Appendix D

Technical Memorandums from Gordan Gjerapic at Golder Associates to John Borovsky at Barr. Dated May 7, 2007, May 29, 2007, May 31, 2007 Regarding Ponding and Percolation Estimates; December 17, 2007 and December 21, 2007 Regarding Percolation Estimates of Other Mine Site Deatures; and May 20, 2008 Regarding HELP Modeling of Stockpile Liner Leakage

TECHNICAL MEMORANDUM

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TO: John Borovsky, Barr Engineering **DATE:** May 7, 2007

FROM: Gordan Gjerapic P.E., GAI **OUR REF.:** 053-2209

CC: Brent R. Bronson P.E., GAI

RE: PONDING AND PERCOLATION ESTIMATES FOR CATEGORIES 3 AND 4 WASTE ROCK STOCKPILES, POLYMET PROJECT, MINNESOTA

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this technical memorandum for Barr Engineering (Barr) to present predicted estimates of ponding and percolation for the Category 3 and 4 waste rock stockpiles. This work was completed based on authorization provided during phone conversations and e-mail correspondence between Barr and Golder on April 30 and May 1 2007. The purpose of this work is to allow more refined estimates of potential head development and liner leakage to be predicted relative to the more simplistic and conservative approach previously conducted. The predicted results presented in this memorandum were obtained using the HELP (Hydrologic Evaluation of Landfill Performance) model and should be viewed as estimates. The predicted results may be subject to further revisions pending on the future changes in the stockpile design and more detailed information on the properties of the stockpile, overliner and cover materials.

2.0 INPUT PARAMETERS

All simulations use a 100-year weather record for Duluth, Minnesota synthetically generated by HELP. The lower model boundary consists of an 80-mil LLDPE placed on a 12-inch thick subgrade material. The proposed liner is overlain by 12 inches of the overliner material and 40-ft of the stockpile rock. HELP simulations summarized in Table 2.1 assume the stockpile is exposed to the atmosphere (i.e., the final cover has not been constructed on the stockpile). HELP simulations evaluating the final cover performance are summarized in Table 2.2.

Table 2.1. Baseline Modeling Scenarios 3 without the Final Cover

Scenario	Liner Installation Defects (holes/acre)	Liner Manufacturing Defects (pinholes/acre)	Spacing of Leachate Collection Pipes (ft)	Stockpile Rock and Overliner Permeability (cm/s)
Case 1	4	0	100	0.3
Case 2	4	4	100	0.3
Case 3	4	4	50	0.3
Case 4	4	4	50	0.03

Table 2.2. Modeling Scenarios with a Constructed Final Cover

Scenario	Cover Installation Defects (holes/acre)	Cover Manufacturing Defects (pinholes/acre)	Vegetative Cover Thickness (inch)	LAI
Case 5	6	4	18	2.0
Case 6	n/a	n/a	36	3.0

To conservatively account for localized settlement of the subgrade materials, the overliner slope is set to 0.2% for all HELP simulations. Liner properties and spacing of the leachate collection pipes for Case 2 scenario (Table 2.1) are used for all scenarios evaluating the final cover performance. Case 6 evaluates the performance of the vegetative cover, i.e. considers the cover performance without the geo-synthetic barrier layer. Material properties used for HELP simulations are summarized in the following tables 2.3 and 2.4.

Table 2.3. Material Properties – Stockpile without Closure Cover Simulations

Material Type	HELP Material Number	HELP Material Type	Thickness (inch)	Permeability (cm/s)
Stockpile Rock (Case 1, 2, 3)	21	Gravel	480	0.3
Overliner Material (Case 1, 2, 3)	21	Gravel	12	0.3
Stockpile Rock (Case 4)	21	Gravel	480	0.03
Overliner Material (Case 4)	21	Gravel	12	0.03
LLDPE (Case 1 to 6)	36	LDPE	0.08	4.00E-13
Subgrade Material (Cat. 3)	16	Barrier Soil	12	1.00E-05
Subgrade Material (Cat. 4)	16	Barrier Soil	12	1.00E-06

Table 2.4. Material Properties – Simulation for Stockpile with Final Cover

Material Type	HELP Material Number	HELP Material Type	Thickness (inch)	Permeability (cm/s)
Vegetative cover (Case 5)	10	Clayey Sand	18	1.2e-4
Vegetative Cover (Case 6)	10	Clayey Sand	36	1e-5
Cover geomembrane (LLDPE, Case 5)	36	LDPE	0.06	4.00E-13
Stockpile Rock (Cat 3)	21	Gravel	1120	0.3
Stockpile Rock (Cat 4)	21	Gravel	860	0.3

3.0 RESULTS

HELP results are summarized in the following tables:

Table 3.1. HELP Results for Category 3 Stockpiles without a Final Cover

Quantity	Case 1	Case 2	Case 3	Case 4
Avg. annual precipitation (inch)	29.2	29.2	29.2	29.16
Avg. annual runoff (inch)	3.9	3.9	3.9	4.034
Avg. annual evaporation (inch)	12.4	12.4	12.4	14.25
Avg annual lateral drainage (inch)	12.7	12.7	12.7	10.58
Avg. annual percolation (inch)	2.34E-02	3.77E-02	2.05E-02	7.8E-02
Average annual head on liner (inch)	0.9	0.9	0.5	2.03
Change in water storage (inch)	0.1	0.1	0.1	0.214
Peak daily percolation (inch)	1.75E-04	2.81E-04	1.57E-04	4.19E-04
Peak daily head on liner (inch)	3.1	3.1	1.6	4.19

Table 3.2. HELP Results for Category 4 Stockpile without a Final Cover

Quantity	Case 1	Case 2
Avg. annual precipitation (inch)	29.2	29.2
Avg. annual runoff (inch)	3.9	3.9
Avg. annual evaporation (inch)	12.4	12.4
Avg annual lateral drainage (inch)	12.7	12.7
Avg. annual percolation (inch)	4.30E-03	6.92E-03
Average annual head on liner (inch)	0.9	0.9
Change in water storage (inch)	0.1	0.1
Peak daily percolation (inch)	3.20E-05	5.20E-05
Peak daily head on liner (inch)	3.1	3.1

Table 3.3. Summary of Calculated Percolation Rates without a Final Cover

Simulation	Case 1	Case 2	Case 3	Case 4
Category 3 Stockpile Avg. annual perc. (gal/acre/day)	1.7	2.8	1.5	5.8
Category 3 Stockpile Peak daily percolation (gal/acre/day)	4.7	7.6	4.3	11.3
Category 4 Stockpile Avg. annual perc. (gal/acre/day)	0.3	0.5	-	-
Category 4 Stockpile Peak daily percolation (gal/acre/day)	0.9	1.4	-	-

Table 3.4. HELP Results for Category 3 Stockpile with a Final Cover

Quantity	Case 5	Case 6
Avg. annual precipitation (inch)	29.2	29.2
Avg. annual runoff (inch)	5.9	9.9
Avg. annual evaporation (inch)	22.6	19.1
Avg annual lateral drainage (inch)	0.5	0.1
Avg. annual percolation – cover (inch)	6.7e-1	~ 0.1
Avg. annual percolation – liner (inch)	2.0e-3	4.4E-04
Average annual head on liner (inch)	<0.1 inch	<0.1 inch
Change in water storage (inch)	0.2	0.1
Peak daily percolation (inch)	0.54	0.14
Peak daily head on liner (inch)	0.4	0.2

Table 3.5 HELP Results for Category 4 Stockpile with a Final Cover

Quantity	Case 5	Case 6
Avg. annual precipitation (inch)	29.2	29.2
Avg. annual runoff (inch)	5.9	9.9
Avg. annual evaporation (inch)	22.5	19.1
Avg annual lateral drainage (inch)	0.5	0.1
Avg. annual percolation - cover (inch)	6.7e-1	~0.1
Avg. annual percolation - liner (inch)	4.1e-4	8e-5
Average annual head on liner (inch)	<0.1 inch	<0.1 inch
Change in water storage (inch)	0.2	0.1
Peak daily percolation (gal/acre/day)	0.11	<0.1
Peak daily head on liner (inch)	0.4	0.2

4.0 CONCLUSIONS

HELP model simulations indicate an average annual percolation rates for Category 3 stockpiles without a final cover ranging from approximately 2 to 6 gal/acre/day with the average head on the liner varying from about 1 to 2 inches. For Category 3 open stockpiles, the maximum head on the liner is not likely to exceed 4 inches with the corresponding maximum percolation of approximately 10 gal/acre/day.

HELP model results for the Category 4 stockpile without final cover indicate the average annual percolation rate is below 1 gal/acre/day with the corresponding average annual head on the liner of approximately 1 inch. The maximum calculated daily head for the open Category 4 stockpile is 3.1 inches. The corresponding maximum daily percolation rate is likely to remain below 2 gal/acre/day.

HELP simulations considering stockpiles with the constructed final cover indicate percolation rates well below 1 gal/acre/day. Consequently, the corresponding head on the liner is less than 1 inch for all modeling scenarios considering capped stockpiles.

TECHNICAL MEMORANDUM

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TO:	John Borovsky, Barr Engineering	**DATE:**	May 29, 2007
FROM:	Gordan Gjerapic P.E., GAI	**OUR REF.:**	053-2209
CC:	Brent R. Bronson P.E., GAI		
RE:	**PONDING AND PERCOLATION ESTIMATES FOR THE CATEGORY 4 WASTE ROCK STOCKPILES, POLYMET PROJECT, MINNESOTA**		

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this technical memorandum for Barr Engineering (Barr) to present predicted estimates of ponding and percolation for the Category 4 waste rock stockpiles. This work was completed based on the authorization provided during phone conversations and e-mail correspondence between Barr and Golder on May 9 and May 15 2007. The purpose of this work is to refine analyses presented in the technical memorandum "Ponding and Percolation Estimates for Categories 3 and 4 Waste Rock Stockpiles, PolyMet Project, Minnesota" by Golder from May 7 2007, and investigate the influence of liner grades and waste rock heights to water balance quantities. The results in this memorandum were obtained by using the HELP (Hydrologic Evaluation of Landfill Performance) model and should be viewed as estimates. The predicted results may be subject to further revisions pending on the future changes in the stockpile design and more detailed information on the properties of the stockpile, overliner, and cover materials.

2.0 INPUT PARAMETERS

All simulations use a 100-year weather record for Duluth, Minnesota, synthetically generated by HELP. The following material parameters were used for HELP simulations:

Table 2.1 Material Parameters for Modeling Scenarios without the Final Cover

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage Grades and Geomembrane Defects
Waste rock	21	3.00E-01	480 (1120)*	
Waste rock	21	0.03	480 (1120)*	
Overliner (50 ft drains)	21	3.00E-01	12	0.2, 0.5, 1 and 2%
Overliner (50 ft drains)	21	3.00E-02	12	0.2, 0.5, 1 and 2%
LLDPE	36	4.00E-13	0.08	4 holes, 1 pinhole per acre
subgrade	16	1.00E-06	12	

* waste rock thickness of 1120 inch was used to model capped stockpiles.

As indicated in Table 2.1, the lower model boundary consists of an 80-mil LLDPE placed on a 12-inch thick subgrade material. The proposed liner is overlain by 12 inches of the overliner material and 40 to 93 ft of the stockpile waste rock. Model parameters used to simulate cover materials are summarized in Table 2.2.

Table 2.2. Final Cover Materials

Cover Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Geomembrane Defects
Veg. layer (LLDPE cap)	10	1.20E-04	18	
Veg layer (ET cover)	10	1.00E-05	36	
LLDPE	36	4.00E-13	0.06	6 holes/acre, 2 pinholes/acre
Rock	21	3.00E-01	1120	

Modeling scenarios are summarized in the following table:

Table 2.3. Modeling Scenarios

Case Scenario ID	Stockpile Configuration	Liner Grade (%)	Waste Rock Permeability (cm/s)
1	Open/Capped	0.2	0.3
2	Open/Capped	0.5	0.3
3	Open/Capped	1	0.3
4	Open/Capped	2	0.3
5	Open/Capped	0.2	0.03
6	Open/Capped	0.5	0.03
7	Open/Capped	1	0.03
8	Open/Capped	2	0.03

As noted in the above tables, all base case modeling scenarios used the waste rock thickness of 40 ft for open stockpiles and the “average” waste rock height of approximately 93 ft for capped stockpiles. In addition to these base case scenarios, limited sensitivity studies were conducted to investigate the influence of varying waste rock heights.

3.0 RESULTS FOR BASE CASE SCENARIOS

HELP results are summarized in the following tables:

Table 3.1. Average Annual Precipitation, Runoff, and Evaporation Values

Configuration	Avg. Annual Precipitation (inch)	Avg. Annual Runoff (inch)	Avg. Annual Evaporation (inch)
Open Stockpile – Case 1 to 4	29.2	3.9	12.4
Open Stockpile – Case 5 to 8	29.2	4.0	14.3
ET Cover – Case 1 to 8	29.2	9.9	19.1
Geomembrane Cover – Case 1 to 8	29.2	6.1	22.7

Table 3.2. HELP Results for Lateral Drainage, Percolation and Head on Liner Open Stockpile

Case Scenario ID	Avg. Annual Lateral Drainage (inch)	Avg. Annual Percolation (inch)	Avg. Annual Head on Liner (inch)	Peak Daily Percolation (inch)	Peak Daily Head on Liner (inch)
1	12.7	2.6E-03	0.5	2.1E-05	1.6
2	12.7	1.3E-03	0.2	1.4E-05	1.2
3	12.7	6.8E-04	0.1	8.0E-06	0.8
4	12.7	3.6E-04	0.1	4.0E-06	0.5
5	10.7	1.0E-02	2.0	5.5E-05	4.9
6	10.7	7.6E-03	1.5	4.7E-05	4.1
7	10.7	4.7E-03	0.9	3.6E-05	3.2
8	10.7	2.5E-03	0.4	2.2E-05	2.2

Table 3.3. HELP Results for Lateral Drainage, Percolation and Head on Liner Stockpile with ET Cover

Case Scenario ID	Avg. Annual Lateral Drainage (inch)	Avg. Annual Percolation (inch)	Avg. Annual Head on Liner (inch)	Peak Daily Percolation (inch)	Peak Daily Head on Liner (inch)
1	0.1	4.0E-05	<0.1	<1.0E-06	0.1
2	0.1	2.0E-05	<0.1	<1.0E-06	<0.1
3	0.1	1.0E-05	<0.1	<1.0E-06	<0.1
4	0.1	1.0E-05	<0.1	<1.0E-06	<0.1
5	<0.1	2.0E-05	<0.1	<1.0E-06	0.1
6	<0.1	1.0E-05	<0.1	<1.0E-06	<0.1
7	<0.1	1.0E-05	<0.1	<1.0E-06	<0.1
8	<0.1	<1.0E-05	<0.1	<1.0E-06	<0.1

Table 3.4 HELP Results for Lateral Drainage, Percolation and Head on Liner Stockpile with Geomembrane Cover

Case Scenario ID	Avg. Annual Lateral Drainage (inch)	Avg. Annual Percolation (inch)	Avg. Annual Head on Liner (inch)	Peak Daily Percolation (inch)	Peak Daily Head on Liner (inch)
1	0.2	5.0E-05	<0.1	1.0E-06	0.2
2	0.2	3.0E-05	<0.1	<1.0E-06	<0.1
3	0.2	2.0E-05	<0.1	<1.0E-06	<0.1
4	0.2	1.0E-05	<0.1	<1.0E-06	<0.1
5	0.1	1.1E-04	<0.1	3.0E-06	0.4
6	0.1	5.1E-05	<0.1	2.0E-06	0.2
7	0.1	3.0E-05	<0.1	1.0E-06	0.1
8	0.1	2.0E-05	<0.1	1.0E-06	0.1

Table 3.5. Summary of Calculated Percolation Rates

Case Scenario ID	Open Stockpile Avg. Annual Perc. (gal/acre/day)	Open Stockpile Peak Daily Perc. (gal/acre/day)	Capped Stockpile Avg. Annual Perc. (gal/acre/day)	Capped Stockpile Peak Daily Perc. (gal/acre/day)
1	0.2	0.6	<0.1	<0.1
2	0.1	0.4	<0.1	<0.1
3	0.1	0.2	<0.1	<0.1
4	<0.1	0.1	<0.1	<0.1
5	0.8	1.5	<0.1	0.1
6	0.6	1.3	<0.1	<0.1
7	0.4	1.0	<0.1	<0.1
8	0.2	0.6	<0.1	<0.1

4.0 SENSITIVITY STUDIES

Results of sensitivity studies, conducted to investigating the influence of varying waste rock heights to water balance quantities, are divided into two sections:

- Sensitivity studies for open stockpiles;
- Sensitivity studies for capped stockpiles.

