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488-4D Ash Landfill Closure Cap HELP Modeling

Mark A. Phifer

November 2014

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Tad Whiteside provided invaluable help by producing a virtual XP machine, which allowed the Hydrologic Evaluation of Landfill Performance (HELP) computer code to be run on a Windows 7 machine.

EXECUTIVE SUMMARY

At the request of Area Completion Projects (ACP) in support of the 488-4D Landfill closure, the Savannah River National Laboratory (SRNL) has performed Hydrologic Evaluation of Landfill Performance (HELP) modeling of the planned 488-4D Ash Landfill closure cap to ensure that the South Carolina Department of Health and Environmental Control (SCDHEC) limit of no more than 12 inches of head on top of the barrier layer (saturated hydraulic conductivity of no more than 1.0E-05 cm/s) in association with a 25-year, 24-hour storm event is not projected to be exceeded. Based upon Weber 1998 a 25-year, 24-hour storm event at the Savannah River Site (SRS) is 6.1 inches. The results of the HELP modeling indicate that the greatest peak daily head on top of the barrier layer (i.e. geosynthetic clay liner (GCL) or high density polyethylene (HDPE) geomembrane) for any of the runs made was 0.079 inches associated with a peak daily precipitation of 6.16 inches. This is well below the SCDHEC limit of 12 inches.

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ACP	Area Completion Projects
CLM	Central Climatology site
ET	evapotranspiration
GCL	geosynthetic clay liner
GDL	geosynthetic drainage layer
HDPE	high density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
LS	loamy sand
SC	clayey sand
SCDHEC	South Carolina Department of Health and Environmental Control
SCL	sandy clay loam
SM	silty sand
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WES	Waterways Experiment Station

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1.0 Introduction

The South Carolina Department of Health and Environmental Control (SCDHEC) has requested that Savannah River Nuclear Solutions (SRNS) perform Hydrologic Evaluation of Landfill Performance (HELP) modeling of the planned 488-4D Ash Landfill closure cap to ensure that no more than a 12 inch head will develop on top of the barrier layer (saturated hydraulic conductivity of no more than 1.0E-05 cm/s) in association with a 25-year, 24-hour storm event. In addition SCDHEC has requested that HELP modeling also be performed for an alternative closure cap that utilizes high density polyethylene (HDPE) geomembrane as the barrier layer rather than the current geosynthetic clay liner (GCL).

This report documents performance of the requested HELP modeling as follows:

- Section 1.1 provides a brief overview of the 488-4D closure cap.
- Section 1.2 provides a brief overview of the HELP model.
- Section 2.1 provides an overview of the development of the HELP model weather input.
- Section 2.2 provides an overview of the development of the 488-4D Ash Landfill soil, geomembrane, and closure cap design input.
- Section 3.0 provides the results and conclusions.

1.1 488-4D Ash Landfill Closure Cap

Removal of ash from the 488-2D Ash Landfill, placement of the 488-2D ash within the 488-4D Ash Landfill, and construction of a closure cap over the 488-4D Ash Landfill is planned (C-SPP-D-00002). Figure 1-1 provides the planned profile of the 488-4D closure cap (C-CG-D-00017). HELP modeling has been performed based upon this base case profile and for an alternative profile where the GCL has been replaced with a HDPE geomembrane.

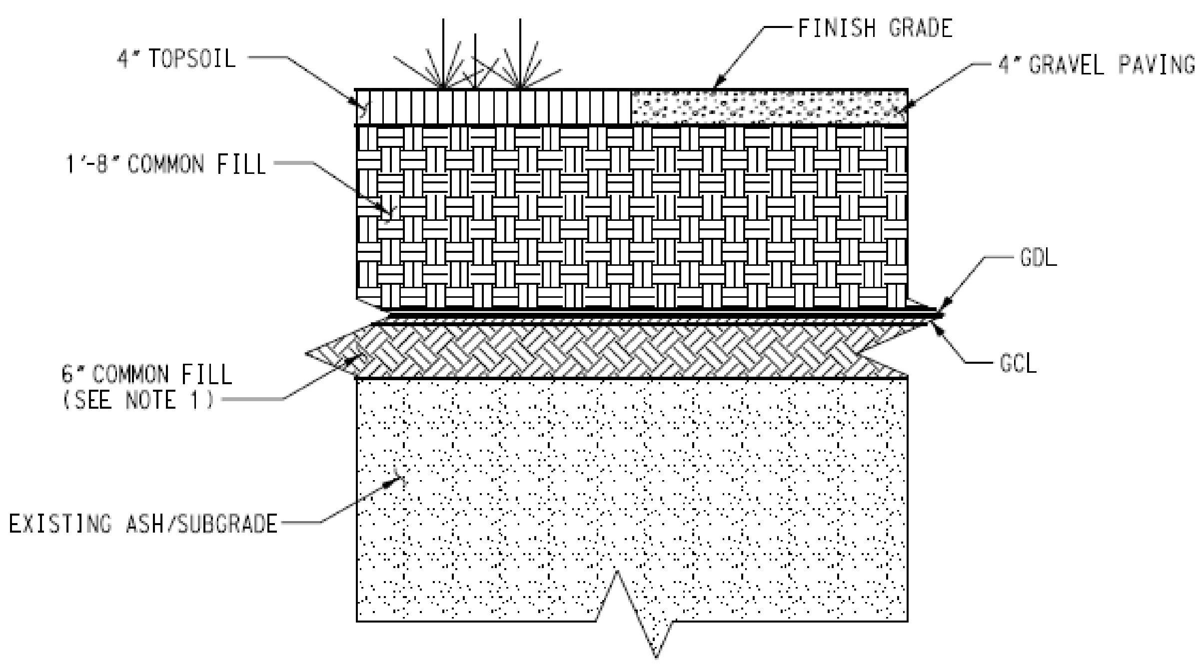

Figure 1-1. 488-4D Closure Cap Profile

(GDL = geosynthetic drainage layer; GCL = geosynthetic clay liner)

1.2 HELP Model

The HELP model is a quasi-two-dimensional water balance model designed to conduct landfill water balance analyses. The model requires the input of weather, soil, and closure cap design data. It provides estimates of runoff, evapotranspiration, lateral drainage, vertical percolation (i.e., infiltration), hydraulic head, and water storage for the evaluation of various landfill designs.

