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488-1D Ash Basin Closure Cap HELP Modeling – MicroDrain® Liner Option

J. A. Dyer

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PREFACE

This report generously borrows from and builds upon previous technical reports summarizing the results of HELP model simulations for the planned 488-1D (Millings 2015) and 488-4D (Phifer 2014) Ash Basin closure caps.

Revision 1 addresses two changes to the assumed design parameters for the MicroDrain Liner® system—a decrease in the thickness of the geomembrane layer from 60 mil to 50 mil, and a decrease in the index transmissivity of the MicroDrain drainage layer from 1.4E-03 m^2/sec to 1.2E-03 m^2/sec based on more recent input from the manufacturer, Agru America. These changes result in only a small increase in the peak maximum daily hydraulic head on the geomembrane liner, which is still calculated by HELP v3.07 to be approximately two orders of magnitude below the SCDHEC upper limit of 12 inches.

EXECUTIVE SUMMARY

At the request of Area Completion Engineering and in support of the 488-1D Ash Basin closure, the Savannah River National Laboratory (SRNL) performed hydrologic simulations of the revised 488-1D Ash Basin closure cap design using the Hydrologic Evaluation of Landfill Performance (HELP) model. The revised design substitutes a MicroDrain Liner®—50-mil linear low-density polyethylene geomembrane structurally integrated with 130-mil drainage layer—for the previously planned drainage/barrier system—300-mil geosynthetic drainage layer (GDL), 300-mil geosynthetic clay liner (GCL), and 6-inch common fill soil layer.

For a 25-year, 24-hour storm event, HELP model v3.07 was employed to (1) predict the peak maximum daily hydraulic head for the geomembrane layer, and (2) ensure that South Carolina Department of Health and Environmental Control (SCDHEC) requirements for the barrier layer (i.e., ≤ 12 inches hydraulic head on top of a barrier having a saturated hydraulic conductivity ≤ 1.0E-05 cm/s) will not be exceeded. A 25-year, 24-hour storm event at the Savannah River Site (SRS) is 6.1 inches rainfall (Weber 1998).

HELP model v3.07 results based upon the new planned cap design suggest that the peak maximum daily hydraulic head on the geomembrane barrier layer will be 0.179 inches for a minimum slope equal to 3%, which is approximately two orders of magnitude below the SCDHEC upper limit of 12 inches.

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CLM	Central Climatology site
ET	evapotranspiration
GCL	geosynthetic clay liner
GDL	geosynthetic drainage layer
HELP	Hydrologic Evaluation of Landfill Performance
K_{sat}	saturated hydraulic conductivity
LLDPE	Linear low density polyethylene
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) requested that Savannah River Nuclear Solutions (SRNS) perform Hydrologic Evaluation of Landfill Performance (HELP) model simulations of the planned 488-1D Ash Basin closure cap to ensure, for a 25-year, 24-hour storm event, that no more than a 12-inch hydraulic head will develop on top of a barrier layer having a saturated hydraulic conductivity ≤ 1.0E-05 cm/s.

This report documents the performance of the HELP model for the requested evaluation scenario as follows:

- Section 1.1 provides a brief overview of the planned 488-1D closure cap design.
- Section 1.2 gives a brief overview of the HELP model.
- Section 2.1 presents an overview of the development of the HELP model weather input files.
- Section 2.2 discusses the development of the 488-1D Ash Basin soil and closure cap design input.
- Section 3.0 summarizes results and conclusions.

Many of the input parameters and much of the data for this evaluation are unchanged from those used by Millings (2015) and Phifer (2014) to model the 488-1D and 488-4D Ash Basin closure caps, respectively. The following input/cap design parameters were modified to reflect the new proposed design for the 488-1D Ash Basin closure cap:

- Slope of the surface and drainage layers ranging from 3% minimum to 7% maximum;
- Maximum slope length equal to 371 feet;
- Elimination of the 6-inch thick common fill layer beneath the barrier layer;
- Replacement of the 300-mil geosynthetic drainage layer (GDL) and 300-mil geosynthetic clay liner (GCL) with a 130-mil drainage layer overlaying a 50-mil linear low-density polyethylene (LLDPE) geomembrane liner;
- Adjustment of the saturated hydraulic conductivity (K_{sat}) values for the drainage and barrier layers to reflect the new MicroDrain Liner® design.