4.1 Sensitivity studies for open stockpiles

Results of sensitivity studies for open stockpiles are summarized in the following tables:

Table 4.1.1. Percentiles for Annual Head on Liner – Open Stockpile, Case 1

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.36	0.36	0.34	0.29
10	0.38	0.39	0.39	0.39
25	0.41	0.43	0.44	0.43
50	0.47	0.47	0.46	0.46
75	0.50	0.51	0.51	0.51
90	0.56	0.54	0.54	0.53
95	0.57	0.56	0.56	0.56

Table 4.1.2. Percentiles for Daily Head on Liner – Open Stockpile, Case 1

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.18	0.18	0.17	0.13
10	0.23	0.24	0.23	0.22
25	0.30	0.35	0.35	0.34
50	0.41	0.46	0.48	0.48
75	0.58	0.57	0.57	0.57
90	0.75	0.68	0.65	0.64
95	0.86	0.74	0.70	0.67

Table 4.1.3. Percentiles for Annual Percolation Rates – Open Stockpile, Case 1

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.16	0.16	0.15	0.13
10	0.16	0.17	0.17	0.17
25	0.18	0.18	0.19	0.19
50	0.20	0.20	0.20	0.20
75	0.21	0.22	0.22	0.22
90	0.23	0.23	0.23	0.23
95	0.24	0.24	0.24	0.23

Table 4.1.4 Percentiles for Daily Percolation Rates – Open Stockpile, Case 1

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.09	0.09	0.08	0.07
10	0.11	0.11	0.11	0.10
25	0.14	0.16	0.15	0.15
50	0.18	0.20	0.20	0.21
75	0.25	0.24	0.24	0.24
90	0.31	0.28	0.27	0.27
95	0.35	0.31	0.29	0.28

Table 4.1.5. Percentiles for Annual Head on Liner – Open Stockpile, Case 2

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.15	0.15	0.14	0.12
10	0.16	0.17	0.17	0.16
25	0.18	0.18	0.19	0.19
50	0.21	0.20	0.20	0.20
75	0.23	0.22	0.23	0.23
90	0.26	0.25	0.25	0.24
95	0.28	0.26	0.25	0.25

Table 4.1.6. Percentiles for Daily Head on Liner – Open Stockpile, Case 2

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.06	0.05	0.04	0.03
10	0.09	0.08	0.07	0.07
25	0.12	0.14	0.14	0.13
50	0.17	0.20	0.21	0.21
75	0.27	0.26	0.26	0.26
90	0.37	0.32	0.31	0.30
95	0.44	0.36	0.33	0.32

Table 4.1.7. Percentiles for Annual Percolation Rates – Open Stockpile, Case 2

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.07	0.07	0.07	0.06
10	0.08	0.08	0.08	0.08
25	0.08	0.09	0.09	0.09
50	0.10	0.09	0.09	0.09
75	0.10	0.10	0.10	0.10
90	0.12	0.11	0.11	0.11
95	0.12	0.12	0.11	0.11

Table 4.1.8. Percentiles for Daily Percolation Rates – Open Stockpile, Case 2

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.03	0.03	0.02	0.02
10	0.04	0.04	0.04	0.03
25	0.06	0.07	0.07	0.07
50	0.08	0.09	0.10	0.10
75	0.12	0.12	0.12	0.12
90	0.16	0.14	0.14	0.13
95	0.19	0.16	0.15	0.14

Table 4.1.9. Percentiles for Annual Head on Liner – Open Stockpile, Case 3

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.08	0.07	0.07	0.06
10	0.08	0.08	0.08	0.08
25	0.09	0.09	0.09	0.09
50	0.10	0.10	0.10	0.10
75	0.11	0.11	0.11	0.11
90	0.13	0.12	0.12	0.12
95	0.14	0.13	0.13	0.13

Table 4.1.10. Percentiles for Daily Head on Liner – Open Stockpile, Case 3

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.02	0.02	0.01	0.01
10	0.04	0.03	0.03	0.03
25	0.06	0.07	0.07	0.07
50	0.09	0.10	0.11	0.11
75	0.13	0.13	0.13	0.13
90	0.19	0.16	0.15	0.15
95	0.23	0.19	0.17	0.16

Table 4.1.11. Percentiles for Annual Percolation Rates – Open Stockpile, Case 3

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.04	0.04	0.04	0.03
10	0.04	0.04	0.04	0.04
25	0.04	0.05	0.05	0.05
50	0.05	0.05	0.05	0.05
75	0.06	0.05	0.06	0.06
90	0.06	0.06	0.06	0.06
95	0.07	0.06	0.06	0.06

Table 4.1.12. Percentiles for Daily Percolation Rates – Open Stockpile, Case 3

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.01	0.01	0.01	0.01
10	0.02	0.02	0.02	0.01
25	0.03	0.04	0.04	0.03
50	0.04	0.05	0.05	0.05
75	0.06	0.06	0.06	0.06
90	0.09	0.08	0.07	0.07
95	0.10	0.09	0.08	0.08

Table 4.1.13. Percentiles for Annual Head on Liner – Open Stockpile, Case 4

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.04	0.04	0.04	0.03
10	0.04	0.04	0.04	0.04
25	0.04	0.05	0.05	0.05
50	0.05	0.05	0.05	0.05
75	0.06	0.06	0.06	0.06
90	0.06	0.06	0.06	0.06
95	0.07	0.06	0.06	0.06

Table 4.1.14. Percentiles for Daily Head on Liner – Open Stockpile, Case 4

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.01	0.01	<0.01	<0.01
10	0.02	0.01	0.01	0.01
25	0.03	0.04	0.04	0.03
50	0.04	0.05	0.05	0.05
75	0.07	0.07	0.07	0.07
90	0.10	0.08	0.08	0.08
95	0.11	0.09	0.09	0.08

Table 4.1.15. Percentiles for Annual Percolation Rates – Open Stockpile, Case 4

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.02	0.02	0.02	0.02
10	0.02	0.02	0.02	0.02
25	0.02	0.02	0.03	0.03
50	0.03	0.03	0.03	0.03
75	0.03	0.03	0.03	0.03
90	0.03	0.03	0.03	0.03
95	0.04	0.03	0.03	0.03

Table 4.1.16. Percentiles for Daily Percolation Rates – Open Stockpile, Case 4

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.01	0.00	0.00	<0.01
10	0.01	0.01	0.01	0.01
25	0.02	0.02	0.02	0.02
50	0.02	0.03	0.03	0.03
75	0.04	0.03	0.03	0.03
90	0.05	0.04	0.04	0.04
95	0.06	0.05	0.04	0.04

Table 4.1.17. Percentiles for Annual Head on Liner – Open Stockpile, Case 5

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	1.68	1.51	0.40	0.02
10	1.80	1.79	1.67	1.37
25	1.92	1.95	1.92	1.93
50	2.08	2.07	2.06	2.05
75	2.23	2.24	2.19	2.20
90	2.33	2.31	2.31	2.30
95	2.41	2.38	2.37	2.34

Table 4.1.18. Percentiles for Daily Head on Liner – Open Stockpile, Case 5

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	1.28	1.15	0.23	<0.01
10	1.41	1.40	1.32	1.11
25	1.68	1.70	1.67	1.62
50	2.00	2.06	2.05	2.03
75	2.38	2.38	2.39	2.40
90	2.77	2.63	2.60	2.58
95	2.99	2.76	2.71	2.68

Table 4.1.19. Percentiles for Annual Percolation Rates – Open Stockpile, Case 5

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.64	0.59	0.18	0.01
10	0.68	0.68	0.64	0.53
25	0.73	0.74	0.73	0.73
50	0.78	0.78	0.78	0.77
75	0.83	0.84	0.82	0.83
90	0.87	0.87	0.86	0.86
95	0.90	0.89	0.88	0.87

Table 4.1.20. Percentiles for Daily Percolation Rates – Open Stockpile, Case 5

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.50	0.46	0.10	<0.01
10	0.55	0.54	0.52	0.44
25	0.64	0.65	0.64	0.62
50	0.76	0.78	0.77	0.76
75	0.89	0.89	0.89	0.89
90	1.02	0.97	0.96	0.96
95	1.09	1.02	1.00	0.99

Table 4.1.21. Percentiles for Annual Head on Liner – Open Stockpile, Case 6

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	1.13	0.98	0.18	0.01
10	1.24	1.23	1.13	0.85
25	1.35	1.38	1.35	1.36
50	1.50	1.49	1.49	1.48
75	1.64	1.65	1.61	1.62
90	1.74	1.72	1.72	1.70
95	1.82	1.78	1.78	1.74

Table 4.1.22. Percentiles for Daily Head on Liner – Open Stockpile, Case 6

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.76	0.65	0.09	<0.01
10	0.88	0.86	0.79	0.63
25	1.12	1.14	1.11	1.07
50	1.42	1.48	1.47	1.45
75	1.79	1.78	1.79	1.80
90	2.15	2.02	1.99	1.98
95	2.37	2.15	2.10	2.07

Table 4.1.23. Percentiles for Annual Percolation Rates – Open Stockpile, Case 6

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.45	0.39	0.08	0.01
10	0.49	0.48	0.45	0.35
25	0.53	0.54	0.53	0.53
50	0.58	0.58	0.58	0.57
75	0.63	0.63	0.62	0.62
90	0.66	0.66	0.66	0.65
95	0.69	0.68	0.68	0.66

Table 4.1.24. Percentiles for Daily Percolation Rates – Open Stockpile, Case 6

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.31	0.27	0.05	<0.01
10	0.36	0.35	0.32	0.26
25	0.45	0.45	0.44	0.43
50	0.55	0.58	0.57	0.56
75	0.68	0.68	0.68	0.69
90	0.81	0.76	0.75	0.75
95	0.88	0.81	0.79	0.78

Table 4.1.25. Percentiles for Annual Head on Liner – Open Stockpile, Case 7

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.61	0.51	0.09	0.01
10	0.68	0.67	0.61	0.44
25	0.77	0.78	0.76	0.76
50	0.87	0.86	0.86	0.85
75	0.96	0.98	0.95	0.95
90	1.07	1.03	1.02	1.02
95	1.13	1.08	1.08	1.05

Table 4.1.26. Percentiles for Daily Head on Liner – Open Stockpile, Case 7

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.33	0.27	0.04	<0.01
10	0.42	0.40	0.35	0.26
25	0.59	0.59	0.57	0.54
50	0.80	0.85	0.85	0.83
75	1.08	1.07	1.08	1.09
90	1.38	1.27	1.24	1.23
95	1.57	1.38	1.33	1.30

Table 4.1.27. Percentiles for Annual Percolation Rates – Open Stockpile, Case 7

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.25	0.22	0.05	<0.01
10	0.28	0.28	0.25	0.19
25	0.31	0.32	0.31	0.31
50	0.35	0.35	0.35	0.35
75	0.39	0.39	0.38	0.38
90	0.42	0.41	0.41	0.41
95	0.45	0.43	0.43	0.42

Table 4.1.28. Percentiles for Daily Percolation Rates – Open Stockpile, Case 7

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.15	0.12	0.02	<0.01
10	0.18	0.17	0.16	0.12
25	0.25	0.25	0.24	0.23
50	0.33	0.35	0.35	0.34
75	0.43	0.43	0.43	0.43
90	0.54	0.50	0.49	0.48
95	0.61	0.54	0.52	0.51

Table 4.1.29. Percentiles for Annual Head on Liner – Open Stockpile, Case 8

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.30	0.26	0.05	<0.01
10	0.34	0.34	0.31	0.22
25	0.38	0.39	0.38	0.38
50	0.44	0.43	0.43	0.43
75	0.48	0.49	0.48	0.47
90	0.54	0.52	0.51	0.51
95	0.57	0.54	0.54	0.53

Table 4.1.30. Percentiles for Daily Head on Liner – Open Stockpile, Case 8

Percentile	Head on Liner for Waste Rock Height = 40 ft (inch)	Head on Liner for Waste Rock Height = 80 ft (inch)	Head on Liner for Waste Rock Height = 120 ft (inch)	Head on Liner for Waste Rock Height = 160 ft (inch)
5	0.13	0.10	0.02	<0.01
10	0.18	0.16	0.14	0.10
25	0.29	0.28	0.26	0.24
50	0.40	0.44	0.44	0.44
75	0.55	0.55	0.55	0.55
90	0.71	0.65	0.63	0.62
95	0.82	0.71	0.67	0.66

Table 4.1.31. Percentiles for Annual Percolation Rates – Open Stockpile, Case 8

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.14	0.12	0.02	<0.01
10	0.15	0.15	0.14	0.10
25	0.17	0.17	0.17	0.17
50	0.19	0.19	0.19	0.18
75	0.21	0.21	0.20	0.20
90	0.23	0.22	0.22	0.22
95	0.24	0.23	0.23	0.22

Table 4.1.32. Percentiles for Daily Percolation Rates – Open Stockpile, Case 8

Percentile	Percolation Rate for Waste Rock Height = 40 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 80 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 120 ft (gal/acre/day)	Percolation Rate for Waste Rock Height = 160 ft (gal/acre/day)
5	0.06	0.05	0.01	<0.01
10	0.09	0.08	0.07	0.05
25	0.13	0.13	0.12	0.11
50	0.18	0.19	0.19	0.19
75	0.23	0.23	0.23	0.23
90	0.29	0.27	0.26	0.26
95	0.33	0.29	0.28	0.28

4.2 Sensitivity studies for capped stockpiles

Results of sensitivity studies for capped stockpiles are summarized in the following tables:

Table 4.2.1. Percentiles for Annual Head on Liner – Capped Stockpile, Case 1

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.01	<0.01
75	<0.01	<0.01	0.02	0.01
90	0.01	<0.01	0.02	0.02
95	0.01	<0.01	0.02	0.02

Table 4.2.2. Percentiles for Daily Head on Liner – Capped Stockpile, Case 1

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.01	<0.01
75	<0.01	<0.01	0.02	0.01
90	0.01	<0.01	0.03	0.02
95	0.01	<0.01	0.03	0.03

Table 4.2.3. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 1

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	0.01	0.01

Table 4.2.4. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 1

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	0.01	0.01
95	<0.01	<0.01	0.01	0.01