United States Army Corps of Engineers (USACE) personnel at the Waterways Experiment Station (WES) in Vicksburg, Mississippi developed the HELP model, under an interagency agreement (DW21931425) with the U.S. Environmental Protection Agency (USEPA). As such the HELP model is a USEPA-sanctioned model for conducting landfill water balance analyses. HELP model version 3.07, issued on November 1, 1997, is the latest version of the model. It is public domain software available from the WES website at:

http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=landfill.

USEPA and the USACE have provided the following documentation associated with the HELP model:

- A user’s guide (Schroeder et al. 1994a), which provides instructions for HELP model use.
- Engineering documentation (Schroeder et al. 1994b), which provides information on the source language used to write the code, the hardware necessary to operate the code, data generation methodologies available for use, and the methods of solution.
- Verification test reports comparing the model’s drainage layer estimates to the results of large-scale physical models (Schroeder et al. 1987a) and comparing the model’s water balance estimates to “field data from a total of 20 landfill cells at 7 sites in the United States” (Schroeder et al. 1987b).

2.0 HELP Model Input Data

2.1 HELP Model Weather Input

Required HELP model weather input includes:

- Precipitation data
- Temperature data
- Solar Radiation data
- Evapotranspiration data

The HELP model has a synthetic weather data option for the creation of precipitation, temperature, and solar radiation data. The option allows the generation of synthetic weather data based upon city specific data stored within the HELP model modified by the user’s site specific data. Therefore synthetic daily precipitation and temperature data over 100 years has been generated based upon the HELP synthetic weather data option for Augusta, GA, that has been modified with the SRS specific average monthly precipitation and temperature data, respectively. SRS collects meteorological data from a network of weather stations. The primary SRS precipitation data has been collected from the Savannah River National Laboratory (SRNL) (773-A) weather station between 1952 and 1995 and from the Central Climatology site (CLM) since 1995. The primary SRS temperature data has been collected from the SRNL weather station between 1968 and 1995 and from the CLM since 1995. This data (Tables 2-1 and 2-2, respectively) has been extracted from the Atmospheric Technologies Center web page (http://shweather.srs.gov/Weather/) and has been used to generate the HELP model precipitation and temperature input data. The synthetic weather data option for Augusta, GA, has also been utilized to generate the solar radiation input data, and the default Augusta, GA values for evapotranspiration data have been used to generate the evapotranspiration input data. The evaporative zone depth has been set to 24 inches based upon the thickness of soil material over the GDL and the acceptable range of evaporative zone depth for Augusta, GA, of 10 to 40 inches. The maximum leaf area index has been set at 3.5, which represents a good stand of grass, based upon the sodding and permanent seeding requirements of Specification C-SPP-D-00002. The following are the weather input files which have been generated:

- Precipitation data: DALPREC.D4
- Temperature data: DALTEMP.D7
- Solar Radiation data: DALSOLR.D13
- Evapotranspiration data: DALEVAP.D11

Table 2-1. SRS Specific Precipitation Data

Year	Jan Precip. (inches)	Feb Precip. (inches)	March Precip. (inches)	April Precip. (inches)	May Precip. (inches)	June Precip. (inches)	July Precip. (inches)	Aug Precip. (inches)	Sept Precip. (inches)	Oct Precip. (inches)	Nov Precip. (inches)	Dec Precip. (inches)
1952	2.07	3.23	6.55	3.12	5.56	5.67	2.82	5.98	3.34	1.36	2.86	3.99
1953	2.69	5.48	3.83	2.96	4.42	5.38	3.63	3.61	8.53	0.11	1.04	7.51
1954	1.26	1.64	2.95	2.5	2.89	2.91	2.03	4.1	1.43	1.29	2.94	2.88
1955	4.75	2.62	2.21	5.57	4.53	3.31	3.94	5.07	3.42	1.32	2.93	0.46
1956	1.67	7.94	4.84	3.21	3.07	2.34	4.34	3.18	4.56	1.83	0.93	2.05
1957	2.05	1.58	4.29	2.75	8.02	4.17	3.51	2.41	5.04	6.12	6.46	2.24
1958	4.01	4.38	4.96	5.63	2.07	2.5	5.32	2.76	1.12	0.96	0.21	4.42
1959	3.54	6.06	6.44	2.03	3.81	4.06	5.8	2.93	8.71	10.86	1.97	3.54
1960	6.91	5.81	5.76	5.07	1.96	3.66	5.27	2.81	4.84	0.97	0.83	2.93
1961	3.59	5.76	7.23	8.2	3.88	3.01	3.09	7.15	1	0.07	1.83	6.6
1962	4.64	5.14	6.52	4.03	3.5	4.41	2.56	3.43	5.55	2.27	3.5	2.2
1963	5.96	3.64	3.34	3.7	2.98	8.42	3.18	1.04	5.37	0	3.68	4.47
1964	7.79	6	5.79	5.94	3.62	4.5	10.42	12.34	5.43	6.53	0.6	4.1
1965	1.83	6.19	10.18	2.81	1.63	5.14	9.57	1.29	2.36	2.95	1.99	1.69
1966	7.81	6.22	4.3	2.93	5.28	4.81	3.52	5.84	3.98	1.51	1.37	3.85
1967	3.91	4.43	7.54	2.6	5.94	4.06	7.23	8.48	0.99	0.31	2.81	3.37
1968	4.56	0.97	1.58	2.23	4.24	5.28	3.58	8.05	5.06	3.33	4.14	2.93
1969	2.2	2.47	3.42	4.71	2.57	4.26	1.94	4.38	4.05	2	0.4	4.42
1970	3.12	2.75	7.9	1.28	4.01	4.68	4.69	3.78	2.75	4.02	1.5	5.62
1971	5.01	3.8	9.71	2.57	3.62	4.81	13.71	9.98	4.74	5.27	2.16	2.79
1972	7.81	3.71	2.68	0.6	4.1	5.64	1.92	8.19	1.52	1.03	2.92	4.26
1973	5.5	4.47	6.67	4.55	4.91	12.97	6.86	3.9	4.38	1.72	0.98	3.99
1974	2.42	6.66	3.03	3.05	3.35	2.8	4.44	6.77	3.32	0.09	1.99	4.11
1975	4.98	6.64	5.92	4.42	5.15	3.83	8.55	3.83	5.18	1.74	3.41	2.03
1976	4.18	1.08	3.83	2.5	10.9	4.35	1.95	1.64	5.48	4.92	4.19	5.08
1977	3.72	1.62	6.86	1.27	1.79	2.47	3.42	7.3	5.5	4.27	1.63	3.86