1.1 488-1D Ash Basin Closure Cap

The updated planned vertical profile of the 488-1D Ash Basin closure cap is shown in Figure 1-1. Figure 1-2 shows a detail drawing of the MicroDrain Liner®.

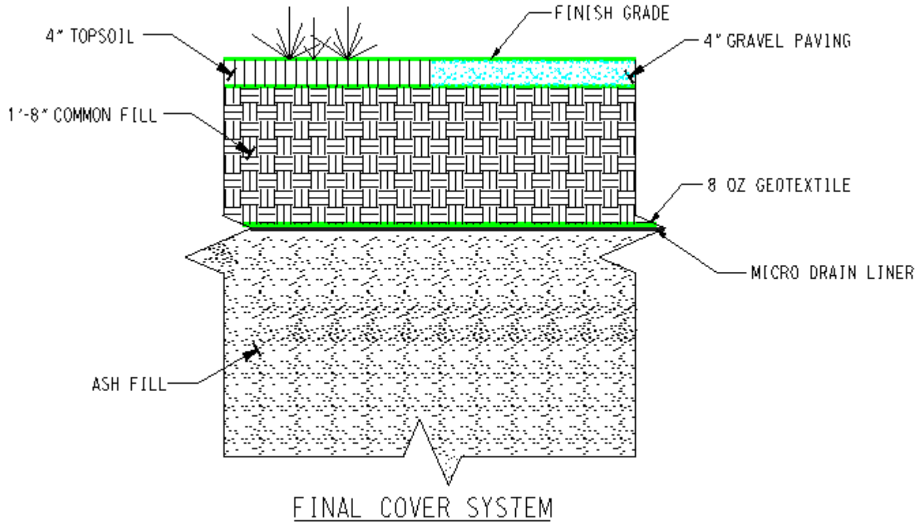

Figure 1-1. 488-1D Closure Cap Profile

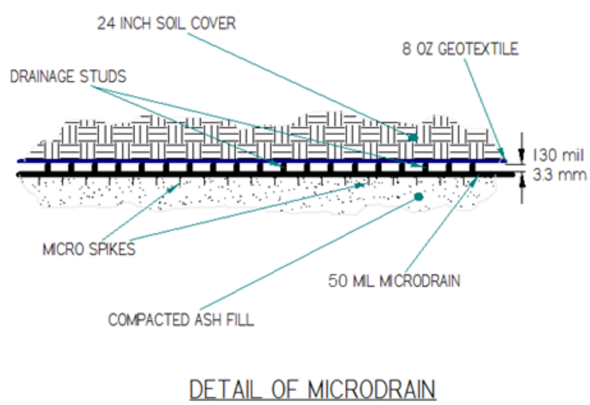

Figure 1-2. 488-1D MicroDrain Liner® Detail

1.2 HELP Model

The HELP model is a quasi-two-dimensional hydrologic model for conducting landfill water balance calculations. The model requires the input of weather, soil, and closure cap design data, and provides quantitative estimates of surface runoff, evapotranspiration, lateral drainage, vertical percolation (i.e., infiltration), hydraulic head build-up, and water storage for the evaluation of different landfill designs.

United States Army Corps of Engineers (USACE) personnel at the Waterways Experiment Station (WES) in Vicksburg, MS 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 water balance analyses of landfills and other land disposal systems. HELP model version 3.07 (released November 1, 1997) is the latest public-domain version of the model that is available for download at https://www.epa.gov/land-research/hydrologic-evaluation-landfill-performance-help-model. The graphical user interface (GUI) for HELP v3.07 is not compatible with Windows 7 or later; therefore, the user must execute the program using Windows XP or from within a virtual Windows XP environment.

USEPA and the USACE have provided the following documentation for the HELP model:

- A user's guide (Schroeder et al. 1994a) that gives instructions on setting up and executing the HELP model.
- Engineering documentation (Schroeder et al. 1994b) that provides information on the FORTRAN source code, hardware necessary to operate the code, data generation methodologies available for use, and 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 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, and
- evapotranspiration data.