Table 4.2.5. Percentiles for Annual Head on Liner – Capped Stockpile, Case 2

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.6. Percentiles for Daily Head on Liner – Capped Stockpile, Case 2

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	0.01	<0.01
95	<0.01	<0.01	0.01	0.01

Table 4.2.7. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 2

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.8. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 2

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.9. Percentiles for Annual Head on Liner – Capped Stockpile, Case 3

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.10. Percentiles for Daily Head on Liner – Capped Stockpile, Case 3

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.11. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 3

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.12. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 3

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.13. Percentiles for Annual Head on Liner – Capped Stockpile, Case 4

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.14. Percentiles for Daily Head on Liner – Capped Stockpile, Case 4

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.15. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 4

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.16. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 4

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	<0.01	<0.01

Table 4.2.17. Percentiles for Annual Head on Liner – Capped Stockpile, Case 5

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	0.03	<0.01	0.10	<0.01
75	0.06	<0.01	0.15	0.02
90	0.09	<0.01	0.20	0.06
95	0.11	0.01	0.23	0.10

Table 4.2.18. Percentiles for Daily Head on Liner – Capped Stockpile, Case 5

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	0.02	<0.01	0.08	<0.01
75	0.06	<0.01	0.16	0.02
90	0.10	<0.01	0.22	0.07
95	0.11	0.01	0.24	0.11

Table 4.2.19. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 5

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	0.02	<0.01	0.04	<0.01
75	0.03	<0.01	0.06	<0.01
90	0.05	<0.01	0.07	0.02
95	0.06	<0.01	0.08	0.04

Table 4.2.20. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 5

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	0.01	<0.01	0.03	<0.01
75	0.03	<0.01	0.06	<0.01
90	0.05	<0.01	0.08	0.03
95	0.06	<0.01	0.08	0.04

Table 4.2.21. Percentiles for Annual Head on Liner – Capped Stockpile, Case 6

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	0.01	<0.01	0.04	<0.01
75	0.02	<0.01	0.06	<0.01
90	0.04	<0.01	0.08	0.03
95	0.05	<0.01	0.10	0.04

Table 4.2.22. Percentiles for Daily Head on Liner – Capped Stockpile, Case 6

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.03	<0.01
75	0.02	<0.01	0.07	<0.01
90	0.04	<0.01	0.09	0.03
95	0.05	<0.01	0.11	0.05

Table 4.2.23. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 6

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.02	<0.01
75	0.01	<0.01	0.02	<0.01
90	0.02	<0.01	0.03	0.01
95	0.02	<0.01	0.04	0.02

Table 4.2.24. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 6

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.01	<0.01
75	0.01	<0.01	0.03	<0.01
90	0.02	<0.01	0.04	0.01
95	0.03	<0.01	0.04	0.02

Table 4.2.25. Percentiles for Annual Head on Liner – Capped Stockpile, Case 7

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.02	<0.01
75	0.01	<0.01	0.03	<0.01
90	0.02	<0.01	0.04	0.01
95	0.02	<0.01	0.05	0.02

Table 4.2.26. Percentiles for Daily Head on Liner – Capped Stockpile, Case 7

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.01	<0.01
75	0.01	<0.01	0.03	<0.01
90	0.02	<0.01	0.05	0.02
95	0.02	<0.01	0.06	0.02

Table 4.2.27. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 7

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	0.01	<0.01
90	0.01	<0.01	0.02	<0.01
95	0.01	<0.01	0.02	0.01

Table 4.2.28. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 7

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	0.01	<0.01
90	0.01	<0.01	0.02	<0.01
95	0.01	<0.01	0.02	0.01

Table 4.2.29. Percentiles for Annual Head on Liner – Capped Stockpile, Case 8

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	0.01	<0.01
75	<0.01	<0.01	0.02	<0.01
90	<0.01	<0.01	0.02	<0.01
95	0.01	<0.01	0.02	0.01

Table 4.2.30. Percentiles for Daily Head on Liner – Capped Stockpile, Case 8

Percentile	Head on Liner for Waste Rock Height = 40 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 93 ft ET Cover (inch)	Head on Liner for Waste Rock Height = 40 ft LLDPE Cap (inch)	Head on Liner for Waste Rock Height =93 ft LLDPE Cap (inch)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	0.02	<0.01
90	<0.01	<0.01	0.02	<0.01
95	0.01	<0.01	0.03	0.01

Table 4.2.31. Percentiles for Annual Percolation Rates – Capped Stockpile, Case 8

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	<0.01	<0.01
95	<0.01	<0.01	0.01	<0.01

Table 4.2.32. Percentiles for Daily Percolation Rates – Capped Stockpile, Case 8

Percentile	Percolation Rate for Waste Rock Height = 40 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 93 ft ET Cover (gal/acre/day)	Percolation Rate for Waste Rock Height = 40 ft LLDPE Cap (gal/acre/day)	Percolation Rate for Waste Rock Height =93 ft LLDPE Cap (gal/acre/day)
5	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01
25	<0.01	<0.01	<0.01	<0.01
50	<0.01	<0.01	<0.01	<0.01
75	<0.01	<0.01	<0.01	<0.01
90	<0.01	<0.01	0.01	<0.01
95	<0.01	<0.01	0.01	<0.01

5.0 CONCLUSIONS

HELP model simulations indicate percolation rates for the open Category 4 stockpiles below 1 gal/acre/day. The maximum calculated daily head for the open Category 4 stockpile with the liner grades constructed at 0.2% is 4.9 inches. In general, the head on the liner decreases for steeper liner grades. For the liner grade at 2%, the maximum calculated head for the open Category 4 stockpile is 2.2 inches.

HELP simulations considering stockpiles with the constructed final cover indicate percolation rates well below 1 gal/acre/day. Consequently, the corresponding head on the liner is less than 1 inch for all modeling scenarios considering capped stockpiles.

TECHNICAL MEMORANDUM

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TO:	John Borovsky, Barr Engineering	**DATE:**	May 31, 2007
FROM:	Gordan Gjerapic P.E., GAI	**OUR REF.:**	053-2209
CC:	Brent R. Bronson P.E., GAI		
RE:	**PONDING AND PERCOLATION ESTIMATES FOR THE CATEGORY 1/2 AND CATEGORY 3 WASTE ROCK STOCKPILES, POLYMET PROJECT, MINNESOTA**		

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this technical memorandum for Barr Engineering (Barr) to present predicted estimates of ponding and percolation for the Category 1/2 and Category 3 waste rock stockpiles. This work was completed based on the authorization provided via e-mail correspondence between Barr and Golder on May 28, 2007. The purpose of this work is to refine analyses presented in the previous reports (RS-23 and RS-49 issued by Golder on February 16, 2007) and the technical memorandum "Ponding and Percolation Estimates for Categories 3 and 4 Waste Rock Stockpiles, PolyMet Project, Minnesota" (Golder, May 7 2007). In particular, this memorandum investigates the influence of liner grades and spacing between the leach collection pipes to the water balance and to predicted percolation rates. The results in this memorandum were obtained by using the HELP (Hydrologic Evaluation of Landfill Performance) model developed by the US Environmental Protection Agency (Schroeder, P.R. et. al.). The predicted results may be subject to further revisions pending on the future changes in the stockpile design and more detailed information on the properties of the stockpile, overliner, and cover materials.

2.0 INPUT PARAMETERS

All simulations use a 100-year weather record for Duluth, Minnesota, synthetically generated by HELP. The following material parameters were used for HELP simulations:

Table 2.1. Material Parameters for Modeling Scenarios without the Final Cover

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage Grades and Geomembrane Defects
Waste rock	21	3.00E-01	480	
Overliner (50 or 100 ft drains)	21	3.00E-01	12	0.2%, 0.5% slope
LLDPE	36	4.00E-13	0.08	4 holes, 1 pinhole per acre
Subgrade Cat. 1/2	16	5.00E-07	12	
Subgrade Cat. 3	16	1.00E-05	12	

As indicated in Table 2.1, the lower model boundary for Category 3 stockpiles consists of an 80-mil LLDPE placed on a 12 inch thick subgrade material. The proposed liner is overlain by 12 inches of the overliner material and 40 ft of the stockpile waste rock. The HELP model for Category 1/2 stockpiles assumes 12 inch of subgrade material overlain by 12 inches of the overliner material and 40 ft of the stockpile waste rock.

Modeling scenarios are summarized in the following table:

Table 2.2. Modeling Scenarios

Simulation No.	Type	Liner Grade (%)	Drainage Length (ft)	Simulation ID
Cat. 1-1	Open Stockpile	0.2	50	C1OS1DF
Cat. 1-2	Open Stockpile	0.2	100	C1OS1DH
Cat. 1-3	Open Stockpile	0.5	50	C1OS2DF
Cat. 1-4	Open Stockpile	0.5	100	C1OS2DH
Cat. 3-1	Open Stockpile	0.2	50	C3OS1DF
Cat. 3-2	Open Stockpile	0.2	100	C3OS1DH
Cat. 3-3	Open Stockpile	0.5	50	C3OS2DF
Cat. 3-4	Open Stockpile	0.5	100	C3OS2DH

3.0 RESULTS

HELP results are summarized in the following tables:

Table 3.1. Average Annual Precipitation, Runoff, and Evaporation Values

Avg. Annual Precipitation (inch)	Avg. Annual Runoff (inch)	Avg. Annual Evaporation (inch)
29.2	3.9	12.4

Table 3.2. HELP Results for Lateral Drainage, Percolation, and Head on Liner Open Stockpile

Simulation No.	Avg. Annual Lateral Drainage (inch)	Avg. Annual Percolation (inch)	Avg. Annual Head on Liner (inch)	Peak Daily Percolation (inch)	Peak Daily Head on Liner (inch)
Cat. 1-1	6.68	6.05	0.25	1.9e-2	1.51
Cat. 1-2	6.50	6.24	0.49	2.0e-2	2.80
Cat. 1-3	6.87	5.86	0.11	1.8e-2	1.06
Cat. 1-4	6.73	6.01	0.22	1.9e-2	2.0
Cat. 3-1	12.72	0.01	0.46	1.1e-4	1.64
Cat. 3-2	12.70	0.03	0.92	2.0e-4	3.10
Cat. 3-3	12.73	0.01	0.21	7.5e-5	1.16
Cat. 3-4	12.72	0.01	0.41	1.3e-4	2.19

Table 3.5. Summary of Calculated Percolation Rates

Simulation No.	Open Stockpile Avg. Annual Perc. (gal/acre/day)	Open Stockpile Peak Daily Perc. (gal/acre/day)
Cat. 1-1	450	513
Cat. 1-2	464	556
Cat. 1-3	436	493
Cat. 1-4	447	520
Cat. 3-1	1.1	3.0
Cat. 3-2	2.0	5.5
Cat. 3-3	0.5	2.0
Cat. 3-4	1.0	3.6

4.0 CONCLUSIONS

HELP model simulations indicate average annual percolation rates for the open Category 1/2 stockpiles is between 400 and 500 gal/acre/day. The maximum calculated daily head for the open Category 1/2 stockpile with the liner grades constructed at 0.2% is 2.8 inches. In general, the head on the liner decreases for steeper liner grades and smaller spacing between the leach collection pipes.

HELP simulations for Category 3 stockpiles indicate maximum percolation rates of approximately 2 gal/acre/day for the liner grades of 0.2% and the leach collection pipe spacing of 100 ft. The maximum calculated daily head for the open Category 3 stockpile is 3.1 inches.

The presented percolation values are likely conservative as they neglect the waste rock uptake potential and the buffering of peak daily values for the stockpile heights in excess of 40 ft.

5.0 REFERENCES

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

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TECHNICAL MEMORANDUM

TO: Miguel Wong, Barr Engineering **DATE:** December 17, 2007

FR: Gordan Gjerapic P.E., Golder Associates Inc. **OUR REF:** 053-2209

CC: Brent Bronson, P.E., Golder Associates Inc.

RE: DRAFT PERCOLATION ESTIMATES FOR DRAINAGE SUMPS, PROCESS WATER PONDS AND WWTF EQUALIZATION PONDS, POLYMET PROJECT, MINNESOTA

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this draft technical memorandum for Barr Engineering (Barr) to present predicted percolation estimates for drainage sumps, process water ponds and Waste Water Treatment Facility (WWTF) equalization ponds. This work was completed based on authorization provided via e-mail correspondence between Barr and Golder on December 6, 2007. The methodology used to estimate the percolation through the drainage sump liner systems for (1) Category 1 and 2 stockpiles and (2) Category 3 and 4 stockpiles are based on the previous technical memorandum by Golder "Percolation Estimates for Drainage Sumps, PolyMet Project, Minnesota" dated July 26,2007. Estimated percolation rates for WWTF equalization ponds and process water ponds were determined based on the input parameters from Barr as outlined in the e-mail correspondence from December 6, 2007.

2.0 APPROACH

All calculations were conducted using the methodology for leakage through single, double and composite liners described by Hutchison et al. (1992) relying on work by Bonaparte et al. (1989), Giroud and Bonaparte (1989) and Giroud et al. (1989; 1992; 1994). The calculations involving liquid migration through composite liners were updated using the formulation by Giroud (1997) for geosynthetics with circular, square and rectangular defects:

$$Q = C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]a^{0.1}\,h^{0.9}\,k_s^{0.74} \quad \text{- for circular defects} \quad (1)$$

$$Q = C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]b^{0.2}\,h^{0.9}\,k_s^{0.74} \quad \text{- for square defects} \quad (2)$$

$$Q = C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]b^{0.2}\,h^{0.9}\,k_s^{0.74} + C_{q\infty}\left[1+0.2\left(h/t_s\right)^{0.95}\right](B-b)\,b^{0.1}\,h^{0.45}\,k_s^{0.87}$$

$$\text{- for rectangular defects} \quad (3)$$

Where:

Q = flow rate through the composite liner (m^3/s);

C_{qo} = flow coefficient through circular opening depending on the quality of contact between the soil and geomembrane (extreme values are 0.21 for good contact and 1.15 for poor contact);

$C_{q\infty}$ = flow coefficient through an infinitely long defect ($B=\infty$) with the width b depending on the quality of contact between the soil and geomembrane (extreme values are 0.52 for good contact and 1.22 for poor contact);

a = circular defect area (m^2);

b = width of square/rectangular defect (m);

B =length of rectangular defect (m);

h = head of liquid on top of the geomembrane (m);

k_s = hydraulic conductivity of the soil layer below geomembrane (m/s); and

t_s = thickness of the soil layer below geomembrane (m).

Giroud (1997) noted that Equations (1), (2) and (3) are not applicable for the liquid head on top of geomembrane larger than 3 m or for the soil liner permeability (k_s) above the k_g value defined as:

$$k_g = \left\{ \frac{0.3891 d^{1.8}}{C_{qo}\left[1 + 0.1\left(h/t_s\right)^{0.95}\right] h^{0.4}} \right\}, \quad (4)$$

where d is the diameter of the circular defect. For the case where k_s exceeds the k_g value, Torricelli's equation for orifice flow is used (see e.g. Giroud and Bonaparte, 1989 and Foose et al., 2001):

$$Q = 0.6\, a \sqrt{2\, g\, h}\,, \quad (5)$$

with the variables defined above. Based on the Geosyntec recommendations outlined in Hutchison (1992), a circular defect area (a) of 0.1 cm^2 (0.016 $inch^2$) was used for drainage sumps and process ponds liner system performance evaluations containing geomembrane. Similar recommendations can be found in Giroud et al. (1994). All liners were assumed to exhibit good contact between the soil and the geomembrane. Percolation through the WWTF equalization pond liners was calculated based on the input parameters provided by Barr as follows:

- Liner is a composite Geomembrane / Geosynthetic Clay liner
- Circular, square, and rectangular defects are present
- Total frequency of defects is 2.5 per acre (n = 2.5)
- Total liner leakage is based on summing the leakage rate for 2.5 circular defects, 2.5 square defects, and 2.5 rectangular defects and then dividing by 3 (i.e. assuming 0.83 defects of each type per acre)
- Defect Sizes:
    - Circular = 1 cm diameter
    - Square = 1 cm width (b)
    - Rectangular = 2 meter length (B) x 1 cm width (b)

- Contact quality coefficient of 0.21 assumed for circular and square defects, coefficients of 0.21 and 0.52 assumed for rectangular defects.
- Liner thickness = 6.5 mm
- Subgrade soil permeability K_s = 3 x 10^{-9} cm/sec.