Year	Jan Precip. (inches)	Feb Precip. (inches)	March Precip. (inches)	April Precip. (inches)	May Precip. (inches)	June Precip. (inches)	July Precip. (inches)	Aug Precip. (inches)	Sept Precip. (inches)	Oct Precip. (inches)	Nov Precip. (inches)	Dec Precip. (inches)
1978	10.02	1.31	3.06	3.53	3.64	3.42	4.11	5.1	4.06	0.06	3.54	1.87
1979	3.59	7.74	3.09	6.49	8.94	1.54	7.85	2.12	6.13	1.35	3.95	2.17
1980	5.12	3.48	10.96	1.69	3.49	2.99	0.9	2.03	5.86	2.14	2.5	1.91
1981	0.89	5.02	4.72	2.07	6.9	4.29	3.96	5.79	0.54	2.81	1	9.55
1982	3.94	4.46	2.51	5.68	2.73	4.28	11.49	5.02	4.62	3.87	2.41	4.85
1983	3.75	7.22	6.62	5.77	1.67	6.57	4.85	6.32	3.56	1.92	5.39	4.15
1984	3.51	7.09	6.05	8	9.79	2.54	7.28	5.52	0.6	0.31	0.9	1.38
1985	3.01	6.92	1.31	0.84	1.7	4.62	8.1	4.38	0.49	6.34	6.36	2.48
1986	1.46	3.58	4.08	1.45	3.84	3.03	2.96	10.9	1.54	4.19	5.82	5.83
1987	7.39	7.55	4.97	0.7	3.57	5.64	4.87	4.93	3.56	0.29	2.74	1.42
1988	4.15	3.19	2.91	4.78	2.85	7.12	1.78	6.8	4.4	3.39	2.17	2.91
1989	1.42	3.59	5.52	4.89	2.6	6.67	11.46	3.27	4.87	3.36	3	4.41
1990	3.07	2.38	2.37	1.21	2.95	0.89	7.31	8.07	0.62	19.62	1.41	1.57
1991	7.03	1.84	7.89	4.73	3.06	2.17	7.89	9.26	4.4	0.99	1.55	3.32
1992	4.45	3.89	2.98	2.4	1.34	6.27	3.69	4.83	6.38	3.11	7.78	2.86
1993	7.45	3.62	8.37	1.74	1.43	3.27	3.12	2.23	7.29	0.99	1.87	1.81
1994	4.8	3.91	6.42	1.05	1.45	5.08	7.47	3.47	0.99	10.01	3.05	4.62
1995	6.96	7.97	0.92	1.28	1.77	8.15	5.71	6.92	5.75	2.64	2.38	4.47
1996	3.65	2.43	6.64	2.4	2.96	3.04	5.57	6.91	3.67	2.16	2.32	3.2
1997	4.2	5.45	2.69	4.38	2.38	6.9	7.09	2.01	4.89	4.08	5.51	9.09
1998	7.73	8.9	6.69	7.35	4.05	4.65	5.27	2.88	4.81	0.78	0.82	1.8
1999	5.31	2.29	3.44	1.95	1.26	7.52	4.91	3.14	4.46	2.57	1.5	1.21
2000	5.77	0.73	3.95	1.34	1.36	4.74	2.47	4.49	7.7	0.02	3.5	1.53
2001	3.11	2.68	7.21	1.28	3.85	6.49	4.79	3.55	3.33	0.5	1.03	0.54
2002	2.85	2.13	3.86	2.58	1.69	2.3	5.95	5.47	3.45	3.19	4	3.58
2003	1.73	5	7.09	8.43	5.57	10.99	8.91	4.59	2.7	3.03	1.21	1.93
2004	2.85	6.71	0.81	1.34	3.45	6.41	1.23	2.96	10.26	1.02	3.17	2.69

Year	Jan Precip. (inches)	Feb Precip. (inches)	March Precip. (inches)	April Precip. (inches)	May Precip. (inches)	June Precip. (inches)	July Precip. (inches)	Aug Precip. (inches)	Sept Precip. (inches)	Oct Precip. (inches)	Nov Precip. (inches)	Dec Precip. (inches)
2005	2.14	3.89	6.09	1.69	2.87	8.23	5.81	4.08	0.19	3.6	2.67	6.16
2006	3.38	2.9	1.76	2.41	1.83	6.89	5.22	2.19	2.5	1.66	2.98	4.56
2007	3.27	3.6	1.98	2.95	1.23	4.83	4.57	2.66	0.97	1.35	0.55	8.79
2008	3.72	5.36	3.04	2.39	1.82	1.37	5.44	5.4	0.94	4.12	5.14	2.87
2009	1.98	1.68	3.65	4.6	5.2	2.73	2.56	3.13	3.73	3	5.45	10.24
2010	4.83	2.37	3.03	1.51	2.56	5.65	2.74	5.22	2.86	0.31	1.32	1.34
2011	2.24	4.92	5.5	1.83	1.1	1.47	4	2.98	4.34	2.07	1.13	1.66
2012	1.8	1.5	3.57	1.78	8.93	2.37	5.95	6.36	2.57	0.29	1.29	4.8
2013	0.77	10.11	3.25	5.04	2.36	9.64	12.92	5.64	1.14	1.44	1.72	4.6
Ave	**4.05**	**4.32**	**4.80**	**3.29**	**3.65**	**4.75**	**5.28**	**4.85**	**3.84**	**2.73**	**2.62**	**3.67**