The HELP model includes a weather generator for creating synthetic precipitation, temperature, and solar radiation data input files using city-specific, monthly average default data provided with the software or site-specific monthly average data provided by the user. In this evaluation, synthetic daily precipitation and temperature data for a 100-year period were generated using HELP's synthetic weather generator option for the city of Augusta, GA and SRS-specific monthly average precipitation and temperature data. SRS collects meteorological data from a network of weather stations. Sources of SRS precipitation data for this evaluation were the SRNL (773-A) weather station for years 1952 to 1995 and the Central Climatology site (CLM) for years 1995 to 2013. Weber (1998) reports that a 25-year, 24-hour storm event for SRS is 6.1 inches. Sources of SRS temperature data were the SRNL weather station (1968-1995) and the CLM (1995-2013). The monthly average SRS data (Appendix A and Appendix B, respectively) were extracted from the Atmospheric Technologies Center website (https://weather.srs.gov/weather/) and used to generate input files containing 100 years of synthetic precipitation and temperature data for the SRS site. The synthetic weather data option for Augusta, GA was also utilized to generate solar radiation input data, and default parameters for Augusta, GA were used to generate the evapotranspiration input data. The evaporative zone depth was set equal to 24 inches based upon the thickness of the topsoil (4 inches) and common fill (20 inches) layers placed above the MicroDrain Liner®. An acceptable range of evaporative zone depth for Augusta, GA is 10 to 40 inches. The maximum leaf area index, which affects evapotranspiration rates, was set at 3.5 (good stand of grass) in light of the sodding and permanent seeding requirements of Specification C-SPP-D-00003.

The resulting HELP model weather input files were:

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

2.2 488-1D Ash Basin Closure Cap Design and Soil HELP Model Input

Closure cap design and soil input data required for execution of the HELP model include:

- Surface and drainage layer slopes and slope lengths, landfill area, layer types and thicknesses
- Saturated hydraulic conductivity, porosity, field capacity, and wilting point, respectively

Development of this input data for the 488-1D closure cap is outlined below.

Surface and Drainage Layer Percent Slopes and Slope Lengths: Because the cover profile is constant across the 488-1D Ash Basin closure cap (drawing C-CG-D-00034), percent slope and slope length for both the surface and drainage layers are assumed equivalent for any one flow path. In addition, the majority of the water is assumed to drain along the nominal length as opposed to the corner length of the cap.

Note that the HELP model allows input of only constant surface and drainage layer percent slopes and slope lengths (i.e., they cannot change during a HELP model run). For this reason, approximate surface and drainage layer percent slopes and slope lengths were used for the 488-1D simulations.

Figures 2-1 and 2-2 provide the basis for choosing slopes and slope lengths for the 488-1D closure cap surface and drainage layers, and originate from drawings C-CG-D-00029, C-CG-D-0030, and C-CG-D-00034. HELP model input parameter values derived from these drawings are summarized below:

- *Slope Length*: Nominal cap slope length varies between 364.5 ft and 370.5 ft as shown on Figure 2-1. A conservative upper bound value of 371 ft was selected for the HELP model simulations. A sensitivity analysis using the HELP model indicated that the impact of slope length on peak maximum daily head is negligible over the range 364.5 ft to 370.5 ft.
- *Percent Slope* = Figure 2-2 shows a nominal 6.5% slope for the ash basin cap design. For this evaluation, percent slope values of 3%, 4%, 5%, 6%, and 7% were considered to be conservative (peak maximum daily head increases as percent slope decreases).