For double liner systems, the ability of the Leachate Collection and Removal System (LCRS) LCRS to remove the flow through the primary liner is directly proportional to its hydraulic conductivity. Assuming that the drainage from the LCRS mobilizes only a portion of the LCRS area with an effective width L_w, the head on the bottom liner (underlying LCRS) can be calculated as

$$h_{LCRS} = \frac{Q}{L_w \, k_{LCRS} \, i_{LCRS}},$$

where i_{LCRS} denotes the LCRS gradient (minimum drainage grade). All calculations in this memorandum utilize the LCRS gradient of 1% and the effective drainage width of 20 ft.

The rate of percolation for the overburden process water ponds constructed without geomembrane was calculated as

$$Q = Area \times k_s \times \frac{h_{TOP} + t_s - h_{BOT}}{t_s}, \quad (6)$$

where t_s denotes the thickness of the soil liner, h_{TOP} is the height of the ponded water on top of the liner and h_{BOT} stands for the pore pressure head on the bottom of the liner. The results presented in this memorandum were determined for the pore pressures at the bottom of the soil liner equal to zero.

3.0 INPUTS

Input parameters used to estimate percolation were based on the e-mail correspondence with Barr on December 6, 2007, design recommendations by Golder (2007), and material parameters reported by Schoeder et al. (1994). Input parameters are summarized in the following tables:

Table 3.1

Input Parameters for Categories 1 and 2 Stockpile Drainage Sumps and Haul Road Process Ponds

Input Parameter	Value
Geomembrane type	60 mil HDPE
Geomembrane defect, *a*	0.1 cm^2
Defect frequency	1 hole per acre
Soil liner thickness, t_s	1 ft
Soil liner permeability, k_s	1x10^{-6} cm/s
Flow/contact coefficient, C_{qo}	0.21
Head on the liner, *h*	6 feet (6 to 12 ft for Haul Road Process Pond)

Table 3.2

Input Parameters for Categories 3 and 4 Stockpile Drainage Sumps and Rail Transfer Process Pond

Input Parameter	Value
Top geomembrane type	60 mil HDPE
Top geomembrane defect, *a*	0.1 cm^2
Top geomembrane defect frequency	1 hole per acre
Top geomembrane contact coefficient, C_{qo}	0.21
Head on the top liner, *h*	6 feet (6 to 12 ft for Rail TransferPond)
LRCS type	Geonet
LRCS thickness	0.6 cm
LRCS permeability	33 cm/s
Bottom geomembrane type	40 mil HDPE
Bottom geomembrane defect, *a*	0.1 cm^2
Bottom geomembrane defect frequency	1 hole per acre
Bottom geomembrane contact coefficient, C_{qo}	0.21
Soil liner thickness, t_s	1 ft
Soil liner permeability, k_s	$1x10^{-6}$ cm/s

Table 3.3

Input Parameters for Overburden Process Ponds

Input Parameter	Value
Soil liner thickness, t_s	2 ft
Soil liner permeability, k_s	$1x10^{-6}$ cm/s
Head on the liner, *h*	6 to 12 feet

Table 3.4

Input Parameters WWTF Equalization Ponds

Input Parameter	Value
Geomembrane type	60 mil HDPE
Geomembrane circular defect area, *a*	0.785 cm^2
Geomembrane square defect area	1.0 cm^2
Geomembrane rectangular defect area	200 cm^2
Defect frequency	2.5 defects per acre (0.83 defects of each type per acre)
GCL thickness, t_s	6.5 mm
GCL permeability, k_s	$3x10^{-9}$ cm/s
Flow/contact coefficient, C_{qo}	0.21
Flow/contact coefficient, $C_{q\infty}$	0.52
Head on the liner, *h*	varies

Sump design details (effective liner areas and average liquid depths) were provided by Barr and are summarized in the following tables:

Table 3.5

Sump Design Details

Sump	Area (acres)	Stockpile	Average Depth (ft)	Liner Type
S-1	0.1	Cat 1/2	6	1/2
S-2	0.2	Cat 1/2	6	1/2
S-3	0.1	Cat 1/2	6	1/2
S-4	0.1	Cat 1/2	6	1/2
S-5	0.1	Cat 1/2	6	1/2
S-6	1.5	Cat 4 LO	6	3/4
S-7	1.1	Cat 4 LO	6	3/4
S-8	1.3	Cat 4	6	3/4
S-9	1.3	Cat 3 LO	6	3/4
S-10	1.5	Cat 3 LO	6	3/4
S-11	1.5	Cat 3	6	3/4

Table 3.6

Process Water Pond Design Details

Pond	Water Source	Liner Type	Design Option 1*		Design Option 2*	
			Area 1 (acres)	Avg. Depth 1 (ft)	Area 2 (acres)	Avg. Depth 2 (ft)
PW-1	Overburden	None	1.7	12	3.3	6
PW-7	Overburden	None	3.1	12	6.2	6
PW-2	Haul Roads	1/2	0.7	12	1.4	6
PW-4	Haul Roads	1/2	1.5	12	2.9	6
PW-3	Rail Transfer	3/4	0.4	12	0.7	6

* Note – Two possible design scenarios exist for each pond (resulting in the same volume, but different depths/areas)

4.0 RESULTS

The results of the calculations discussed above are summarized in the following tables.

Table 4.1

Unitized Drainage Sump Percolation Rates

	Category 1 and 2	Category 3 and 4
Flow rate (m^3/s/acre)	$2.2x10^{-7}$	$3.5x10^{-10}$
Flow rate (gal/acre/day)	5.0	$8.0x10^{-3}$

Table 4.2

Unitized Process Water Ponds Percolation Rates (gal/acre/day)

	Head on Liner, *h*=6 ft	Head on Liner, *h*=12 ft*
Overburden Ponds	$3.7x10^{3}$	$6.5x10^{3}$
Haul Road Ponds	5.0	12.4
Rail Transfer Pond	$8.0x10^{-3}$	$1.1x10^{-2}$

* The application of the Giroud's (1997) liner leakage equations is restricted to the pond levels up to 10 ft. Therefore, the percolation results for 12 ft head should be viewed as approximate noting that the liner head exceeds the published threshold value by 20%.

Table 4.3

Unitized WWTF Equalization Ponds Percolation Rates

Head (ft)	Qcircular (m^3/s/defect)	Qsquare (m^3/s/defect)	Qrectangular (m^3/s/defect)	Q_{avg}* (gal/acre/day)
1	2.2E-09	2.3E-09	4.6E-09	0.2
2	7.2E-09	7.4E-09	1.3E-08	0.5
3	1.5E-08	1.5E-08	2.5E-08	1.0
4	2.5E-08	2.5E-08	4.0E-08	1.7
5	3.7E-08	3.8E-08	5.8E-08	2.5
6	5.1E-08	5.2E-08	7.8E-08	3.5
7	6.7E-08	6.9E-08	1.0E-07	4.5
8	8.6E-08	8.8E-08	1.3E-07	5.7
9	1.1E-07	1.1E-07	1.5E-07	7.0
10	1.3E-07	1.3E-07	1.8E-07	8.5
11	1.5E-07	1.6E-07	2.2E-07	10.0
12	1.8E-07	1.8E-07	2.5E-07	11.7

* Assumes 0.83 defects of each type per acre

5.0 CONCLUSIONS

The liner percolation calculations illustrate the effectiveness of the lined and double lined ponds comparatively to the unlined ponds. As indicated in Table 4.2, ponds utilizing a single liner are likely to be over 1000 times more efficient than for the unlined ponds. Similarly, the percolation through the ponds constructed with the secondary containment is likely to be approximately 1000 times smaller than percolation from the ponds using a conventional composite liner. There are minor discrepancies between Table 4.3 and the WWTF percolation rates sent by Barr for Golder's review (e-mail from Greg Williams on November 26, 2007). These discrepancies are due to:

- Head exponent in Column "O" in Barr's spreadsheet is 0.9375 vs. the value of 0.9 used by Golder [Equation (1)].
- Head exponent in Column "P" in Barr's spreadsheet is 0.9375. In addition, there is a factor of 0.976 in front of the equation. This factor is typically used if there is a need to convert Equation (1) to a format using a circular defect diameter but is not recommended for square defects. Equation (2) calls for the head exponent of 0.9.

- Head exponent in Column "Q" equals 0.9375 for both the "square" and the "infinitely long" opening contributions. The head exponents in Equation (3) calls for the value of 0.9 for the "square" opening and 0.45 for the "infinitely long" opening. In addition there is a value of 0.1 using to calculate the gradient factor corresponding to the "infinitely long" opening rather than the value of 0.2 [see Equation (3)].

Effectively, the equations used by Barr are

$$Q = C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]a^{0.1}\,h^{0.9375}\,k_s^{0.74}$$ - for circular defects

$$Q = 0.976\,C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]b^{0.2}\,h^{0.9375}\,k_s^{0.74}$$ - for square defects

$$Q = C_{qo}\left[1+0.1\left(h/t_s\right)^{0.95}\right]b^{0.2}\,h^{0.9375}\,k_s^{0.74} + C_{q\infty}\left[1+0.1\left(h/t_s\right)^{0.95}\right](B-b)\,b^{0.1}\,h^{0.9375}\,k_s^{0.87}$$

- for rectangular defects.

6.0 REFERENCES

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TECHNICAL MEMORANDUM

Golder Associates Inc.
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Telephone: 303-980-0540
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TO: Miguel Wong, Barr Engineering **DATE:** December 21, 2007

FROM: Gordan Gjerapic P.E., Golder **OUR REF.:** 053-2209

CC: Brent R. Bronson P.E., Golder

RE: DRAFT PERCOLATION ESTIMATES FOR OVERBURDEN STOCKPILES, POLYMET PROJECT, MINNESOTA

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this draft technical memorandum for Barr Engineering (Barr) to present deep percolation estimates for overburden stockpiles. This work was completed based on the authorization provided via e-mail correspondence between Barr and Golder on December 6, 2007. Predicted percolation rates were determined using the HELP model. Material properties for both the stockpiled overburden and foundation materials were estimated based on the available data from geotechnical field investigations by Barr in March, 2005 and Golder in August, 2006 ("Phase I Geotechnical Field Investigation, PolyMet NorthMet Site, Near Babbitt, Minnesota.")

2.0 FOUNDATION SOILS

Material parameters for the proposed overburden stockpile (Overburden Stockpile and Overburden Storage Pile) were determined based on the available borehole and test pit data. Material properties of the topsoil layer were assumed to have no impact to infiltration as the reported numbers should be viewed as deep percolation estimates. The subsurface data used to estimate foundation properties for the Overburden Storage Pile are summarized in the following table:

Table 2.1 Boreholes Used to Estimate Subsurface Properties of Overburden Storage Pile

Borehole	Subsurface Properties
MW-05-02	6.5 feet of sandy clay (CL)
SB-05-03	10.0 ft of sandy clay w/ sand lenses at larger depths

Overburden Stockpile (adjacent to Category 1 and 2 stockpile) was divided into two parts: 1) North Overburden Stockpile containing overburden material with the maximum height of 40 to 80 ft over the engineered liner ($k=5 \times 10^{-7}$ cm/s). 2) West Overburden Stockpile containing overburden material in excess of 200 ft constructed without an engineered liner. As the North Overburden Stockpile is constructed with an engineered liner, percolation estimates can be determined by using the specified liner permeability for the base permeability. Conversely, the West Overburden Stockpile is unlined

and is likely to exhibit significant variation in foundation material properties. The subsurface data used to estimate foundation properties for the West Overburden Stockpile are summarized in the following table:

Table 2.2 Boreholes and Test Pits Used to Estimate Subsurface Properties of West Overburden Stockpile

Borehole or Test Pit	Subsurface Properties
TP-1	Silty sands (SM) to 20 ft (encountered no bedrock)
TP-4	Sily sands (SM) to 13.5 ft
TP-5	3.5 feet of clay (CL) over 10 ft of silty sand (SM)
TP-6	Silty sands (SM) and sandy silts (ML) to 20 ft (encountered no bedrock)

Based on the laboratory testing, the lowest amount of fines for the samples collected from the test in Table 2.2 was found in the TP-1 borehole (28.6%). As laboratory data for other test pits in Table 2.2 (TP-4, TP-5 and TP-6) indicate larger fines content, the foundation soil permeabilities for the West Overburden Stockpile were assumed to be dominated by the finer portion of the porous matrix. Hence, the percolation estimates for the West Overburden Stockpile were determined by using the foundation permeability ranging from 10^{-5} to 10^{-6} cm/s. Noting that the surface soils from the boreholes closest to the Overburden Storage Pile footprint were classified as sandy clays (see Table 2.1), the same range of permeabilities was used for the Overburden Storage Pile foundation materials.

3.0 STOCKPILED OVERBURDEN MATERIAL

Majority of the stockpiled overburden is likely to consist of glacial tills classified as SM and CL materials. Furthermore, the subsurface investigations by Barr (2005) and Golder (2006) indicate that a portion of the stockpiled overburden is also likely to contain peat and more pervious sands and gravels (see e.g. MW-05-08, MW-05-09, SB-05-10, TP-8, TP-9 and TP-10). The available subsurface data, however, indicate that the majority of the stockpiled overburden is likely to consist of relatively less pervious SM, CL and ML materials. Hence, the effective permeability for the stockpiled overburden materials was assumed to range from 10^{-4} to 10^{-5} cm/s.

4.0 INPUTS

Input parameters for HELP modeling were adopted from Schoeder et al. (1994) [" The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3", EPA/600/R-94/168b, US. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, OH].