Table 2-2. SRS Specific Temperature Data

Year	Jan Temp. (°F)	Feb Temp. (°F)	March Temp. (°F)	April Temp. (°F)	May Temp. (°F)	June Temp. (°F)	July Temp. (°F)	Aug Temp. (°F)	Sept Temp. (°F)	Oct Temp. (°F)	Nov Temp. (°F)	Dec Temp. (°F)
1968	43.5	43.4	57.1	66.5	71.3	80	83.1	82.8	77	67	55.4	45.9
1969	46.5	46.6	51.5	64.5	70.5	80.3	83.3	77.6	72.8	66.1	52.1	45.4
1970	39	47.2	55.9	66.8	74.2	79	81.1	80.8	78.6	67	51.6	49.3
1971	44.6	46.4	49.5	63.4	70.7	81.3	80.7	80.4	75.2	70.2	55.5	56.9
1972	51.7	45.6	57.6	67.4	72.4	75.3	79.7	80.6	77.2	64.8	54.4	53.2
1973	46.1	45.9	60.7	61.9	70.5	77.7	79.1	74.5	70.5	62.4	59	50.3
1974	59.6	50.8	62.2	66.2	75.3	77.5	81.5	80.9	75.3	64.5	56.6	49
1975	51.4	53.2	55.8	63.9	75.6	79.1	79.7	82.4	75.7	68.7	59.3	48.5
1976	44.2	55.7	61.5	64.8	68.9	75.6	80.4	78	73.1	60.1	48.7	44.8
1977	35.3	47.1	60	66.9	73.3	80.6	83.6	80.6	77.9	62.1	58.2	46.7
1978	39.3	41.3	54.2	65.7	70.9	79.7	82.1	81.2	77.1	65.6	60.7	49.6

Year	Jan Temp. (°F)	Feb Temp. (°F)	March Temp. (°F)	April Temp. (°F)	May Temp. (°F)	June Temp. (°F)	July Temp. (°F)	Aug Temp. (°F)	Sept Temp. (°F)	Oct Temp. (°F)	Nov Temp. (°F)	Dec Temp. (°F)
1979	42.1	44.6	57.5	64.5	71.3	75.1	79.6	80.5	73.4	64.8	57.4	47.4
1980	45.9	44.3	52.6	63.5	71.2	78.3	83.8	82.5	79.2	62.7	52.8	46
1981	40.4	48.5	53	67	68.6	81.3	81.3	76.3	74	62.1	54.4	43.2
1982	43	50	58.9	62.4	75.7	78.8	80.9	80.1	75	66.2	58.7	54.8
1983	43.3	48	55.3	59.4	66.8	76.7	84.3	83.9	74.8	67.2	56.4	45.8
1984	45	51.7	56.5	62.6	71.9	80.1	80.1	80.8	74	73.4	53.4	56.9
1985	42.9	49.5	60.2	67.5	74.5	80.8	81.1	79.7	75.7	70.8	65.5	45.4
1986	45.4	54.6	57.9	66.4	74.4	82.7	86.9	80.1	78.4	67.1	61.3	49.3
1987	46.2	48.6	56.5	62.3	74.5	79.9	82.8	83.8	76.6	60.7	59.1	52.9
1988	42.3	47.8	56.8	64.2	70.4	76.8	81.6	81.4	75.4	61.2	58	49.1
1989	52.2	52	58.3	64.2	70.6	79.8	81.4	80.9	75.3	67.3	52.4	44.2
1990	54.9	57.5	60	64	72.9	80.5	83.7	83.8	79	69.4	59.9	54.6
1991	47.9	54.1	60.3	69.2	76.9	79.5	83.6	81.2	77.4	68.1	55.4	54
1992	49.5	54.1	57.2	65	71.2	78.9	83.7	80.7	76.9	65	57.1	48
1993	51.7	47.8	53.2	58.9	69.7	78.2	83.6	80	75.2	62.8	55.2	43.6
1994	41.5	50.1	60.2	68	71.2	82.3	81.8	81.2	77.4	67.2	62.3	53.3
1995	45.5	49.9	58.6	65.9	73.5	75	79.9	79	71.8	65.9	50.8	43.8
1996	44.6	50.1	50.6	61.6	72.9	76.5	79.3	76	72.7	62.1	51.6	48.8
1997	48.2	52.9	63.3	61.2	68.5	74	80.2	79	75	64.1	51.6	47
1998	49.7	51.1	53.6	62.7	74.6	82.1	82.6	80.3	75.8	66.9	60.5	53.6
1999	51.9	51.6	53.4	67.2	69.7	76.6	80.7	82.9	73.8	64.3	58.1	48.6
2000	44.4	50.2	58.5	60.7	75.1	78	79.9	77.6	71.7	62.5	53.1	38.2
2001	43.8	52.4	53	63.9	71.3	75.3	77.7	78.8	71.2	62.2	60	52.4
2002	47.3	48	57.6	68.1	70.2	77.5	80.5	78.4	75.4	66.7	51.7	44.5
2003	42	47.5	57.6	61.6	70.6	75.2	77.3	77.7	71.9	63.7	58.2	42.9
2004	43.7	45.2	58.5	63.4	74	77.7	80.1	77.3	73.2	66.2	56.1	45.8
2005	47.9	49	53.1	60.9	68	75.4	79.4	78.8	77	64.7	56.1	44.3

Year	Jan Temp. (ºF)	Feb Temp. (ºF)	March Temp. (ºF)	April Temp. (ºF)	May Temp. (ºF)	June Temp. (ºF)	July Temp. (ºF)	Aug Temp. (ºF)	Sept Temp. (ºF)	Oct Temp. (ºF)	Nov Temp. (ºF)	Dec Temp. (ºF)
2006	50.8	47.3	55.3	66.3	70.1	76.2	80.3	80.5	72.9	62.4	53.6	50.6
2007	48.6	46.4	58.4	61.8	70.2	76.5	77.4	81.9	75.2	68.7	54	52.3
2008	43.8	51.1	55.3	61.8	70.2	80.1	78.7	77.9	73.7	61.1	50	52.1
2009	44.9	47.4	55.2	62.3	70.7	79.2	78.6	78.2	74.1	62.7	54.6	45.5
2010	40.8	41.4	51.9	64.6	73.7	80	81	80	76.2	64	54	39.2
2011	41.3	50.9	56.8	66.8	72	81.4	81.9	81.3	74.1	60.8	55.6	51
2012	49.6	52.5	63.7	65.7	72.6	74.8	80.6	76	72.8	64.3	51.5	51.2
2013	52.1	46.8	49.7	62.6	68.5	76.2	76.9	76.3	73.7	64.6	52.6	50.9
Ave	**46.0**	**49.1**	**56.6**	**64.3**	**71.8**	**78.3**	**81.0**	**79.9**	**75.0**	**65.1**	**55.8**	**48.5**

2.2 488-4D Ash Landfill Closure Cap Design and Soil HELP Model Input

Required HELP model closure cap design, soil, and geomembrane input include:

- Closure cap design data includes: Surface and drainage layer slopes and slope lengths; landfill area; layer thicknesses; and layer types.
- Soil data includes: saturated hydraulic conductivity, porosity, field capacity, and wilting point.
- Geomembrane data includes: saturated hydraulic conductivity, geomembrane pinhole density, geomembrane installation defects, and geomembrane placement quality.