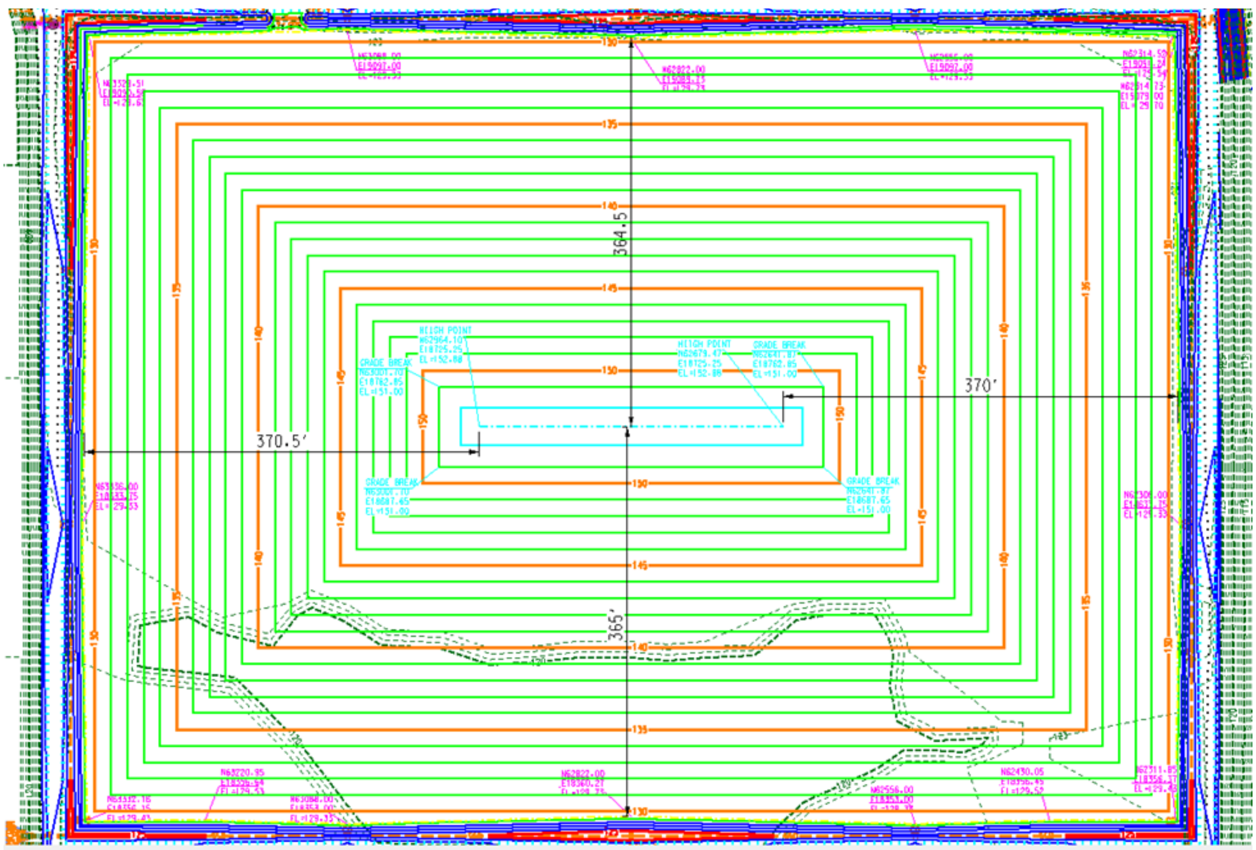

Figure 2-1. Nominal Surface and Drain Lengths (C-CG-D-00029 and C-CG-D-0030)