Input parameters are summarized in the following table:

Table 4.1 Input Parameters for HELP model simulations

Materials	HELP No.	ksat (cm/s)	Thickness (ft)
Foundation - North Overburden Stockpile	16	5.0e-7	1.0
Foundation – West Overburden Stockpile	16	1.0e-05 to 1.0e-6	15
Foundation – Overburden	16	1.0e-05 to 1.0e-6	10

Materials	HELP No.	ksat (cm/s)	Thickness (ft)
Storage Pile			
Stockpiled overburden – North Overburden Stockpile	10	1.0e-04 to 1.0e-5	40 to 80
Stockpiled overburden – West Overburden Stockpile	10	1.0e-04 to 1.0e-5	200
Stockpiled overburden – Overburden Storage Pile	10	1.0e-04 to 1.0e-5	40
Overliner* – North Overburden Stockpile	21	3.00e-01	1.0

* assumed 0.2% drainage grade and 100 ft spacing of drainage collection pipes

Modeling scenarios are summarized in the following tables:

Table 4.2 Modeling Scenarios – North Overburden Stockpile

Case Scenario ID	Stockpiled Overburden Height (ft)	Stockpiled Overburden Permeability (cm/s)	Foundation Permeability (cm/s)
OBN-1	40	1.0e-4	5.0e-7
OBN-2	40	1.0e-5	5.0e-7
OBN-3	80	1.0e-4	5.0e-7
OBN-4	80	1.0e-5	5.0e-7

Table 4.3 Modeling Scenarios – West Overburden Stockpile

Case Scenario ID	Stockpiled Overburden Height (ft)	Stockpiled Overburden Permeability (cm/s)	Foundation Permeability (cm/s)
OBW-1	200	1.0e-4	1.0e-5
OBW-2	200	1.0e-4	1.0e-6
OBW-3	200	1.0e-5	1.0e-5
OBW-4	200	1.0e-5	1.0e-6

Table 4.4 Modeling Scenarios – Overburden Storage Pile

Case Scenario ID	Stockpiled Overburden Height (ft)	Stockpiled Overburden Permeability (cm/s)	Foundation Permeability (cm/s)
OBS-1	40	1.0e-4	1.0e-5
OBS-2	40	1.0e-4	1.0e-6
OBS-3	40	1.0e-5	1.0e-5
OBS-4	40	1.0e-5	1.0e-6

5.0 RESULTS

HELP simulation results are summarized in the following tables:

Table 5.1 Percolation through North Overburden Stockpile

Case Scenario ID	Average Annual Percolation (inch)	Average Annual Percolation (% Precip.)	Average Annual Percolation (gal/acre/day)
OBN-1	5.00	17.1	372
OBN-2	2.19	7.5	163
OBN-3	4.94	16.9	368
OBN-4	1.92	6.6	143

Table 5.2 Percolation through West Overburden Stockpile

Case Scenario ID	Average Annual Percolation (inch)	Average Annual Percolation (% Precip.)	Average Annual Percolation (gal/acre/day)
OBW-1	6.43	22.1	478
OBW-2	6.43	22.1	478
OBW-3	5.65	19.4	420
OBW-4	5.65	19.4	420

Table 5.3 Percolation through Overburden Storage Pile

Case Scenario ID	Average Annual Percolation (inch)	Average Annual Percolation (% Precip.)	Average Annual Percolation (gal/acre/day)
OBS-1	7.03	24.1	523
OBS-2	7.03	24.1	523
OBS-3	7.20	24.7	535
OBS-4	7.20	24.7	535

6.0 CONCLUSIONS

Based on the estimated overburden material properties, the average annual percolation rates through the Overburden Stockpile and Overburden Storage Pile are likely to range from about 150 to approximately 500 gal/acre/day. The estimated percolation rates are likely to exhibit smaller values for the overburden material placed over the engineered liner with the drainage layer and the solution collection piping system. The estimated average annual percolation rates for the overburden materials placed without the engineered liner, i.e. for the overburden placement directly over the native soils, may exceed 500 gal/acre/day.

DRAFT
TECHNICAL MEMORANDUM

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Telephone: 303-980-0540
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TO: Miguel Wong, Barr Engineering **DATE:** May 20, 2008

FROM: Gordan Gjerapic P.E., GAI **OUR REF.:** 053-2209

CC: Brent R. Bronson P.E., GAI

RE: DRAFT HELP RUNS FOR SENSITIVITY ANALYSIS OF LINER LEAKAGE RATES

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this technical memorandum for Barr Engineering (Barr) presenting sensitivity analyses of liner leakage rates to be reported in Draft 02 of RS74 (Water Quality Modeling) as agreed by Barr (Miguel Wong and Christie Kearney) and MDNR (Paul Eger and John Adams) on May 5. Barr (Miguel Wong, Katie Wenigmann and Christie Kearney), MDNR (Paul Eger) and Jim Kunkel (Knight Piesold) decided to expand the number of required analyses on May 20, 2008. This work was completed based on the authorization provided via e-mail correspondence between Barr and Golder on May 6 (initial 103 analyses) and May 20, 2008 (additional 13 analyses). The results in this memorandum were obtained by using the HELP (Hydrologic Evaluation of Landfill Performance) model calibrated to a range of liner yields agreed upon between Barr and MNDR. 116 HELP simulations were conducted to evaluate linear leakage sensitivity.

2.0 INPUT PARAMETERS

All simulations use a 100 year weather record for Duluth, Minnesota, synthetically generated by HELP. The following material parameters were used for HELP simulations:

Table 2.1 Material Parameters for HELP Modeling Scenarios

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage grades and geomembrane defects
Waste rock	21	3.00E-01	480, 1200	
Overliner (with 100 ft drains)	21	3.00E-01	12	0.2%, 0.5% , 1.0% and 2.0% slope
LLDPE	36	4.00E-13	0.08	1, 4 and 8 installation

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage grades and geomembrane defects
				defects per acre
Subgrade Cat. 1/2	16	1.00E-07, 5.00E-07, 5.00E-06	12	
Subgrade Cat. 3, 4	16	1.00E-05, 1.00E-06, 1.00E-07	12	

As indicated in Table 2.1, the lower model boundary for Category 3 and 4 stockpiles consists of a 80 mil LLDPE placed on a 12 inch thick subgrade material. The proposed liner is overlain by 12 inches of the overliner material and 100 ft of the stockpile waste rock. HELP model for Category 1/2 stockpiles assumes 12 inch of subgrade material overlain by 12 inches of the overliner material and 40 ft of the stockpile waste rock.

3.0 MODELING SCENARIOS

To reproduce target yield values, Category 1/2 stockpiles were modeled with a 24 inch thick surface layer material with varying permeability (see Figure 1). Similarly, Category 3 and 4 stockpiles utilized a 36 inch thick layer of surface material or geomembrane cover overlain by 18 inches of topsoil. In addition, the calibration process employed varying evaporation depths, scaling of the average wind speed and solar radiation values, and reduction of the stockpile areas available to runoff in order to attain target yields. The average annual precipitation employed for HELP simulations was 29.2 inches.

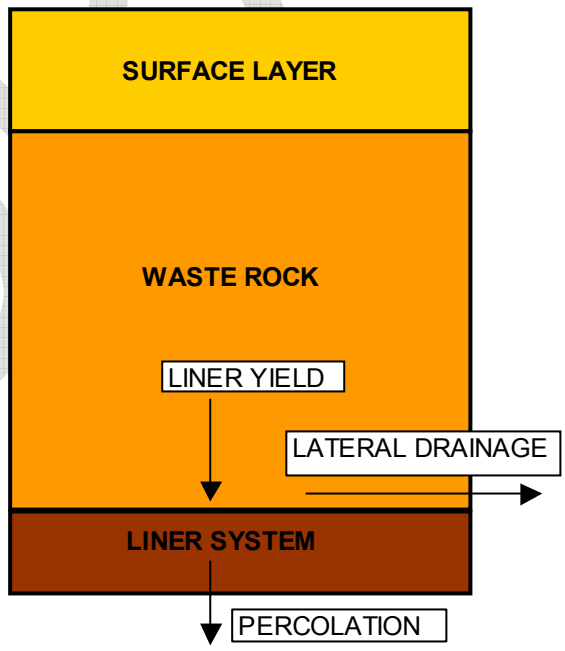

Figure 1 Modeling Geometry

The analyzed HELP case scenarios are summarized in the following tables:

Table 3.1 Case Scenarios for Category 1/2 Stockpiles

Case	Case Designation	Target Liner Yield (inch/year)	Permeability of Soil Liner in Liner System (cm/s)	Slope of Overliner in Liner System
1	Cat1_WR-1	20.4	5.00E-06	0.20%
2	Cat1_WR-2	14.7	5.00E-06	0.20%
3	Cat1_WR-3A	14.2	1.00E-07	0.20%
4	Cat1_WR-3B	14.2	5.00E-07	0.20%
5	Cat1_WR-3C	14.2	5.00E-06	0.20%
6	Cat1_WR-3D	14.2	1.00E-07	0.50%
7	Cat1_WR-3E	14.2	5.00E-07	0.50%
8	Cat1_WR-3F	14.2	5.00E-06	0.50%
9	Cat1_WR-4A	10.2	1.00E-07	0.20%
10	Cat1_WR-4B	10.2	5.00E-07	0.20%
11	Cat1_WR-4C	10.2	5.00E-06	0.20%
12	Cat1_WR-4D	10.2	1.00E-07	0.50%
13	Cat1_WR-4E	10.2	5.00E-07	0.50%
14	Cat1_WR-4F	10.2	5.00E-06	0.50%
15	Cat1_WR-5	8.2	1.00E-07	0.50%
16	Cat1_WR-6	4.7	1.00E-07	0.50%
104	Cat1_WR-5_Extra 1	8.2	5.00E-07	0.50%
105	Cat1_WR-5_Extra 2	8.2	5.00E-06	0.20%
106	Cat1_WR-6_Extra 1	4.7	5.00E-07	0.50%
107	Cat1_WR-6_Extra 2	4.7	5.00E-06	0.20%

Table 3.2 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
20	Cat3-4_WR-LO-4A	0.50%	1	1.00E-05
21	Cat3-4_WR-LO-4B	1.00%	1	1.00E-05
22	Cat3-4_WR-LO-4C	2.00%	1	1.00E-05
23	Cat3-4_WR-LO-4D	0.50%	4	1.00E-05
24	Cat3-4_WR-LO-4E	1.00%	4	1.00E-05
25	Cat3-4_WR-LO-4F	2.00%	4	1.00E-05
26	Cat3-4_WR-LO-4G	0.50%	8	1.00E-05
27	Cat3-4_WR-LO-4H	1.00%	8	1.00E-05
28	Cat3-4_WR-LO-4I	2.00%	8	1.00E-05
29	Cat3-4_WR-LO-5A	0.50%	1	1.00E-06
30	Cat3-4_WR-LO-5B	1.00%	1	1.00E-06
31	Cat3-4_WR-LO-5C	2.00%	1	1.00E-06

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
32	Cat3-4_WR-LO-5D	0.50%	4	1.00E-06
33	Cat3-4_WR-LO-5E	1.00%	4	1.00E-06
34	Cat3-4_WR-LO-5F	2.00%	4	1.00E-06
35	Cat3-4_WR-LO-5G	0.50%	8	1.00E-06
36	Cat3-4_WR-LO-5H	1.00%	8	1.00E-06
37	Cat3-4_WR-LO-5I	2.00%	8	1.00E-06
38	Cat3-4_WR-LO-6A	0.50%	1	1.00E-07
39	Cat3-4_WR-LO-6B	1.00%	1	1.00E-07
40	Cat3-4_WR-LO-6C	2.00%	1	1.00E-07
41	Cat3-4_WR-LO-6D	0.50%	4	1.00E-07
42	Cat3-4_WR-LO-6E	1.00%	4	1.00E-07
43	Cat3-4_WR-LO-6F	2.00%	4	1.00E-07
44	Cat3-4_WR-LO-6G	0.50%	8	1.00E-07
45	Cat3-4_WR-LO-6H	1.00%	8	1.00E-07
46	Cat3-4_WR-LO-6I	2.00%	8	1.00E-07

Table 3.3 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
47	Cat3-4_WR-LO-7A	0.50%	1	1.00E-05
48	Cat3-4_WR-LO-7B	1.00%	1	1.00E-05
49	Cat3-4_WR-LO-7C	2.00%	1	1.00E-05
50	Cat3-4_WR-LO-7D	0.50%	4	1.00E-05
51	Cat3-4_WR-LO-7E	1.00%	4	1.00E-05
52	Cat3-4_WR-LO-7F	2.00%	4	1.00E-05
53	Cat3-4_WR-LO-7G	0.50%	8	1.00E-05
54	Cat3-4_WR-LO-7H	1.00%	8	1.00E-05
55	Cat3-4_WR-LO-7I	2.00%	8	1.00E-05
56	Cat3-4_WR-LO-8A	0.50%	1	1.00E-06
57	Cat3-4_WR-LO-8B	1.00%	1	1.00E-06
58	Cat3-4_WR-LO-8C	2.00%	1	1.00E-06
59	Cat3-4_WR-LO-8D	0.50%	4	1.00E-06
60	Cat3-4_WR-LO-8E	1.00%	4	1.00E-06
61	Cat3-4_WR-LO-8F	2.00%	4	1.00E-06
62	Cat3-4_WR-LO-8G	0.50%	8	1.00E-06
63	Cat3-4_WR-LO-8H	1.00%	8	1.00E-06
64	Cat3-4_WR-LO-8I	2.00%	8	1.00E-06
65	Cat3-4_WR-LO-9A	0.50%	1	1.00E-07

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
66	Cat3-4_WR-LO-9B	1.00%	1	1.00E-07
67	Cat3-4_WR-LO-9C	2.00%	1	1.00E-07
68	Cat3-4_WR-LO-9D	0.50%	4	1.00E-07
69	Cat3-4_WR-LO-9E	1.00%	4	1.00E-07
70	Cat3-4_WR-LO-9F	2.00%	4	1.00E-07
71	Cat3-4_WR-LO-9G	0.50%	8	1.00E-07
72	Cat3-4_WR-LO-9H	1.00%	8	1.00E-07
73	Cat3-4_WR-LO-9I	2.00%	8	1.00E-07

Table 3.4 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
74	Cat3-4_WR-LO-10A	0.50%	1	1.00E-05
75	Cat3-4_WR-LO-10B	1.00%	1	1.00E-05
76	Cat3-4_WR-LO-10C	2.00%	1	1.00E-05
77	Cat3-4_WR-LO-10D	0.50%	4	1.00E-05
78	Cat3-4_WR-LO-10E	1.00%	4	1.00E-05
79	Cat3-4_WR-LO-10F	2.00%	4	1.00E-05
80	Cat3-4_WR-LO-10G	0.50%	8	1.00E-05
81	Cat3-4_WR-LO-10H	1.00%	8	1.00E-05
82	Cat3-4_WR-LO-10I	2.00%	8	1.00E-05
83	Cat3-4_WR-LO-11A	0.50%	1	1.00E-06
84	Cat3-4_WR-LO-11B	1.00%	1	1.00E-06
85	Cat3-4_WR-LO-11C	2.00%	1	1.00E-06
86	Cat3-4_WR-LO-11D	0.50%	4	1.00E-06
87	Cat3-4_WR-LO-11E	1.00%	4	1.00E-06
88	Cat3-4_WR-LO-11F	2.00%	4	1.00E-06
89	Cat3-4_WR-LO-11G	0.50%	8	1.00E-06
90	Cat3-4_WR-LO-11H	1.00%	8	1.00E-06
91	Cat3-4_WR-LO-11I	2.00%	8	1.00E-06
92	Cat3-4_WR-LO-12A	0.50%	1	1.00E-07
93	Cat3-4_WR-LO-12B	1.00%	1	1.00E-07
94	Cat3-4_WR-LO-12C	2.00%	1	1.00E-07
95	Cat3-4_WR-LO-12D	0.50%	4	1.00E-07
96	Cat3-4_WR-LO-12E	1.00%	4	1.00E-07
97	Cat3-4_WR-LO-12F	2.00%	4	1.00E-07
98	Cat3-4_WR-LO-12G	0.50%	8	1.00E-07
99	Cat3-4_WR-LO-12H	1.00%	8	1.00E-07
100	Cat3-4_WR-LO-12I	2.00%	8	1.00E-07

Table 3.5 Case Scenarios for Category 3 and 4 Stockpiles, Varying Yield

Case	Case Designation	Target Liner Yield (inch/year)	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
17	Cat3-4_WR-LO-1	20.4	0.50%	8	1.00E-05
18	Cat3-4_WR-LO-2	14.7	0.50%	8	1.00E-05
19	Cat3-4_WR-LO-3	1.5	0.50%	8	1.00E-05
101	Cat3-4_WR-LO-13	8.2	2.00%	1	1.00E-07
102	Cat3-4_WR-LO-14	4.7	2.00%	1	1.00E-07
103	Cat3-4_WR-LO-15	see Note *	2.00%	1	1.00E-07
108	Cat3-4_WR-LO-13_Extra 1	8.2	1.00%	4	1.00E-05
109	Cat3-4_WR-LO-13_Extra 2	8.2	1.00%	4	1.00E-06
110	Cat3-4_WR-LO-14_Extra 1	4.7	1.00%	4	1.00E-05
111	Cat3-4_WR-LO-15_Extra 1	see Note *	1.00%	4	1.00E-05
112	Cat3-4_WR-LO-14_Extra 2	4.7	1.00%	4	1.00E-06
113	Cat3-4_WR-LO-15_Extra 2	see Note *	1.00%	4	1.00E-06
114	Cat3-4_WR-LO-13_Extra 3	8.2	0.50%	8	1.00E-05
115	Cat3-4_WR-LO-14_Extra 3	4.7	0.50%	8	1.00E-05
116	Cat3-4_WR-LO-15_Extra 3	see Note *	0.50%	8	1.00E-05

* Value corresponds to liner yield reported in Table 3.5, Appendix C, Draft 02 RS49.

