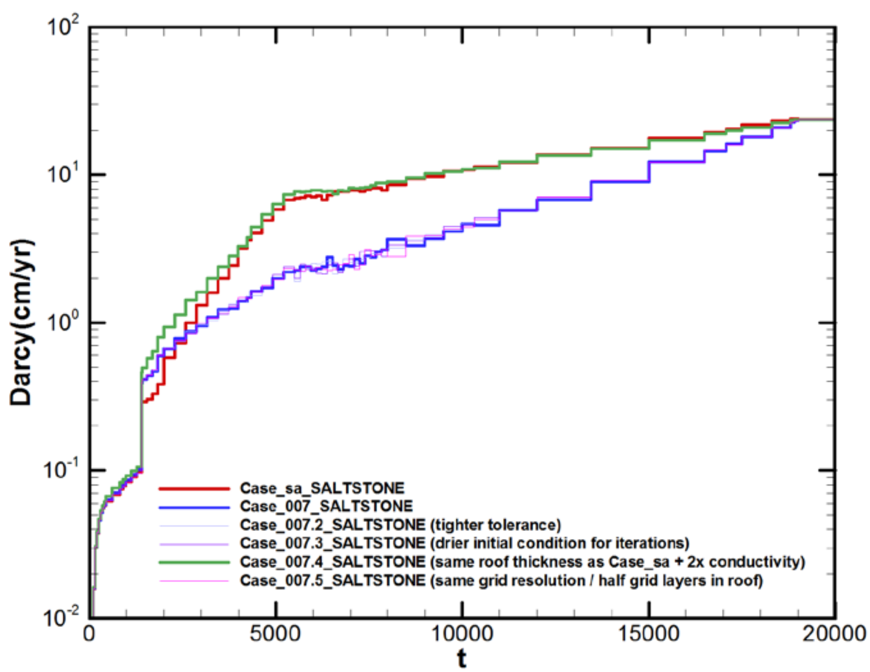


Figure 2-5. Flow through the saltstone monolith for Case_007 diagnostic cases.