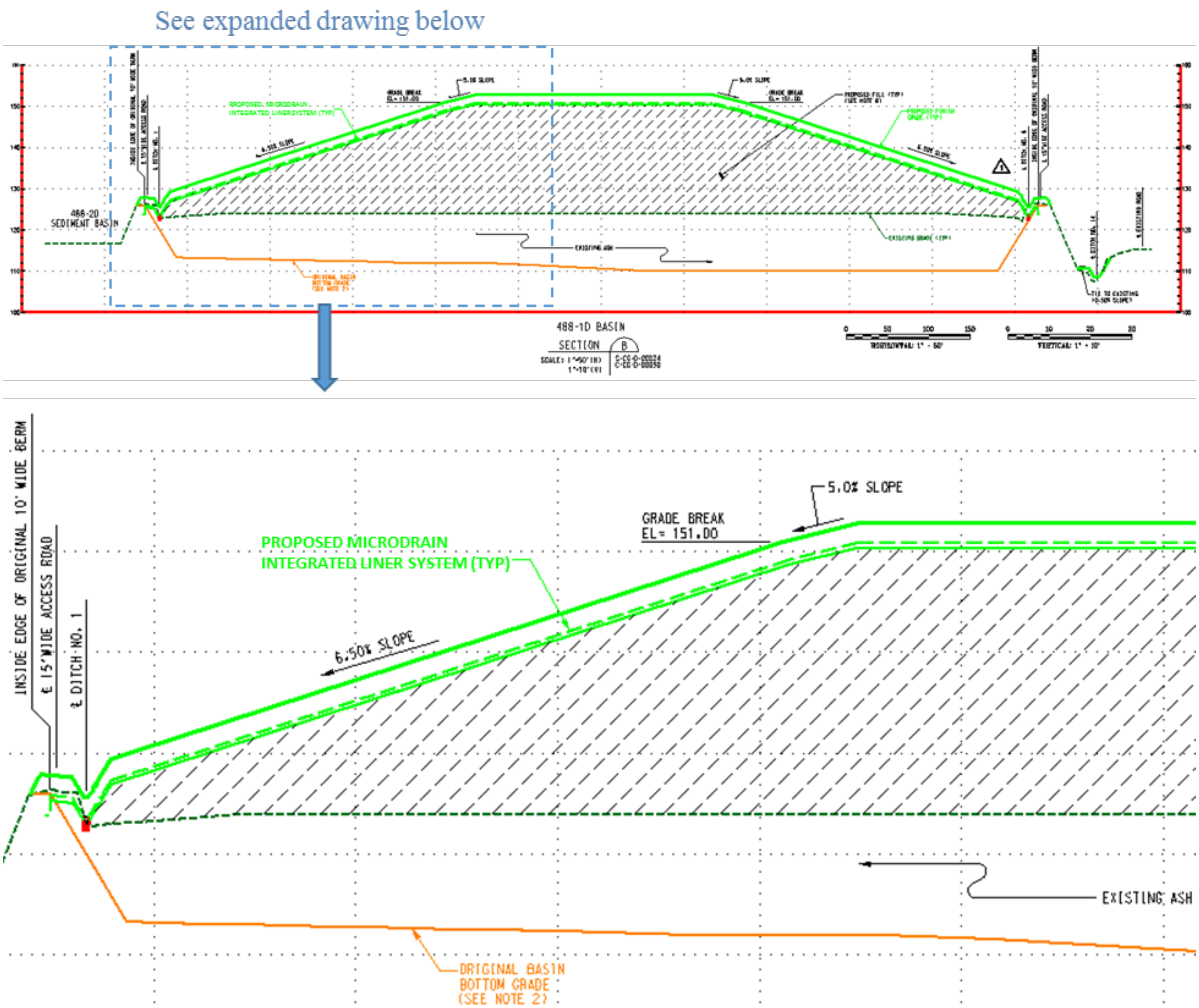

Figure 2-2. Surface and Drain Slope (6.5% Slope typical) (C-CG-D-00034)

<u>Topsoil (Layer 1)</u>: Properties for the topsoil layer were developed as follows:

- The topsoil is defined as a vertical percolation layer in HELP.
- Per specification C-SPP-D-00002, topsoil is to be a "medium textured soil such as loam per ASTM D5268." ASTM D5268 specifies the following particle-size range for topsoil: 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-00042.

- Yu et al. (1993) provides saturated hydraulic conductivity, total porosity, and water retention (suction head versus saturation) data for two samples of SRS topsoil. Phifer et al. (2007) transformed these data into the 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

- The topsoil property values above are similar to property values for default soil #4 in the HELP model database, which 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).

Common Fill (Layer 2): Properties for the common fill were developed as follows:

- The common fill is defined as a vertical percolation layer in HELP.

- The common fill thickness is 20 inches per Detail 5 of drawing C-CG-D-00042.

- The common fill used during construction of the low-permeability soil cover at the Old Radioactive Burial Grounds was analyzed for saturated hydraulic conductivity, total porosity, and water retention (suction head versus saturation). These same data were used for the common fill assumed in this evaluation:

  - 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 field capacity as the "volumetric water content (θ_v) at a soil suction head (Ψ) equal to 0.33 bar" (Schroeder et al. 1994a; Schroeder et al. 1994b) or approximately 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 on the water retention curve (suction head versus saturation).