4.0 RESULTS

HELP results are summarized in the following tables:

Table 4.1 HELP Results for Category 1/2 Stockpiles (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
1	0.297	20.103	0.087	0.197
2	0.108	14.622	0.019	0.178
3	12.897	1.334	0.201	0.004
4	8.239	5.993	0.183	0.021
5	0.107	14.108	0.030	0.182
6	12.939	1.274	0.208	0.004
7	8.484	5.730	0.191	0.020
8	0.256	13.959	0.049	0.178
9	8.907	1.298	0.107	0.004
10	4.503	5.703	0.090	0.020
11	0.052	10.157	0.002	0.165

12	8.966	1.241	0.118	0.004
13	4.725	5.483	0.103	0.019
14	0.129	10.079	0.005	0.171
15	6.971	1.203	0.097	0.004
16	3.618	1.128	0.062	0.004
104	3.109	5.066	0.082	0.018
105	0.035	8.141	0.001	0.165
106	0.755	3.991	0.048	0.018
107	0.013	4.734	0.001	0.068

Table 4.2 HELP Results for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
20	14.221	3.11E-03	0.130	2.60E-05
21	14.224	1.66E-03	0.138	1.50E-05
22	14.225	8.90E-04	0.156	9.00E-06
23	14.212	1.23E-02	0.130	1.02E-04
24	14.219	6.58E-03	0.138	5.80E-05
25	14.223	3.52E-03	0.156	3.40E-05
26	14.200	2.46E-02	0.129	2.03E-04
27	14.212	1.31E-02	0.138	1.15E-04
28	14.219	7.02E-03	0.156	6.90E-05
29	14.224	5.90E-04	0.130	5.00E-06
30	14.225	3.10E-04	0.138	3.00E-06
31	14.226	1.70E-04	0.156	2.00E-06
32	14.222	2.27E-03	0.130	1.90E-05
33	14.224	1.21E-03	0.138	1.10E-05
34	14.225	6.50E-04	0.156	6.00E-06
35	14.220	4.51E-03	0.130	3.70E-05
36	14.223	2.40E-03	0.138	2.10E-05
37	14.225	1.28E-03	0.156	1.30E-05
38	14.224	1.30E-04	0.130	1.00E-06
39	14.225	7.00E-05	0.138	1.00E-06
40	14.226	4.00E-05	0.156	<1.00E-06
41	14.224	4.40E-04	0.130	4.00E-06
42	14.225	2.30E-04	0.138	2.00E-06
43	14.226	1.20E-04	0.156	1.00E-06
44	14.223	8.40E-04	0.130	7.00E-06
45	14.225	4.50E-04	0.138	4.00E-06
46	14.226	2.40E-04	0.156	2.00E-06

Table 4.3 HELP Results for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr

(inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
47	10.198	2.30E-03	0.082	1.70E-05
48	10.200	1.23E-03	0.083	9.00E-06
49	10.201	6.60E-04	0.089	5.00E-06
50	10.191	9.14E-03	0.082	6.70E-05
51	10.196	4.88E-03	0.083	3.60E-05
52	10.199	2.61E-03	0.089	2.10E-05
53	10.182	1.83E-02	0.082	1.34E-04
54	10.191	9.75E-03	0.083	7.30E-05
55	10.196	5.21E-03	0.089	4.10E-05
56	10.200	4.40E-04	0.082	3.00E-06
57	10.201	2.30E-04	0.083	2.00E-06
58	10.202	1.20E-04	0.089	1.00E-06
59	10.198	1.68E-03	0.082	1.20E-05
60	10.200	9.00E-04	0.083	7.00E-06
61	10.201	4.80E-04	0.089	4.00E-06
62	10.197	3.34E-03	0.082	2.50E-05
63	10.199	1.78E-03	0.083	1.30E-05
64	10.201	9.50E-04	0.089	8.00E-06
65	10.200	1.00E-04	0.082	1.00E-06
66	10.201	5.00E-05	0.083	<1.00E-06
67	10.202	3.00E-05	0.089	<1.00E-06
68	10.200	3.20E-04	0.082	2.00E-06
69	10.201	1.70E-04	0.083	1.00E-06
70	10.202	9.00E-05	0.089	1.00E-06
71	10.199	6.20E-04	0.082	5.00E-06
72	10.201	3.30E-04	0.083	2.00E-06
73	10.201	1.80E-04	0.089	1.00E-06

Table 4.4 HELP Results for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
74	0.305	1.00E-04	0.003	1.00E-06
75	0.305	5.00E-05	0.003	1.00E-06
76	0.305	3.00E-05	0.004	<1.00E-06
77	0.305	3.70E-04	0.003	4.00E-06
78	0.305	2.00E-04	0.003	2.00E-06
79	0.305	1.10E-04	0.004	1.00E-06
80	0.305	7.50E-04	0.003	7.00E-06

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
81	0.305	4.00E-04	0.003	4.00E-06
82	0.305	2.20E-04	0.004	2.00E-06
83	0.305	2.00E-05	0.003	<1.00E-06
84	0.305	1.00E-05	0.003	<1.00E-06
85	0.305	1.00E-05	0.004	<1.00E-06
86	0.305	7.00E-05	0.003	1.00E-06
87	0.305	4.00E-05	0.003	<1.00E-06
88	0.305	2.00E-05	0.004	<1.00E-06
89	0.305	1.40E-04	0.003	1.00E-06
90	0.305	8.00E-05	0.003	1.00E-06
91	0.305	4.00E-05	0.004	<1.00E-06
92	0.305	1.00E-05	0.003	<1.00E-06
93	0.305	1.00E-05	0.003	<1.00E-06
94	0.305	<1.00E-05	0.004	<1.00E-06
95	0.305	2.00E-05	0.003	<1.00E-06
96	0.305	1.00E-05	0.003	<1.00E-06
97	0.305	1.00E-05	0.004	<1.00E-06
98	0.305	3.00E-05	0.003	<1.00E-06
99	0.305	2.00E-05	0.003	<1.00E-06
100	0.305	1.00E-05	0.004	<1.00E-06

Table 4.5 HELP Results for Category 3 and 4 Stockpiles, Varying Yield (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
17	20.354	3.42E-02	0.185	2.73E-04
18	14.687	2.54E-02	0.133	2.08E-04
19	1.475	3.17E-03	0.011	2.20E-05
101	8.199	2.00E-05	0.066	<1.00E-06
102	4.727	2.00E-05	0.039	<1.00E-06
103	1.365	1.00E-05	0.009	<1.00E-06
108	8.195	4.00E-03	0.065	2.90E-05
109	8.198	7.40E-04	0.065	5.00E-06
110	4.725	2.42E-03	0.037	1.80E-05
111	1.365	7.90E-04	0.009	5.00E-06
112	4.727	4.50E-04	0.037	3.00E-06
113	1.365	1.50E-04	0.009	1.00E-06
114	8.183	1.49E-02	0.063	1.07E-04
115	4.718	9.04E-03	0.037	6.50E-05
116	1.362	2.95E-03	0.009	1.80E-05

Table 4.6 HELP Results for Category 1/2 Stockpiles (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
1	22.1	1.50E+03	2362.8	5.36E+03
2	8.0	1.09E+03	504.5	4.83E+03
3	959.4	9.92E+01	5469.9	1.18E+02
4	612.9	4.46E+02	4964.5	5.83E+02
5	8.0	1.05E+03	804.0	4.94E+03
6	962.5	9.48E+01	5646.9	1.10E+02
7	631.1	4.26E+02	5196.7	5.44E+02
8	19.1	1.04E+03	1329.1	4.84E+03
9	662.6	9.66E+01	2915.4	1.09E+02
10	335.0	4.24E+02	2457.0	5.38E+02
11	3.9	7.56E+02	66.5	4.48E+03
12	667.0	9.23E+01	3199.4	1.03E+02
13	351.5	4.08E+02	2798.1	5.08E+02
14	9.6	7.50E+02	134.7	4.63E+03
15	518.6	8.95E+01	2629.7	1.01E+02
16	269.1	8.39E+01	1679.6	9.80E+01
104	231.3	3.77E+02	2232.7	4.99E+02
105	2.6	6.06E+02	37.5	4.49E+03
106	56.1	2.97E+02	1296.0	4.83E+02
107	0.9	3.52E+02	17.4	1.86E+03

Table 4.7 HELP Results for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
20	1057.9	2.31E-01	3520.3	7.06E-01
21	1058.1	1.23E-01	3744.6	4.07E-01
22	1058.2	6.62E-02	4237.4	2.44E-01
23	1057.2	9.17E-01	3518.4	2.77E+00
24	1057.7	4.89E-01	3743.8	1.57E+00
25	1058.0	2.62E-01	4236.9	9.23E-01
26	1056.3	1.83E+00	3515.7	5.51E+00
27	1057.3	9.77E-01	3742.7	3.12E+00
28	1057.8	5.22E-01	4235.8	1.87E+00
29	1058.1	4.39E-02	3520.9	1.36E-01
30	1058.2	2.31E-02	3744.9	8.15E-02
31	1058.3	1.26E-02	4237.7	5.43E-02
32	1058.0	1.69E-01	3520.6	5.16E-01
33	1058.1	9.00E-02	3744.6	2.99E-01

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
34	1058.2	4.84E-02	4237.4	1.63E-01
35	1057.8	3.35E-01	3520.0	1.00E+00
36	1058.1	1.79E-01	3744.6	5.70E-01
37	1058.2	9.52E-02	4237.4	3.53E-01
38	1058.1	9.67E-03	3521.1	< 1.00E-01
39	1058.2	5.21E-03	3744.9	< 1.00E-01
40	1058.3	2.98E-03	4237.7	< 1.00E-01
41	1058.1	3.27E-02	3520.9	1.09E-01
42	1058.2	1.71E-02	3744.9	5.43E-02
43	1058.3	8.93E-03	4237.7	< 1.00E-01
44	1058.1	6.25E-02	3520.9	1.90E-01
45	1058.2	3.35E-02	3744.9	1.09E-01
46	1058.3	1.79E-02	4237.7	< 1.00E-01

Table 4.8 HELP Results for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
47	758.6	1.71E-01	2219.4	4.62E-01
48	758.8	9.15E-02	2247.9	2.44E-01
49	758.9	4.91E-02	2413.6	1.36E-01
50	758.1	6.80E-01	2218.4	1.82E+00
51	758.5	3.63E-01	2247.1	9.77E-01
52	758.7	1.94E-01	2413.0	5.70E-01
53	757.4	1.36E+00	2216.5	3.64E+00
54	758.1	7.25E-01	2246.3	1.98E+00
55	758.5	3.88E-01	2412.8	1.11E+00
56	758.8	3.27E-02	2220.0	< 1.00E-01
57	758.8	1.71E-02	2248.2	< 1.00E-01
58	758.9	8.93E-03	2413.6	< 1.00E-01
59	758.7	1.25E-01	2219.7	3.26E-01
60	758.8	6.70E-02	2247.9	1.90E-01
61	758.9	3.57E-02	2413.6	1.09E-01
62	758.5	2.48E-01	2219.4	6.79E-01
63	758.7	1.32E-01	2247.9	3.53E-01
64	758.8	7.07E-02	2413.3	2.17E-01
65	758.8	7.44E-03	2220.0	< 1.00E-01
66	758.9	3.72E-03	2248.2	< 1.00E-01
67	758.9	2.23E-03	2413.6	< 1.00E-01
68	758.8	2.38E-02	2220.0	< 1.00E-01

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
69	758.9	1.26E-02	2248.2	< 1.00E-01
70	758.9	6.70E-03	2413.6	< 1.00E-01
71	758.7	4.61E-02	2220.0	1.36E-01
72	758.8	2.45E-02	2248.2	< 1.00E-01
73	758.9	1.34E-02	2413.6	< 1.00E-01

Table 4.9 HELP Results for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
74	22.7	7.44E-03	89.9	< 1.00E-01
75	22.7	3.72E-03	80.9	< 1.00E-01
76	22.7	2.23E-03	95.0	< 1.00E-01
77	22.7	2.75E-02	89.9	1.09E-01
78	22.7	1.49E-02	92.6	< 1.00E-01
79	22.7	8.18E-03	95.0	< 1.00E-01
80	22.7	5.58E-02	89.6	1.90E-01
81	22.7	2.98E-02	92.6	1.09E-01
82	22.7	1.64E-02	95.0	< 1.00E-01
83	22.7	1.49E-03	89.9	< 1.00E-01
84	22.7	<1.00E-03	92.6	< 1.00E-01
85	22.7	<1.00E-03	95.0	< 1.00E-01
86	22.7	5.21E-03	89.9	< 1.00E-01
87	22.7	2.98E-03	92.6	< 1.00E-01
88	22.7	1.49E-03	95.0	< 1.00E-01
89	22.7	1.04E-02	89.9	< 1.00E-01
90	22.7	5.95E-03	92.6	< 1.00E-01
91	22.7	2.98E-03	95.0	< 1.00E-01
92	22.7	<1.00E-03	89.9	< 1.00E-01
93	22.7	<1.00E-03	92.6	< 1.00E-01
94	22.7	<1.00E-03	95.0	< 1.00E-01
95	22.7	1.49E-03	89.9	< 1.00E-01
96	22.7	<1.00E-03	92.6	< 1.00E-01
97	22.7	<1.00E-03	95.0	< 1.00E-01
98	22.7	2.23E-03	89.9	< 1.00E-01
99	22.7	1.49E-03	92.6	< 1.00E-01
100	22.7	<1.00E-03	95.0	< 1.00E-01

Table 4.10 HELP Results for Category 3 and 4 Stockpiles, Varying Yield

(gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
17	1514.1	2.54E+00	5014.2	7.41E+00
18	1092.6	1.89E+00	3614.3	5.65E+00
19	109.7	2.36E-01	305.2	5.97E-01
101	610.0	1.49E-03	1796.4	< 1.00E-01
102	351.7	1.49E-03	1072.2	< 1.00E-01
103	101.6	7.44E-04	256.3	< 1.00E-01
108	609.6	2.98E-01	1757.3	7.87E-01
109	609.9	5.50E-02	1757.8	1.36E-01
110	351.5	1.80E-01	1004.9	4.89E-01
111	101.5	5.88E-02	249.0	1.36E-01
112	351.6	3.35E-02	1005.2	8.15E-02
113	101.6	1.12E-02	249.3	2.72E-02
114	608.7	1.11E+00	1722.0	2.91E+00
115	351.0	6.72E-01	992.4	1.76E+00
116	101.3	2.19E-01	237.6	4.89E-01

5.0 CONCLUSIONS

HELP analyses were used to calibrate various stockpile configurations to target annual yield values. While these simulations may be used as an indicator of liner performance, the actual performance will be governed by material properties encountered in the field and local climate conditions. It should be noted that based on the calibrated climate and material parameters required to attain some of the specified target yield values, a number of the simulations evaluated are not considered physically realistic.