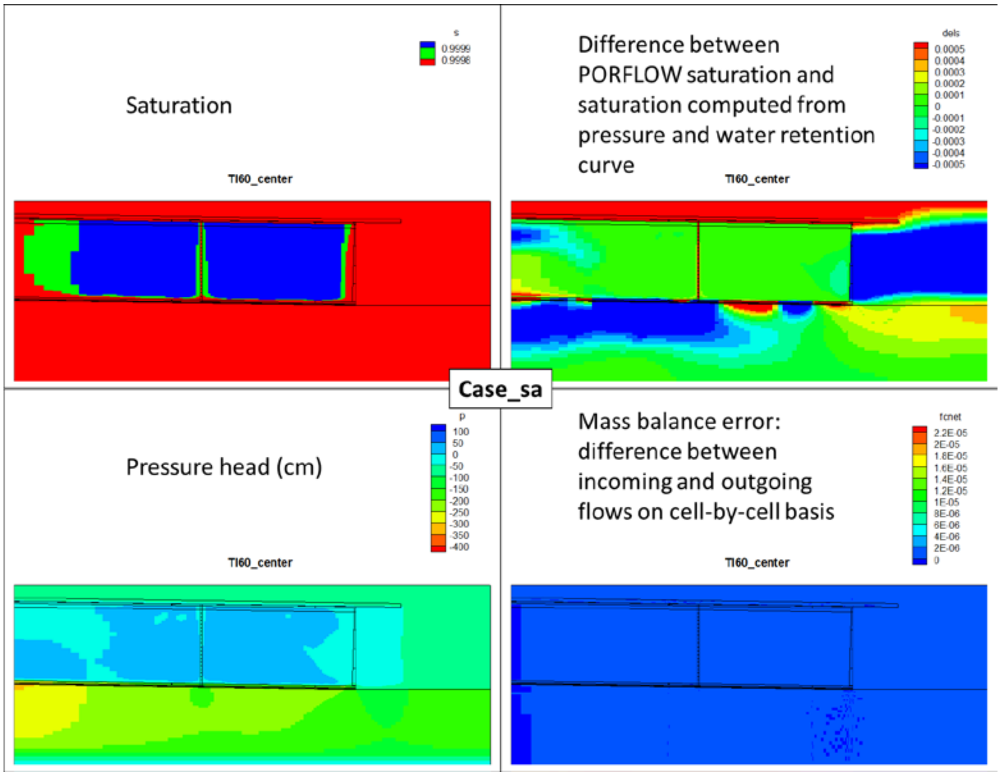


Figure 2-6. Flow diagnostic results for Case_sa.

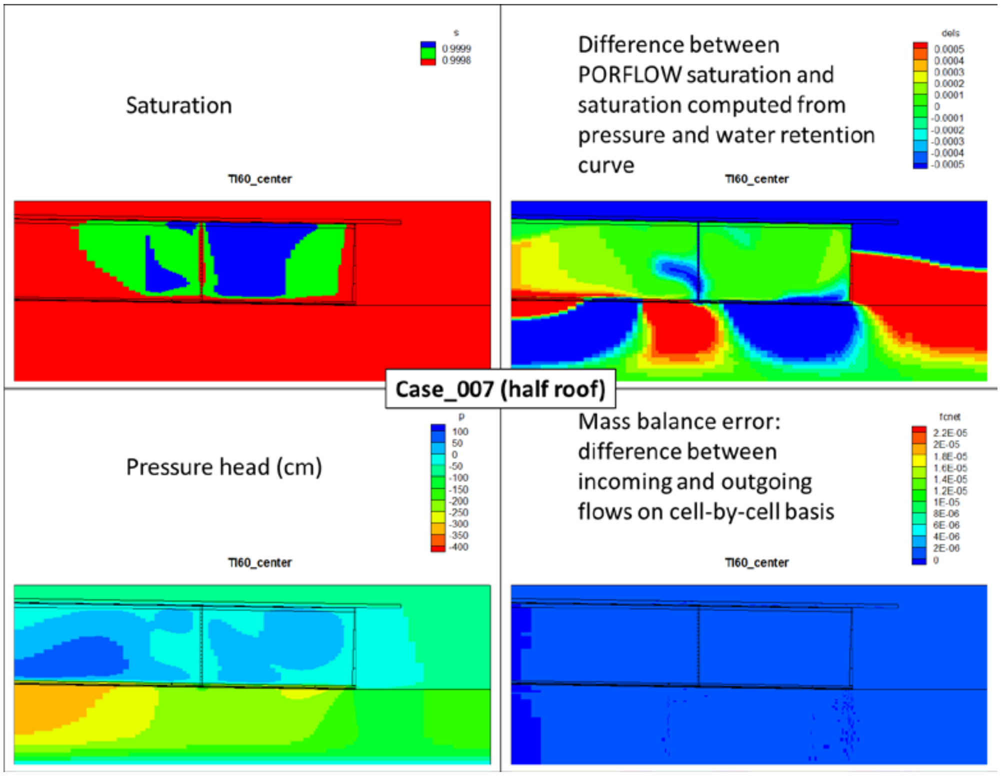


Figure 2-7. Flow diagnostic results for Case_007.