- The HELP model defines 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) or approximately 15,310 cm-H_2O (1 bar ≈ 1,020.7 cm-H_2O at 60 °F). Site-specific data were not available for determining the wilting point of SRS common fill. Instead, the wilting point for a HELP model default soil that closely resembles SRS common fill was utilized. Table 2 by Schroeder 1994b provides HELP model default soil properties for moderate- and high-density soils. Default soil #24, which is classified as clayey sand (SC) by USCS or sandy clay loam (SCL) by USDA, mostly closely resembles the SRS common fill material. For this reason, SRS common fill was assigned a wilting point equal to 0.202.

MicroDrain Drainage Structure (Layer 3): Properties for the MicroDrain drainage layer are based on the following:

- MicroDrain Liner® is an integrated drainage layer/geomembrane liner system offered by Agru America, Inc., which is now proposed for the 488-1D closure cap design in place of the previously proposed 300-mil GDL and 300-mil GCL layers.
- The MicroDrain studded polyethylene drainage structure is defined as a lateral drainage layer in the HELP model.
- The thickness of the MicroDrain studded drainage structure is 0.13 inches (130 mil) (Agru America 2017a).
- Per Agru America (2017b), transmissivity of the MicroDrain drainage structure is 1.2E-03 m^2/s. Per Koerner (1990), saturated hydraulic conductivity (K_{sat}) equals the transmissivity (T) divided by the thickness (t):

$$K_{sat} = \frac{T}{t} = \frac{1.2E-03\ m^2/s \times 10{,}000\ cm^2/m^2}{0.13\ inches \times 2.54\ cm/inch} = 36.3\ cm/s$$

- The following default property values for drainage nets/geonets provided by Schroeder et al. 1994a and Schroeder et al. 1994b will be used in the HELP model simulations:
  - Total porosity (η) = 0.850
  - Field capacity = 0.010
  - Wilting point = 0.005

Geomembrane (Layer 4): Properties for the MicroDrain Liner® LLDPE geomembrane were developed as follows:

- The LLDPE geomembrane provided with the MicroDrain Liner® is defined as a barrier soil liner in the HELP model with a thickness of 0.05 inches (50 mil) (Agru America 2017a).
- K_{sat} for the LLDPE geomembrane liner is assumed to equal 4.0E-13 cm/s using the default value provided for geomembrane materials in the HELP model database (Table 4, Schroeder et al. 1994a). SCDHEC requires a saturated hydraulic conductivity for the barrier layer of less than 1.0E-05 cm/s.

- Zero defects and "good" liner placement were assumed in the HELP model simulations. Sensitivity analyses using the HELP model showed that zero defects is a conservative assumption (i.e., hydraulic head on the liner decreases with increasing defect density).

Fly Ash (Layer 5): Properties for the fly ash layer are outlined below:

- Fly ash is defined as a vertical percolation layer in HELP.
- The maximum thickness of the fly ash layer is approximately 467 inches.
  - Per C-CG-D-00034, the original 488-1D Ash Basin bottom was ~112.5 ft-msl.
  - Per C-CG-D-00033, the center-grade break in the 488-1D closure cap is ~153.47 ft-msl.
  - From C-CG-D-00042 Detail 5, thickness of the closure cap is 2.02 ft (4 inch topsoil + 20 inch common fill + 0.19 inch MicroDrain Liner® system = 24.19 inches or 2.02 ft).
  - Maximum fly ash thickness = (153.47 – 2.02) – 112.5 = 38.95 ft (467.4 inches)
- HELP model default waste #30 provides the following default property 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

Table 2-1 summarizes the input and output HELP model filenames used for the updated 488-1D ash basin closure cap simulations. The input files were populated with the input data summarized in Table 2-2. Five separate HELP model simulations were made for drainage slopes ranging from 3% to 7%.