DRAFT
TECHNICAL MEMORANDUM

Golder Associates Inc.
44 Union Blvd., Suite 300
Lakewood, Colorado 80228

Telephone: 303-980-0540
Fax: 303-985-2080

TO: Miguel Wong, Barr Engineering **DATE:** May 20, 2008

FROM: Gordan Gjerapic P.E., GAI **OUR REF.:** 053-2209

CC: Brent R. Bronson P.E., GAI

RE: DRAFT HELP RUNS FOR SENSITIVITY ANALYSIS OF LINER LEAKAGE RATES

1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this technical memorandum for Barr Engineering (Barr) presenting sensitivity analyses of liner leakage rates to be reported in Draft 02 of RS74 (Water Quality Modeling) as agreed by Barr (Miguel Wong and Christie Kearney) and MDNR (Paul Eger and John Adams) on May 5. Barr (Miguel Wong, Katie Wenigmann and Christie Kearney), MDNR (Paul Eger) and Jim Kunkel (Knight Piesold) decided to expand the number of required analyses on May 20, 2008. This work was completed based on the authorization provided via e-mail correspondence between Barr and Golder on May 6 (initial 103 analyses) and May 20, 2008 (additional 13 analyses). The results in this memorandum were obtained by using the HELP (Hydrologic Evaluation of Landfill Performance) model calibrated to a range of liner yields agreed upon between Barr and MNDR. 116 HELP simulations were conducted to evaluate linear leakage sensitivity.

2.0 INPUT PARAMETERS

All simulations use a 100 year weather record for Duluth, Minnesota, synthetically generated by HELP. The following material parameters were used for HELP simulations:

Table 2.1 Material Parameters for HELP Modeling Scenarios

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage grades and geomembrane defects
Waste rock	21	3.00E-01	480, 1200	
Overliner (with 100 ft drains)	21	3.00E-01	12	0.2%, 0.5% , 1.0% and 2.0% slope
LLDPE	36	4.00E-13	0.08	1, 4 and 8 installation

Materials	HELP No.	ksat (cm/s)	Thickness (inch)	Drainage grades and geomembrane defects
				defects per acre
Subgrade Cat. 1/2	16	1.00E-07, 5.00E-07, 5.00E-06	12	
Subgrade Cat. 3, 4	16	1.00E-05, 1.00E-06, 1.00E-07	12	

As indicated in Table 2.1, the lower model boundary for Category 3 and 4 stockpiles consists of a 80 mil LLDPE placed on a 12 inch thick subgrade material. The proposed liner is overlain by 12 inches of the overliner material and 100 ft of the stockpile waste rock. HELP model for Category 1/2 stockpiles assumes 12 inch of subgrade material overlain by 12 inches of the overliner material and 40 ft of the stockpile waste rock.

3.0 MODELING SCENARIOS

To reproduce target yield values, Category 1/2 stockpiles were modeled with a 24 inch thick surface layer material with varying permeability (see Figure 1). Similarly, Category 3 and 4 stockpiles utilized a 36 inch thick layer of surface material or geomembrane cover overlain by 18 inches of topsoil. In addition, the calibration process employed varying evaporation depths, scaling of the average wind speed and solar radiation values, and reduction of the stockpile areas available to runoff in order to attain target yields. The average annual precipitation employed for HELP simulations was 29.2 inches.

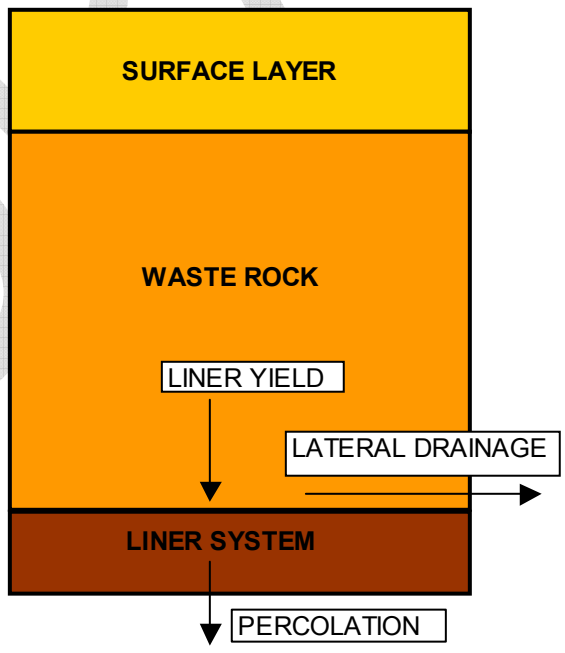

Figure 1 Modeling Geometry

The analyzed HELP case scenarios are summarized in the following tables:

Table 3.1 Case Scenarios for Category 1/2 Stockpiles

Case	Case Designation	Target Liner Yield (inch/year)	Permeability of Soil Liner in Liner System (cm/s)	Slope of Overliner in Liner System
1	Cat1_WR-1	20.4	5.00E-06	0.20%
2	Cat1_WR-2	14.7	5.00E-06	0.20%
3	Cat1_WR-3A	14.2	1.00E-07	0.20%
4	Cat1_WR-3B	14.2	5.00E-07	0.20%
5	Cat1_WR-3C	14.2	5.00E-06	0.20%
6	Cat1_WR-3D	14.2	1.00E-07	0.50%
7	Cat1_WR-3E	14.2	5.00E-07	0.50%
8	Cat1_WR-3F	14.2	5.00E-06	0.50%
9	Cat1_WR-4A	10.2	1.00E-07	0.20%
10	Cat1_WR-4B	10.2	5.00E-07	0.20%
11	Cat1_WR-4C	10.2	5.00E-06	0.20%
12	Cat1_WR-4D	10.2	1.00E-07	0.50%
13	Cat1_WR-4E	10.2	5.00E-07	0.50%
14	Cat1_WR-4F	10.2	5.00E-06	0.50%
15	Cat1_WR-5	8.2	1.00E-07	0.50%
16	Cat1_WR-6	4.7	1.00E-07	0.50%
104	Cat1_WR-5_Extra 1	8.2	5.00E-07	0.50%
105	Cat1_WR-5_Extra 2	8.2	5.00E-06	0.20%
106	Cat1_WR-6_Extra 1	4.7	5.00E-07	0.50%
107	Cat1_WR-6_Extra 2	4.7	5.00E-06	0.20%

Table 3.2 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
20	Cat3-4_WR-LO-4A	0.50%	1	1.00E-05
21	Cat3-4_WR-LO-4B	1.00%	1	1.00E-05
22	Cat3-4_WR-LO-4C	2.00%	1	1.00E-05
23	Cat3-4_WR-LO-4D	0.50%	4	1.00E-05
24	Cat3-4_WR-LO-4E	1.00%	4	1.00E-05
25	Cat3-4_WR-LO-4F	2.00%	4	1.00E-05
26	Cat3-4_WR-LO-4G	0.50%	8	1.00E-05
27	Cat3-4_WR-LO-4H	1.00%	8	1.00E-05
28	Cat3-4_WR-LO-4I	2.00%	8	1.00E-05
29	Cat3-4_WR-LO-5A	0.50%	1	1.00E-06
30	Cat3-4_WR-LO-5B	1.00%	1	1.00E-06
31	Cat3-4_WR-LO-5C	2.00%	1	1.00E-06

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
32	Cat3-4_WR-LO-5D	0.50%	4	1.00E-06
33	Cat3-4_WR-LO-5E	1.00%	4	1.00E-06
34	Cat3-4_WR-LO-5F	2.00%	4	1.00E-06
35	Cat3-4_WR-LO-5G	0.50%	8	1.00E-06
36	Cat3-4_WR-LO-5H	1.00%	8	1.00E-06
37	Cat3-4_WR-LO-5I	2.00%	8	1.00E-06
38	Cat3-4_WR-LO-6A	0.50%	1	1.00E-07
39	Cat3-4_WR-LO-6B	1.00%	1	1.00E-07
40	Cat3-4_WR-LO-6C	2.00%	1	1.00E-07
41	Cat3-4_WR-LO-6D	0.50%	4	1.00E-07
42	Cat3-4_WR-LO-6E	1.00%	4	1.00E-07
43	Cat3-4_WR-LO-6F	2.00%	4	1.00E-07
44	Cat3-4_WR-LO-6G	0.50%	8	1.00E-07
45	Cat3-4_WR-LO-6H	1.00%	8	1.00E-07
46	Cat3-4_WR-LO-6I	2.00%	8	1.00E-07

Table 3.3 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
47	Cat3-4_WR-LO-7A	0.50%	1	1.00E-05
48	Cat3-4_WR-LO-7B	1.00%	1	1.00E-05
49	Cat3-4_WR-LO-7C	2.00%	1	1.00E-05
50	Cat3-4_WR-LO-7D	0.50%	4	1.00E-05
51	Cat3-4_WR-LO-7E	1.00%	4	1.00E-05
52	Cat3-4_WR-LO-7F	2.00%	4	1.00E-05
53	Cat3-4_WR-LO-7G	0.50%	8	1.00E-05
54	Cat3-4_WR-LO-7H	1.00%	8	1.00E-05
55	Cat3-4_WR-LO-7I	2.00%	8	1.00E-05
56	Cat3-4_WR-LO-8A	0.50%	1	1.00E-06
57	Cat3-4_WR-LO-8B	1.00%	1	1.00E-06
58	Cat3-4_WR-LO-8C	2.00%	1	1.00E-06
59	Cat3-4_WR-LO-8D	0.50%	4	1.00E-06
60	Cat3-4_WR-LO-8E	1.00%	4	1.00E-06
61	Cat3-4_WR-LO-8F	2.00%	4	1.00E-06
62	Cat3-4_WR-LO-8G	0.50%	8	1.00E-06
63	Cat3-4_WR-LO-8H	1.00%	8	1.00E-06
64	Cat3-4_WR-LO-8I	2.00%	8	1.00E-06
65	Cat3-4_WR-LO-9A	0.50%	1	1.00E-07

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
66	Cat3-4_WR-LO-9B	1.00%	1	1.00E-07
67	Cat3-4_WR-LO-9C	2.00%	1	1.00E-07
68	Cat3-4_WR-LO-9D	0.50%	4	1.00E-07
69	Cat3-4_WR-LO-9E	1.00%	4	1.00E-07
70	Cat3-4_WR-LO-9F	2.00%	4	1.00E-07
71	Cat3-4_WR-LO-9G	0.50%	8	1.00E-07
72	Cat3-4_WR-LO-9H	1.00%	8	1.00E-07
73	Cat3-4_WR-LO-9I	2.00%	8	1.00E-07

Table 3.4 Case Scenarios for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr

Case	Case Designation	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
74	Cat3-4_WR-LO-10A	0.50%	1	1.00E-05
75	Cat3-4_WR-LO-10B	1.00%	1	1.00E-05
76	Cat3-4_WR-LO-10C	2.00%	1	1.00E-05
77	Cat3-4_WR-LO-10D	0.50%	4	1.00E-05
78	Cat3-4_WR-LO-10E	1.00%	4	1.00E-05
79	Cat3-4_WR-LO-10F	2.00%	4	1.00E-05
80	Cat3-4_WR-LO-10G	0.50%	8	1.00E-05
81	Cat3-4_WR-LO-10H	1.00%	8	1.00E-05
82	Cat3-4_WR-LO-10I	2.00%	8	1.00E-05
83	Cat3-4_WR-LO-11A	0.50%	1	1.00E-06
84	Cat3-4_WR-LO-11B	1.00%	1	1.00E-06
85	Cat3-4_WR-LO-11C	2.00%	1	1.00E-06
86	Cat3-4_WR-LO-11D	0.50%	4	1.00E-06
87	Cat3-4_WR-LO-11E	1.00%	4	1.00E-06
88	Cat3-4_WR-LO-11F	2.00%	4	1.00E-06
89	Cat3-4_WR-LO-11G	0.50%	8	1.00E-06
90	Cat3-4_WR-LO-11H	1.00%	8	1.00E-06
91	Cat3-4_WR-LO-11I	2.00%	8	1.00E-06
92	Cat3-4_WR-LO-12A	0.50%	1	1.00E-07
93	Cat3-4_WR-LO-12B	1.00%	1	1.00E-07
94	Cat3-4_WR-LO-12C	2.00%	1	1.00E-07
95	Cat3-4_WR-LO-12D	0.50%	4	1.00E-07
96	Cat3-4_WR-LO-12E	1.00%	4	1.00E-07
97	Cat3-4_WR-LO-12F	2.00%	4	1.00E-07
98	Cat3-4_WR-LO-12G	0.50%	8	1.00E-07
99	Cat3-4_WR-LO-12H	1.00%	8	1.00E-07
100	Cat3-4_WR-LO-12I	2.00%	8	1.00E-07

Table 3.5 Case Scenarios for Category 3 and 4 Stockpiles, Varying Yield

Case	Case Designation	Target Liner Yield (inch/year)	Slope of Overliner in Liner System	Number of Geomembrane Defects (holes/acre)	Permeability of Subgrade Material (cm/s)
17	Cat3-4_WR-LO-1	20.4	0.50%	8	1.00E-05
18	Cat3-4_WR-LO-2	14.7	0.50%	8	1.00E-05
19	Cat3-4_WR-LO-3	1.5	0.50%	8	1.00E-05
101	Cat3-4_WR-LO-13	8.2	2.00%	1	1.00E-07
102	Cat3-4_WR-LO-14	4.7	2.00%	1	1.00E-07
103	Cat3-4_WR-LO-15	see Note *	2.00%	1	1.00E-07
108	Cat3-4_WR-LO-13_Extra 1	8.2	1.00%	4	1.00E-05
109	Cat3-4_WR-LO-13_Extra 2	8.2	1.00%	4	1.00E-06
110	Cat3-4_WR-LO-14_Extra 1	4.7	1.00%	4	1.00E-05
111	Cat3-4_WR-LO-15_Extra 1	see Note *	1.00%	4	1.00E-05
112	Cat3-4_WR-LO-14_Extra 2	4.7	1.00%	4	1.00E-06
113	Cat3-4_WR-LO-15_Extra 2	see Note *	1.00%	4	1.00E-06
114	Cat3-4_WR-LO-13_Extra 3	8.2	0.50%	8	1.00E-05
115	Cat3-4_WR-LO-14_Extra 3	4.7	0.50%	8	1.00E-05
116	Cat3-4_WR-LO-15_Extra 3	see Note *	0.50%	8	1.00E-05

* Value corresponds to liner yield reported in Table 3.5, Appendix C, Draft 02 RS49.