Development of this data for the 488-4D closure cap is outlined below.

Surface Slope and Slope Length & Drainage Length and Drain Slope: For the 488-4D Ash Landfill Closure Cap it is assumed that the surface slope and lateral drainage layer drainage length and that the surface slope length and lateral drainage layer drain slope are the same for any one flow path because the cover profile is constant over the closure cap (drawing C-CG-D-00017 Detail 5). The HELP model only allows the input of constant surface slopes, slope lengths, drainage lengths, and drain slopes (i.e. they cannot be varied in any one HELP model run). Additionally the HELP model does not have a provision to link multiple runs relative to runoff. Therefore average surface slopes, slope lengths, drainage lengths, and drain slopes have been utilized for 488-D HELP modeling.

Figures 2-1 and 2-2 provide the nominal and corner surface slopes, slope lengths, drainage lengths, and drain slopes (averages) to be used within the HELP model runs. Summary information is provided below:

- Nominal:
    - Slope Length = 227.55 ft
    - Slope = 14.85%
- Corner:
    - Slope Length = 212.65 ft
    - Slope = 13.8%

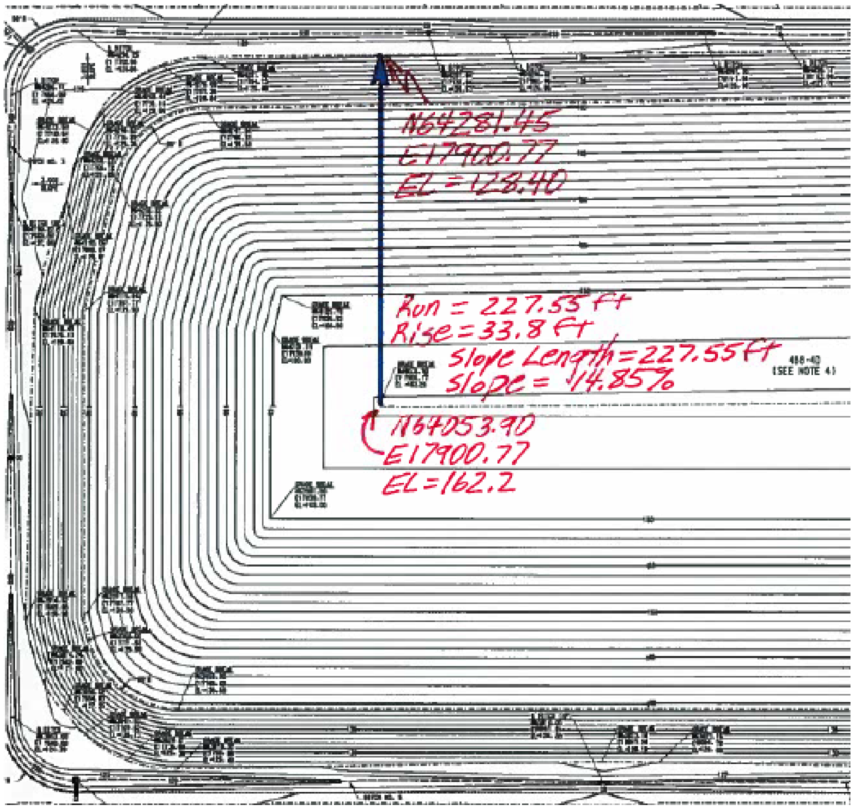

Figure 2-1. Nominal Surface and Drain Slopes and Lengths (C-CG-D-00010)

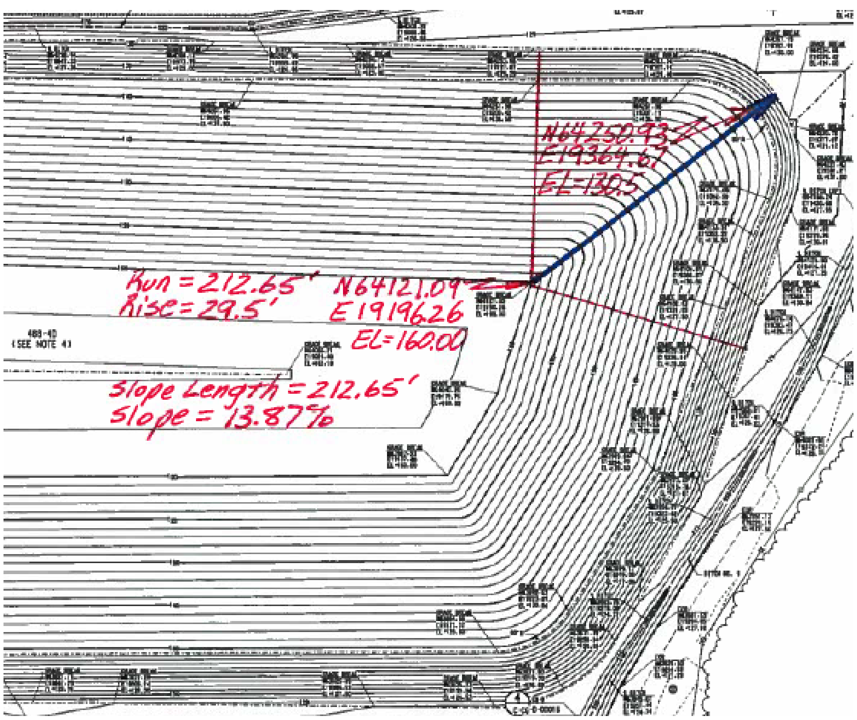

Figure 2-2. Corner Surface and Drain Slopes and Lengths (C-CG-D-00011)