Table 2-1. HELP Model Input and Output File Names Used in this Evaluation

Drainage Length (ft)	Slope (%)	Input File Name	Output File Name
371	3	DAL4881DS3.D10	DAL4883.OUT
371	4	DAL4881DS4.D10	DAL4884.OUT
371	5	DAL4881DS5.D10	DAL4885OUT
371	6	DAL4881DS6.D10	DAL4886.OUT
371	7	DAL4881DS7.D10	DAL4887.OUT

Table 2-2. HELP Model Input Data for D-Area Ash Basin Closure Cap System (as-built) [1]

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	19.3 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 =	varied [1]
Slope length =	371 ft
Soil Texture =	4 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = varied based on slope %	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Common Fill	2	1 (vertical percolation layer)
MicroDrain	3	2 (lateral drainage layer)
LLDPE Geomembrane	4	3 (geomembrane liner)
Fly Ash	5	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	0.13		0.850	0.010	0.005	0.010
4	3	0.05					
5	1	467		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	36.3	371	varied [3]			
4	3	4.0E-13 [4]					
5	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	1	0	3 (Good)	
5	1				

[1] The absence of input values for certain input parameters in specific layers is not an oversight (e.g., total porosity, field capacity, etc. for Layer #4). Blank cells signify that the HELP model does not require input values for these parameters for this layer type.

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

[3] Slope values ranged from 3% to 7%.

[4] K_{sat} for the LLDPE geomembrane liner is assumed to equal 4.0E-13 cm/s using the default value provided for geomembrane materials in the HELP model database (Table 4, Schroeder et al. 1994a).

2.3 Quality Assurance

The software quality assurance plan for the HELP v3.07 model is documented by 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

An updated evaluation of the 488-1D closure cap design was performed using the HELP v3.07 model as described in Section 2.0. Table 3-1 summarizes the annual average and peak daily hydrologic output parameter data generated by the model. As reflected in Table 3-1, infiltration rate and peak maximum daily head through/on the liner decreases as percent slope increases.

SCDHEC defines a design storm event as a storm with a 25-year return period and 24-hour accumulation period. As given in Table XIX by Weber (1998), a 25-year, 24-hour storm event for SRS is 6.1 inches. For landfills, SCDHEC requires that a hydraulic head of no more than 12 inches be allowed to develop on top of a barrier layer with a saturated hydraulic conductivity of ≤ 1.0E-05 cm/s in association with a 25-year, 24-hour storm event. As highlighted in Table 3-1, HELP model results for the planned cap design suggest that the peak maximum daily hydraulic head on the geomembrane layer for a peak daily precipitation rate of 6.16 inches will be 0.179 inches (minimum slope equal to 3%), which is approximately two orders of magnitude below the SCDHEC upper limit of 12 inches.

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

Basis: Agru Index Transmissivity = 1.2E-03 m^2/sec

% Slope	Slope Length (ft)	Liner K_{sat} [1] (cm/s)	Average Annual Precip [2] (in/yr)	Average Annual Runoff (in/yr)	Average Annual ET [3] (in/yr)	Average Annual Lateral Drainage (in/yr)	Average Annual Infiltration Rate thru Liner (in/yr)	Average Annual Head on Liner (in)	Peak Daily Precip (in/day)	Peak Average Daily Head on Liner (in)	Peak Maximum Daily Head on Liner (in)
3%	371	4.0E-13	47.93	0.70	21.41	25.80	0.00008	0.004	6.16	0.090	0.179
4%	371	4.0E-13	47.93	0.69	18.78	28.45	0.00007	0.004	6.16	0.068	0.165
5%	371	4.0E-13	47.93	0.68	17.84	29.40	0.00006	0.003	6.16	0.054	0.105
6%	371	4.0E-13	47.93	0.69	25.40	21.82	0.00004	0.002	6.16	0.045	0.090
7%	371	4.0E-13	47.93	0.66	15.97	31.30	0.00005	0.002	6.16	0.039	0.074

[1] K_{sat} = saturated hydraulic conductivity
[2] Precip = precipitation rate
[3] ET = evapotranspiration

4.0 References

Agru America. 2017a. Low Density Polyethylene MicroDrain Liner® Product Data Sheet, Agru America, Inc., Georgetown, SC.

Agru America. 2017b. Engineering Bulletin: Super Gripnet/Drainliner Transmissivity, Agru America, Inc., Georgetown, SC.

ASTM D5268 – 13, Standard Specification for Topsoil Used for Landscaping Purposes, ASTM International, West Conshohocken, PA. July 2013.