4.0 RESULTS

HELP results are summarized in the following tables:

Table 4.1 HELP Results for Category 1/2 Stockpiles (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
1	0.297	20.103	0.087	0.197
2	0.108	14.622	0.019	0.178
3	12.897	1.334	0.201	0.004
4	8.239	5.993	0.183	0.021
5	0.107	14.108	0.030	0.182
6	12.939	1.274	0.208	0.004
7	8.484	5.730	0.191	0.020
8	0.256	13.959	0.049	0.178
9	8.907	1.298	0.107	0.004
10	4.503	5.703	0.090	0.020
11	0.052	10.157	0.002	0.165

12	8.966	1.241	0.118	0.004
13	4.725	5.483	0.103	0.019
14	0.129	10.079	0.005	0.171
15	6.971	1.203	0.097	0.004
16	3.618	1.128	0.062	0.004
104	3.109	5.066	0.082	0.018
105	0.035	8.141	0.001	0.165
106	0.755	3.991	0.048	0.018
107	0.013	4.734	0.001	0.068

Table 4.2 HELP Results for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
20	14.221	3.11E-03	0.130	2.60E-05
21	14.224	1.66E-03	0.138	1.50E-05
22	14.225	8.90E-04	0.156	9.00E-06
23	14.212	1.23E-02	0.130	1.02E-04
24	14.219	6.58E-03	0.138	5.80E-05
25	14.223	3.52E-03	0.156	3.40E-05
26	14.200	2.46E-02	0.129	2.03E-04
27	14.212	1.31E-02	0.138	1.15E-04
28	14.219	7.02E-03	0.156	6.90E-05
29	14.224	5.90E-04	0.130	5.00E-06
30	14.225	3.10E-04	0.138	3.00E-06
31	14.226	1.70E-04	0.156	2.00E-06
32	14.222	2.27E-03	0.130	1.90E-05
33	14.224	1.21E-03	0.138	1.10E-05
34	14.225	6.50E-04	0.156	6.00E-06
35	14.220	4.51E-03	0.130	3.70E-05
36	14.223	2.40E-03	0.138	2.10E-05
37	14.225	1.28E-03	0.156	1.30E-05
38	14.224	1.30E-04	0.130	1.00E-06
39	14.225	7.00E-05	0.138	1.00E-06
40	14.226	4.00E-05	0.156	<1.00E-06
41	14.224	4.40E-04	0.130	4.00E-06
42	14.225	2.30E-04	0.138	2.00E-06
43	14.226	1.20E-04	0.156	1.00E-06
44	14.223	8.40E-04	0.130	7.00E-06
45	14.225	4.50E-04	0.138	4.00E-06
46	14.226	2.40E-04	0.156	2.00E-06

Table 4.3 HELP Results for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr

(inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
47	10.198	2.30E-03	0.082	1.70E-05
48	10.200	1.23E-03	0.083	9.00E-06
49	10.201	6.60E-04	0.089	5.00E-06
50	10.191	9.14E-03	0.082	6.70E-05
51	10.196	4.88E-03	0.083	3.60E-05
52	10.199	2.61E-03	0.089	2.10E-05
53	10.182	1.83E-02	0.082	1.34E-04
54	10.191	9.75E-03	0.083	7.30E-05
55	10.196	5.21E-03	0.089	4.10E-05
56	10.200	4.40E-04	0.082	3.00E-06
57	10.201	2.30E-04	0.083	2.00E-06
58	10.202	1.20E-04	0.089	1.00E-06
59	10.198	1.68E-03	0.082	1.20E-05
60	10.200	9.00E-04	0.083	7.00E-06
61	10.201	4.80E-04	0.089	4.00E-06
62	10.197	3.34E-03	0.082	2.50E-05
63	10.199	1.78E-03	0.083	1.30E-05
64	10.201	9.50E-04	0.089	8.00E-06
65	10.200	1.00E-04	0.082	1.00E-06
66	10.201	5.00E-05	0.083	<1.00E-06
67	10.202	3.00E-05	0.089	<1.00E-06
68	10.200	3.20E-04	0.082	2.00E-06
69	10.201	1.70E-04	0.083	1.00E-06
70	10.202	9.00E-05	0.089	1.00E-06
71	10.199	6.20E-04	0.082	5.00E-06
72	10.201	3.30E-04	0.083	2.00E-06
73	10.201	1.80E-04	0.089	1.00E-06

Table 4.4 HELP Results for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
74	0.305	1.00E-04	0.003	1.00E-06
75	0.305	5.00E-05	0.003	1.00E-06
76	0.305	3.00E-05	0.004	<1.00E-06
77	0.305	3.70E-04	0.003	4.00E-06
78	0.305	2.00E-04	0.003	2.00E-06
79	0.305	1.10E-04	0.004	1.00E-06
80	0.305	7.50E-04	0.003	7.00E-06

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
81	0.305	4.00E-04	0.003	4.00E-06
82	0.305	2.20E-04	0.004	2.00E-06
83	0.305	2.00E-05	0.003	<1.00E-06
84	0.305	1.00E-05	0.003	<1.00E-06
85	0.305	1.00E-05	0.004	<1.00E-06
86	0.305	7.00E-05	0.003	1.00E-06
87	0.305	4.00E-05	0.003	<1.00E-06
88	0.305	2.00E-05	0.004	<1.00E-06
89	0.305	1.40E-04	0.003	1.00E-06
90	0.305	8.00E-05	0.003	1.00E-06
91	0.305	4.00E-05	0.004	<1.00E-06
92	0.305	1.00E-05	0.003	<1.00E-06
93	0.305	1.00E-05	0.003	<1.00E-06
94	0.305	<1.00E-05	0.004	<1.00E-06
95	0.305	2.00E-05	0.003	<1.00E-06
96	0.305	1.00E-05	0.003	<1.00E-06
97	0.305	1.00E-05	0.004	<1.00E-06
98	0.305	3.00E-05	0.003	<1.00E-06
99	0.305	2.00E-05	0.003	<1.00E-06
100	0.305	1.00E-05	0.004	<1.00E-06

Table 4.5 HELP Results for Category 3 and 4 Stockpiles, Varying Yield (inch/year, inch/day)

Case	Avg. Annual Lateral Drainage (inch/year)	Avg. Annual Percolation (inch/year)	Max. Daily Lateral Drainage (inch/day)	Max. Daily Percolation (inch/day)
17	20.354	3.42E-02	0.185	2.73E-04
18	14.687	2.54E-02	0.133	2.08E-04
19	1.475	3.17E-03	0.011	2.20E-05
101	8.199	2.00E-05	0.066	<1.00E-06
102	4.727	2.00E-05	0.039	<1.00E-06
103	1.365	1.00E-05	0.009	<1.00E-06
108	8.195	4.00E-03	0.065	2.90E-05
109	8.198	7.40E-04	0.065	5.00E-06
110	4.725	2.42E-03	0.037	1.80E-05
111	1.365	7.90E-04	0.009	5.00E-06
112	4.727	4.50E-04	0.037	3.00E-06
113	1.365	1.50E-04	0.009	1.00E-06
114	8.183	1.49E-02	0.063	1.07E-04
115	4.718	9.04E-03	0.037	6.50E-05
116	1.362	2.95E-03	0.009	1.80E-05

Table 4.6 HELP Results for Category 1/2 Stockpiles (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
1	22.1	1.50E+03	2362.8	5.36E+03
2	8.0	1.09E+03	504.5	4.83E+03
3	959.4	9.92E+01	5469.9	1.18E+02
4	612.9	4.46E+02	4964.5	5.83E+02
5	8.0	1.05E+03	804.0	4.94E+03
6	962.5	9.48E+01	5646.9	1.10E+02
7	631.1	4.26E+02	5196.7	5.44E+02
8	19.1	1.04E+03	1329.1	4.84E+03
9	662.6	9.66E+01	2915.4	1.09E+02
10	335.0	4.24E+02	2457.0	5.38E+02
11	3.9	7.56E+02	66.5	4.48E+03
12	667.0	9.23E+01	3199.4	1.03E+02
13	351.5	4.08E+02	2798.1	5.08E+02
14	9.6	7.50E+02	134.7	4.63E+03
15	518.6	8.95E+01	2629.7	1.01E+02
16	269.1	8.39E+01	1679.6	9.80E+01
104	231.3	3.77E+02	2232.7	4.99E+02
105	2.6	6.06E+02	37.5	4.49E+03
106	56.1	2.97E+02	1296.0	4.83E+02
107	0.9	3.52E+02	17.4	1.86E+03

Table 4.7 HELP Results for Category 3/4 Stockpiles, Liner Yield = 14.2 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
20	1057.9	2.31E-01	3520.3	7.06E-01
21	1058.1	1.23E-01	3744.6	4.07E-01
22	1058.2	6.62E-02	4237.4	2.44E-01
23	1057.2	9.17E-01	3518.4	2.77E+00
24	1057.7	4.89E-01	3743.8	1.57E+00
25	1058.0	2.62E-01	4236.9	9.23E-01
26	1056.3	1.83E+00	3515.7	5.51E+00
27	1057.3	9.77E-01	3742.7	3.12E+00
28	1057.8	5.22E-01	4235.8	1.87E+00
29	1058.1	4.39E-02	3520.9	1.36E-01
30	1058.2	2.31E-02	3744.9	8.15E-02
31	1058.3	1.26E-02	4237.7	5.43E-02
32	1058.0	1.69E-01	3520.6	5.16E-01
33	1058.1	9.00E-02	3744.6	2.99E-01

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
34	1058.2	4.84E-02	4237.4	1.63E-01
35	1057.8	3.35E-01	3520.0	1.00E+00
36	1058.1	1.79E-01	3744.6	5.70E-01
37	1058.2	9.52E-02	4237.4	3.53E-01
38	1058.1	9.67E-03	3521.1	< 1.00E-01
39	1058.2	5.21E-03	3744.9	< 1.00E-01
40	1058.3	2.98E-03	4237.7	< 1.00E-01
41	1058.1	3.27E-02	3520.9	1.09E-01
42	1058.2	1.71E-02	3744.9	5.43E-02
43	1058.3	8.93E-03	4237.7	< 1.00E-01
44	1058.1	6.25E-02	3520.9	1.90E-01
45	1058.2	3.35E-02	3744.9	1.09E-01
46	1058.3	1.79E-02	4237.7	< 1.00E-01

Table 4.8 HELP Results for Category 3/4 Stockpiles, Liner Yield = 10.2 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
47	758.6	1.71E-01	2219.4	4.62E-01
48	758.8	9.15E-02	2247.9	2.44E-01
49	758.9	4.91E-02	2413.6	1.36E-01
50	758.1	6.80E-01	2218.4	1.82E+00
51	758.5	3.63E-01	2247.1	9.77E-01
52	758.7	1.94E-01	2413.0	5.70E-01
53	757.4	1.36E+00	2216.5	3.64E+00
54	758.1	7.25E-01	2246.3	1.98E+00
55	758.5	3.88E-01	2412.8	1.11E+00
56	758.8	3.27E-02	2220.0	< 1.00E-01
57	758.8	1.71E-02	2248.2	< 1.00E-01
58	758.9	8.93E-03	2413.6	< 1.00E-01
59	758.7	1.25E-01	2219.7	3.26E-01
60	758.8	6.70E-02	2247.9	1.90E-01
61	758.9	3.57E-02	2413.6	1.09E-01
62	758.5	2.48E-01	2219.4	6.79E-01
63	758.7	1.32E-01	2247.9	3.53E-01
64	758.8	7.07E-02	2413.3	2.17E-01
65	758.8	7.44E-03	2220.0	< 1.00E-01
66	758.9	3.72E-03	2248.2	< 1.00E-01
67	758.9	2.23E-03	2413.6	< 1.00E-01
68	758.8	2.38E-02	2220.0	< 1.00E-01

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
69	758.9	1.26E-02	2248.2	< 1.00E-01
70	758.9	6.70E-03	2413.6	< 1.00E-01
71	758.7	4.61E-02	2220.0	1.36E-01
72	758.8	2.45E-02	2248.2	< 1.00E-01
73	758.9	1.34E-02	2413.6	< 1.00E-01

Table 4.9 HELP Results for Category 3/4 Stockpiles, Liner Yield = 0.3 inch/yr (gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
74	22.7	7.44E-03	89.9	< 1.00E-01
75	22.7	3.72E-03	80.9	< 1.00E-01
76	22.7	2.23E-03	95.0	< 1.00E-01
77	22.7	2.75E-02	89.9	1.09E-01
78	22.7	1.49E-02	92.6	< 1.00E-01
79	22.7	8.18E-03	95.0	< 1.00E-01
80	22.7	5.58E-02	89.6	1.90E-01
81	22.7	2.98E-02	92.6	1.09E-01
82	22.7	1.64E-02	95.0	< 1.00E-01
83	22.7	1.49E-03	89.9	< 1.00E-01
84	22.7	<1.00E-03	92.6	< 1.00E-01
85	22.7	<1.00E-03	95.0	< 1.00E-01
86	22.7	5.21E-03	89.9	< 1.00E-01
87	22.7	2.98E-03	92.6	< 1.00E-01
88	22.7	1.49E-03	95.0	< 1.00E-01
89	22.7	1.04E-02	89.9	< 1.00E-01
90	22.7	5.95E-03	92.6	< 1.00E-01
91	22.7	2.98E-03	95.0	< 1.00E-01
92	22.7	<1.00E-03	89.9	< 1.00E-01
93	22.7	<1.00E-03	92.6	< 1.00E-01
94	22.7	<1.00E-03	95.0	< 1.00E-01
95	22.7	1.49E-03	89.9	< 1.00E-01
96	22.7	<1.00E-03	92.6	< 1.00E-01
97	22.7	<1.00E-03	95.0	< 1.00E-01
98	22.7	2.23E-03	89.9	< 1.00E-01
99	22.7	1.49E-03	92.6	< 1.00E-01
100	22.7	<1.00E-03	95.0	< 1.00E-01

Table 4.10 HELP Results for Category 3 and 4 Stockpiles, Varying Yield

(gal/acre/day)

Case	Avg. Annual Lateral Drainage (gal/acre/day)	Avg. Annual Percolation (gal/acre/day)	Max. Daily Lateral Drainage (gal/acre/day)	Max. Daily Percolation (gal/acre/day)
17	1514.1	2.54E+00	5014.2	7.41E+00
18	1092.6	1.89E+00	3614.3	5.65E+00
19	109.7	2.36E-01	305.2	5.97E-01
101	610.0	1.49E-03	1796.4	< 1.00E-01
102	351.7	1.49E-03	1072.2	< 1.00E-01
103	101.6	7.44E-04	256.3	< 1.00E-01
108	609.6	2.98E-01	1757.3	7.87E-01
109	609.9	5.50E-02	1757.8	1.36E-01
110	351.5	1.80E-01	1004.9	4.89E-01
111	101.5	5.88E-02	249.0	1.36E-01
112	351.6	3.35E-02	1005.2	8.15E-02
113	101.6	1.12E-02	249.3	2.72E-02
114	608.7	1.11E+00	1722.0	2.91E+00
115	351.0	6.72E-01	992.4	1.76E+00
116	101.3	2.19E-01	237.6	4.89E-01

5.0 CONCLUSIONS

HELP analyses were used to calibrate various stockpile configurations to target annual yield values. While these simulations may be used as an indicator of liner performance, the actual performance will be governed by material properties encountered in the field and local climate conditions. It should be noted that based on the calibrated climate and material parameters required to attain some of the specified target yield values, a number of the simulations evaluated are not considered physically realistic.