Topsoil (layer number 1): Properties for the topsoil were developed as follows:

- The topsoil is defined as a vertical percolation layer in HELP.
- Per specification C-SPP-D-00002 the topsoil is to be a "medium textured soil such as loam per ASTM D5268". ASTM D5268 specifies that topsoil have the following particle size range: organic material 2 to 20 (< No. 10 sieve ashing at 440 ± 40°C); sand content 20 to 60 (< No. 10 sieve and retained on No. 200 sieve); and silt and clay content 35 to 70 (< No. 200 sieve).
- Topsoil thickness is 4 inches per Detail 5 of drawing C-CG-D-00017.
- Yu et al. 1993 provided saturated hydraulic conductivity, total porosity, and water retention (suction head versus saturation) data for two samples of SRS topsoil and Phifer et al. 2007 converted this data into the following required HELP model inputs:
  - Saturated hydraulic conductivity = 3.1E-03 cm/s
  - Total porosity (η) = 0.396
  - Field capacity = 0.109
  - Wilting point = 0.047
- These topsoil values are similar to the HELP model default soil #4 that is classified as a silty sand (SM) per the Unified Soil Classification System (USCS) and a loamy sand (LS) per the United States Department of Agriculture (USDA) (Schroeder et al. 1994a, Schroeder et al. 1994b)

Upper and Lower Common Fill (layers number 2 and 5): Properties for the common fill were developed as follows:

- The common fill is defined as a vertical percolation layer in HELP.
- The upper common fill thickness is 20 inches and the lower common fill thickness is 6 inches per Detail 5 of drawing C-CG-D-00017.
- During construction of the low permeability soils cover over the Old Radioactive Burial Grounds, testing of the common fill utilized was conducted for saturated hydraulic conductivity, total porosity, and water retention (suction head versus saturation) data. The following are the required HELP model inputs produced from this data:
  - Saturated hydraulic conductivity = 4.4E-05 cm/s
  - Total porosity (η) = 0.361
  - Field capacity = 0.247
  - Wilting point = 0.202
- The HELP model defines the field capacity as the volumetric water content (θ_v) at a soil suction head (Ψ) of 0.33 bars." (Schroeder et al. 1994a; Schroeder et al. 1994b) 0.33 bars ≈ 337 cm-H_2O (1 bar ≈ 1,020.7 cm-H_2O at 60°F). Field capacity was determined by linear interpolation between two points from the water retention (suction head versus saturation) data.
- The HELP model defines the wilting point as the volumetric water content (θ_v) at a soil suction head (Ψ) of 15 bars." (Schroeder et al. 1994a; Schroeder et al. 1994b) 15 bars ≈ 15,310 cm-H_2O (1 bar ≈ 1,020.7 cm-H_2O at 60 °F). Site specific data are not available for the determination of the SRS common fill wilting point. Therefore the wilting point from a HELP model default soil that closely resembles the SRS common fill was utilized. Table 2 of Schroeder 1994b provides HELP model moderate and high density default soils. The HELP model default soil #24, with a wilting point of 0.202, that is classified as clayey sand (SC) material (USCS) and sandy clay loam (SCL) material (USDA) is considered the closest HELP model default soil to the SRS common fill. Therefore the SRS common fill will be assigned a wilting point of 0.202 for the HELP modeling.

GDL properties (layer number 3): Properties for the GDL were developed as follows:

- The GDL is defined as a lateral drainage layer in HELP.
- Per specification C-SPP-D-00002 "the GDL shall consist of a HDPE geonet with a nonwoven geotextile fabric heat bonded to both sides …"
- Agru America Inc. 300 mil Geocomposite (Agru 2013) is considered representative of the GDL to be used.
- Agru America Inc. 300 mil Geocomposite thickness is 0.3 inches (300 mil) (Agru 2013)
- Per Agru 2013 the transmissivity of the double sided (6 oz/yd^2 geotextile) geocomposite is 9.0E-04 m^2/s. Per Koerner 1990 saturated hydraulic conductivity (K_{sat}) equals the transmissivity (T) divided by the thickness (t):
$$K_{sat} = \frac{T}{t} = \frac{9.0E-04\ m^2/s \times 10{,}000\ cm^2/m^2}{0.3\ inches \times 2.54\ cm/inch} = 11.8\ cm/s$$
- The following are default property values for drainage nets/geonets (Schroeder et al. 1994a, Schroeder et al. 1994b):
  - Total porosity (η) = 0.850
  - Field capacity = 0.010
  - Wilting point = 0.005

GCL properties (layer number 4): Properties for the GCL were developed as follows:

- The GCL is defined as a barrier soil liner in HELP.
- Per specification C-SPP-D-00002 the GCL shall consist of a minimum 0.75 lb/ft^2 sodium montmorillonite clay (bentonite) evenly distributed between two layers of supporting 6 ounces per square yard nonwoven geotextile.
- CETCO Bentomat® SDN (CETCO 2009) is considered representative of the GCL to be used.
- The typical GCL thickness is 7 to 10 mm (0.27 to 0.39 inches) (GRI 2013). Will use a thickness of 0.3 inches, as representative.
- The maximum GCL saturated hydraulic conductivity is 5E-09 cm/s per manufacturers' literature (Phifer et al. 2007, CETCO 2009). In addition to the manufacturer's maximum value, the GCL was also run with saturated hydraulic conductivities of 1.0E-08, 1.0E-07, 1.0E-06, and 1.0E-05 cm/s (i.e. SCDHEC required saturated hydraulic conductivity for the barrier layer).
- The following are default property values for bentonite/GCLs (Schroeder et al. 1994a, Schroeder et al. 1994b):
  - Total porosity (η) = 0.750
  - Field capacity = 0.747
  - Wilting point = 0.400

HDPE geomembrane properties (alternative layer number 4): Properties for the HDPE geomembrane were developed as follows:

- The HDPE geomembrane is defined as a geomembrane liner in HELP.
- The typical thickness of a HDPE geomembrane utilized for closure caps is 60 mils (0.06 inches).
- The default saturated hydraulic conductivity value for HDPE geomembranes (Schroeder et al. 1994a, Schroeder et al. 1994b) is 2.0E-13 cm/s.
- Schroeder et al. 1994a and Schroeder et al. 1994b recommend that "typical geomembranes may have about 0.5 to 1 pinhole per acre from manufacturing defects." Based upon this guidance, the as-installed HDPE geomembrane will be assumed to have 1 pinhole/acre.