C-CG-D-00029, D-Area Operable Unit, 488-1D Ash Basin & 489-D CPRB Closure, 488-1D Final Grading Plan (Sheet 1 of 2).

C-CG-D-00030, D-Area Operable Unit, 488-1D Ash Basin & 489-D CPRB Closure, 488-1D Final Grading Plan (Sheet 2 of 2).

C-CG-D-00033, D-Area Operable Unit, 488-1D Ash Basin & 489-D CPRB Closure, 488-1D Erosion and Sediment Control Plan Phase 2 – Construction (Sheet 2 of 2).

C-CG-D-00034, D-Area Operable Unit, 488-1D Ash Basin & 489-D CPRB Closure, 488-1D Cross Sections (Sheet 1 of 2).

C-CG-D-00042, D-Area Operable Unit, 488-1D Ash Basin & 489-D CPRB Closure, Final Cover Details (Sheet 1 of 2).

C-SPP-D-00003, Rev. 0, 488-1D Ash Basin and 489-D Coal Pile Runoff Basin Closure Specifications, January 22, 2015.

E7 Manual - Conduct of Engineering, Procedure 2.60 - Technical Reviews, Rev. 15, December 31, 2014.

Koerner, R. M. 1990. Designing with Geosynthetics, Second Edition. Prentice Hall, Englewood Cliffs, New Jersey. 1990.

Millings, M. R. 2015. 488-1D Ash Basin Closure Cap HELP Modeling, SRNL-TR-2015-00235, Revision 0, Savannah River National Laboratory, Aiken, SC, October 2015.

Phifer, M. A. 2006. Software Quality Assurance Plan for the Hydrologic Evaluation of Landfill Performance (HELP) Model, Q-SQA-A-00005, Revision 0. Washington Savannah River Company, Aiken, SC. October 2006.

Phifer, M. A. 2014. 488-4D Ash Landfill Closure Cap HELP Modeling, SRNL-STI-2014-00392, Revision 0, Savannah River National Laboratory, Aiken, SC, September 2014.

Phifer, M. A., Jones, W. E., Nelson, E. A., Denham, M. E., Lewis, M. R., and Shine, E. P. 2007. FTF Closure Cap Concept and Infiltration Estimates, WSRC-STI-2007-00184 OUO, Rev 2. Savannah River National Laboratory, Aiken, SC, October 15, 2007.

Schroeder, P. R., Lloyd, C. M., Zappi, P. A., and Aziz, N. M. 1994a. The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3. EPA/600/R-94/168a. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. September 1994.

Schroeder, P. R., Dozier, T. S., Zappi, P. A., McEnroe, B. M., Sjostrom, J. W., and Peyton, R. L. 1994b. The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3. EPA/600/R-94/168b. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. September 1994.

Schroeder, P. R. and Peyton, R. L. 1987a. Verification of the Lateral Drainage Component of the HELP Model Using Physical Models. EPA/600/2-87/049. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. July 1987.

Schroeder, P. R. and Peyton, R. L. 1987b. Verification of the Hydrologic Evaluation of Landfill Performance (HELP) Model Using Field Data. EPA/600/2-87/050. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. July 1987.

Weber, A. H. 1998. Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site, WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, SC. September 1998.

WSRC. 2004. Savannah River National Laboratory Technical Report Design Check Guidelines, WSRC-IM-2002-00011, Revision 2, Westinghouse Savannah River Company, Aiken, SC. August 2004

Yu, A. D., Langton, C. A., and Serrato, M. G. 1993. Physical Properties Measurement Program (U), WSRC-RP-93-894. Westinghouse Savannah River Company, Aiken, SC. June 30, 1993.

Appendix A. SRS Precipitation Data in Inches

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
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
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

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
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
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
Average	**4.05**	**4.32**	**4.80**	**3.29**	**3.65**	**4.75**	**5.28**	**4.85**	**3.84**	**2.73**	**2.62**	**3.67**

Appendix B. SRS Temperature Data in Degrees Fahrenheit

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
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
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	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
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
Average	**46.0**	**49.1**	**56.6**	**64.3**	**71.8**	**78.3**	**81.0**	**79.9**	**75.0**	**65.1**	**55.8**	**48.5**

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