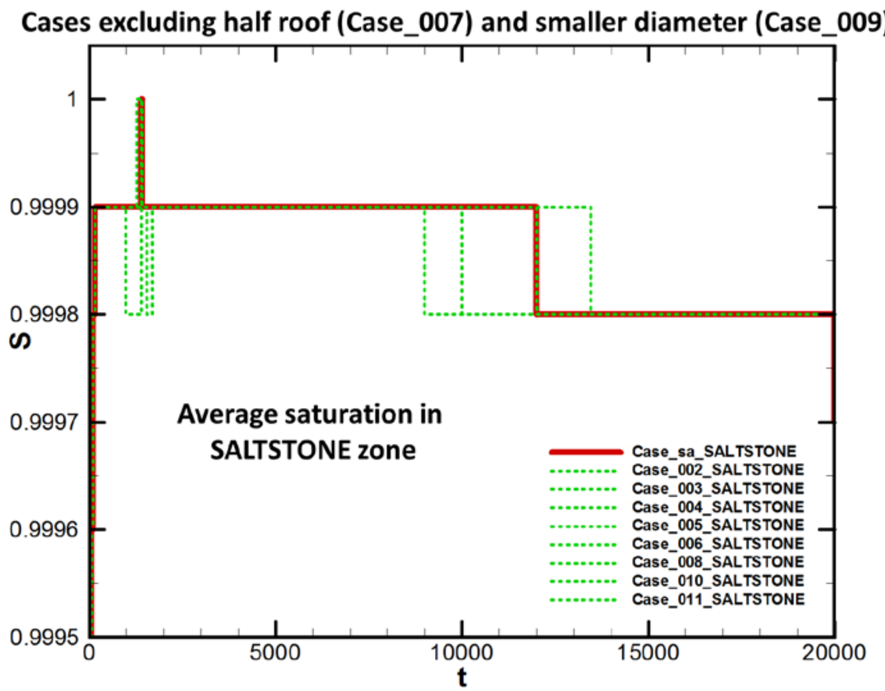


Figure 2-8. Saltstone saturation excluding Case_007 and Case_009.

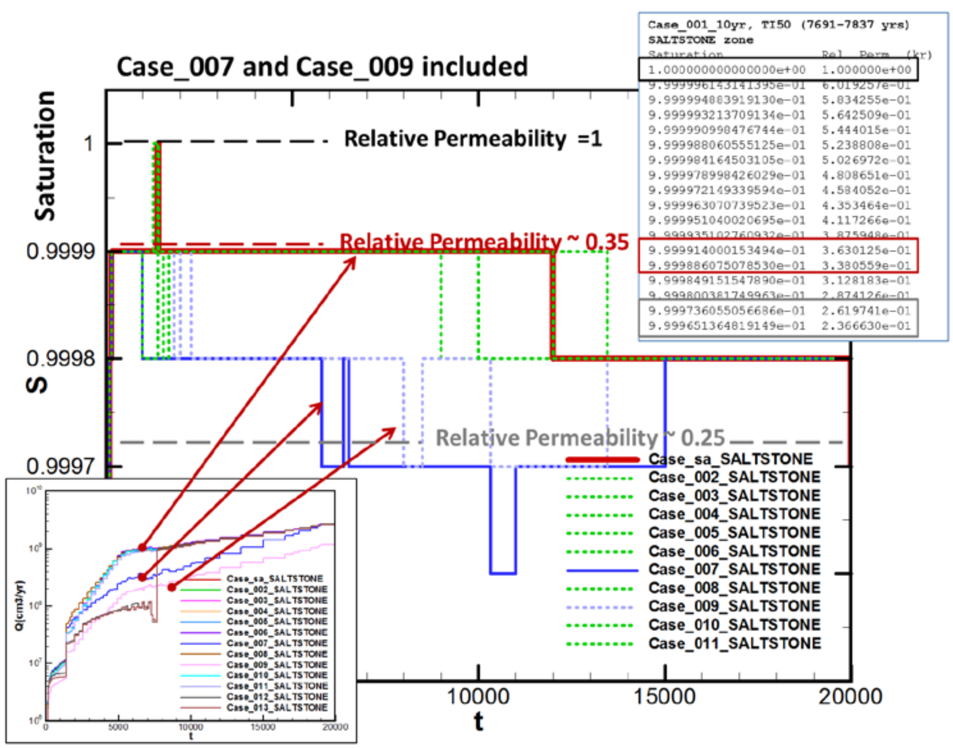


Figure 2-9. Saltstone saturation excluding Case_007 and Case_009.

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