- Schroeder et al. 1994a and Schroeder et al. 1994b recommend an installation defect density of 1 defect per acre for intensively monitored projects and 10 defects per acre or more “when quality assurance is limited to spot checks or when environmental difficulties are encountered during construction”. The as-installed HDPE geomembrane will be assumed to be installed with good quality assurance and will be assumed to have 4 installation defects/acre consistent with the recommendations of Schroeder et al. 1994a and Schroeder et al. 1994b.
- Under the conditions of placement of an HDPE geomembrane directly on top of common fill, Schroeder et al. 1994a and Schroeder et al. 1994b recommend a “good” (HELP model numerical designation 3) geomembrane placement quality designation.

<u>Fly Ash properties (layer number 6):</u> Properties for the fly ash were developed as follows:

- The fly ash is defined as a vertical percolation layer in HELP.
- The maximum thickness of the fly ash layer is approximately 549.6 inches.
    - From C-CG-D-00012 the original 488-4D Ash Landfill bottom was 114 ft-msl.
    - From C-CG-D-00010 the center grade break in the 488-4D closure cap is 162.35 ft-msl.
    - From C-CG-D-00017 Detail 5 the thickness of the closure cap is 2.55 ft (4 inch topsoil + 20 inch common fill + 0.3 inch GDL + 0.3 inch GCL + 6 inch common fill = 30.6 inches (2.55 ft)).
    - Maximum fly ash thickness = (162.35 – 2.55) – 114 = 45.8 ft (549.6 inches)
- HELP model default waste #30 provides the following HELP model default values for high-density electric plant coal fly ash:
    - Saturated hydraulic conductivity = 5.0E-05 cm/s
    - Total porosity (η) = 0.541
    - Field capacity = 0.187
    - Wilting point = 0.047
- The above values will be used to represent the fly ash in 488-4D

All 488-4D HELP model design input data has been summarized in Table 2-3 for the base case involving the use of a GCL barrier layer. Multiple HELP model runs were made to evaluate both the nominal and corner slopes and a range of GCL saturated hydraulic conductivities (i.e. 5E-09 (i.e. manufacturer’s maximum value), 1E-08, 1E-07, 1E-06, and 1E-05 cm/s (i.e. SCDHEC required saturated hydraulic conductivity for the barrier layer)). All 488-4D HELP model design input data has been summarized in Table 2-4 for the alternative case involving the use of a HDPE geomembrane barrier layer rather than a GCL barrier layer. Table 2-3 and Table 2-4 were used to produce the following HELP model input decks (output file name also provided):

Slope	GCL or HDPE K_{sat} (cm/s)	Input File Name	Output File Name
Nominal [1]	5.0E-09 [3]	DALN9.D10	DALN9out.OUT
Nominal	1.0E-08 [3]	DALN8.D10	DALN8out.OUT
Nominal	1.0E-07 [3]	DALN7.D10	DALN7out.OUT
Nominal	1.0E-06 [3]	DALN6.D10	DALN6out.OUT
Nominal	1.0E-05 [3]	DALN5.D10	DALN5out.OUT
Corner [2]	5.0E-09 [3]	DALC9.D10	DALC9out.OUT
Corner	1.0E-08 [3]	DALC8.D10	DALC8out.OUT
Corner	1.0E-07 [3]	DALC7.D10	DALC7out.OUT
Corner	1.0E-06 [3]	DALC6.D10	DALC6out.OUT
Corner	1.0E-05 [3]	DALC5.D10	DALC5out.OUT
Nominal	2.0E-13 [4]	DALNHDPE.D10	DALNHDPE.OUT
Corner	2.0E-13 [4]	DALCHDPE.D10	DALCHDPE.OUT

[1] Nominal: Slope Length = 227.55 ft; Slope = 14.85%
[2] Corner: Slope Length = 212.65 ft; Slope = 13.87%
[3] GCL
[4] HDPE geomembrane

Table 2-3. HELP Model Input Data for D-Area Ash Landfill Base Case Closure Cap with GCL Barrier Layer (as-built):

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	21.5 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	14.85 % [1]
Slope length =	227.55 ft [1]
Soil Texture =	4 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 54.2 [1]	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Common Fill	2	1 (vertical percolation layer)
GDL	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Lower Common Fill	5	1 (vertical percolation layer)
Fly Ash	6	1 (vertical percolation layer)

Layer #	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture [2] (Vol/Vol)
1	1	4		0.396	0.109	0.047	0.109
2	1	20		0.361	0.247	0.202	0.247
3	2	0.3		0.850	0.010	0.005	0.010
4	3	0.3		0.750	0.747	0.400	0.750
5	1	6		0.361	0.247	0.202	0.247
6	1	549.6		0.541	0.187	0.047	0.187

Layer #	Layer Type	Sat. Hyd. Conductivity (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	3.1E-03					
2	1	4.4E-05					
3	2	11.8	227.55 [1]	14.85 [1]			
4	3	5E-09 [3]					
5	1	4.4E-05					
6	1	5.0E-05					

Layer #	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	3				
5	1				
6	1				

Notes to Table 2-3:

- The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

[1] Values associated with the nominal (Slope Length = 227.55 ft; Slope = 14.85%) and corner (Slope Length = 212.65 ft; Slope = 13.87%) flow paths will be used within the HELP model runs. HELP Model Computed Curve Number is 54.2 and 54.4 for the nominal and corner slopes.

[2] Initial moisture is set at field capacity for vertical percolation and lateral drainage layers and at total porosity for barrier soil liners.

[3] The saturated hydraulic conductivity of the GCL (Bentomat® SDN) has been varied using the following values: 5E-09 cm/s, 1E-08 cm/s, 1E-07 cm/s, 1E-06 cm/s, and 1E-05 cm/s.

Table 2-4. HELP Model Input Data for D-Area Ash Landfill Alternative Case Closure Cap with HDPE Geomembrane Barrier Layer (as-built):

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	21.5 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	14.85 % [1]
Slope length =	227.55 ft [1]
Soil Texture =	4 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 54.2 [1]	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Common Fill	2	1 (vertical percolation layer)
GDL	3	2 (lateral drainage layer)
HDPE Geomembrane	4	4 (geomembrane liner)
Lower Common Fill	5	1 (vertical percolation layer)
Fly Ash	6	1 (vertical percolation layer)

Layer #	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture [2] (Vol/Vol)
1	1	4		0.396	0.109	0.047	0.109
2	1	20		0.361	0.247	0.202	0.247
3	2	0.3		0.850	0.010	0.005	0.010
4	4	0.06					
5	1	6		0.361	0.247	0.202	0.247
6	1	549.6		0.541	0.187	0.047	0.187

Layer #	Layer Type	Sat. Hyd. Conductivity (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	3.1E-03					
2	1	4.4E-05					
3	2	11.8	227.55 [1]	14.85 [1]			
4	4	2.0E-13					
5	1	4.4E-05					
6	1	5.0E-05					

Layer #	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	4	1	4	3 (Good)	
5	1				
6	1				

Notes to Table 2-4:

- The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

[1] Values associated with the nominal (Slope Length = 227.55 ft; Slope = 14.85%) and corner (Slope Length = 212.65 ft; Slope = 13.87%) flow paths will be used within the HELP model runs. HELP Model Computed Curve Number is 54.2 and 54.4 for the nominal and corner slopes.

[2] Initial moisture is set at field capacity for vertical percolation and lateral drainage layers and at total porosity for barrier soil liners.

2.3 Quality Assurance

The software quality assurance plan for the use of the HELP model is documented in Phifer 2006. A technical review of this work was performed consistent with the E7 Manual, procedure 2.60 as outlined in SRNL Technical Report Design Check Guidelines (WSRC 2004).

3.0 Results and Conclusions

The HELP model has been run for the 488-4D closure cap as outlined in Section 2.0 for both the base case (GCL barrier layer) and an alternative case (HDPE geomembrane barrier layer), and both annual average and daily output data has been generated. Table 3-1 provides a summary of the results. As shown in Table 3-1 infiltration increases and lateral drainage decreases as the assumed saturated hydraulic conductivity of the GCL increases for the base case. Changing the assumed saturated hydraulic conductivity of the GCL does not impact the runoff or evapotranspiration, because these two parameters are primarily affected by the properties of the topsoil and upper common fill and the slope and slope length. Also as seen in Table 3-1 there is very little difference between the associated nominal and corner runs. A comparison of the Table 3-1 alternative case (HDPE geomembrane barrier layer) results with the base case (GCL barrier layer with a saturated hydraulic conductivity of 5.0E-09 cm/s) results demonstrates the following:

- Both cases resulted in the same runoff and evapotranspiration values.
- Alternative case (HDPE geomembrane barrier layer) resulted in slightly more lateral drainage and slightly less infiltration.
- The heads for both cases were either the same or essentially the same.

The SCDHEC design storm event is a 25-year return period, 24-hour accumulation period storm. Based upon Weber 1998 Table XIX, a 25-year, 24-hour storm event is 6.1 inches. For landfills SCDHEC requires that no more than a 12 inch head develop on top of the barrier layer (saturated hydraulic conductivity of no more than 1.0E-05 cm/s) in association with a 25-year, 24-hour storm event. As seen in Table 3-1 the greatest peak daily head on top of the barrier layer (either GCL or HDPE) for any of the runs made was 0.079 inches associated with a peak daily precipitation of 6.16 inches. This is well below the SCDHEC limit of 12 inches.

Table 3-1. 488-4D HELP Model Summary Output

Slope	GCL or HDPE K_{sat} [1] (cm/s)	Precip [2] (in/yr)	Runoff (in/yr)	ET [3] (in/yr)	Lateral Drainage (in/yr)	Infiltration thru GCL (in/yr)	Average Annual Head on GCL (in)	Peak Daily Precip (in/day)	Peak Average Daily Head on GCL (in)	Peak Maximum Daily Head on GCL (in)
Nominal	5.0E-09 [4]	47.93	0.704	19.793	27.39673	0.02256	0.002	6.16	0.037	0.079
Nominal	1.0E-08 [4]	47.93	0.704	19.793	27.37437	0.04490	0.002	6.16	0.037	0.070
Nominal	1.0E-07 [4]	47.93	0.704	19.793	26.99414	0.42513	0.002	6.16	0.037	0.055
Nominal	1.0E-06 [4]	47.93	0.704	19.793	24.62621	2.79307	0.002	6.16	0.037	0.076
Nominal	1.0E-05 [4]	47.93	0.704	19.793	17.30483	10.11440	0.002	6.16	0.037	0.051
Corner	5.0E-09 [4]	47.93	0.702	19.907	27.28500	0.02269	0.002	6.16	0.037	0.059
Corner	1.0E-08 [4]	47.93	0.702	19.907	27.26259	0.04510	0.002	6.16	0.037	0.078
Corner	1.0E-07 [4]	47.93	0.702	19.907	26.88053	0.42716	0.002	6.16	0.037	0.070
Corner	1.0E-06 [4]	47.93	0.702	19.907	24.50455	2.80313	0.002	6.16	0.037	0.077
Corner	1.0E-05 [4]	47.93	0.702	19.907	17.18225	10.12538	0.002	6.16	0.037	0.057
Normal	2.0E-13 [5]	47.93	0.704	19.793	27.41905	0.00023	0.002	6.16	0.037	0.054
Corner	2.0E-13 [5]	47.93	0.702	19.907	27.30745	0.00023	0.002	6.16	0.037	0.070

[1] K_{sat} = saturated hydraulic conductivity
[2] Precip = precipitation
[3] ET = evapotranspiration
[4] GCL barrier layer
[5] HDPE geomembrane barrier layer

4.0 References

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C-CG-D-00011, D-Area Expanded Operable Unit 488-4D Ash Landfill Closure 488-4D Final Grading Plan (Sheet 2 of 2).

C-CG-D-00012, D-Area Expanded Operable Unit 488-4D Ash Landfill Closure Cross Sections (Sheet 1 of 2).

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