Cinder Lake Landfill Leachate Monitoring Final Presentation

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CENE-486C

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TB ASSOCIATES INC.

Project Overview

- City of Flagstaff looking to improve the modeling of potential leachate migration under Cinder Lake Landfill
- Location: 12 Miles Northeast of downtown Flagstaff
- TA/Client: Ken Fergason
  - Cinder Lake Landfill Manager

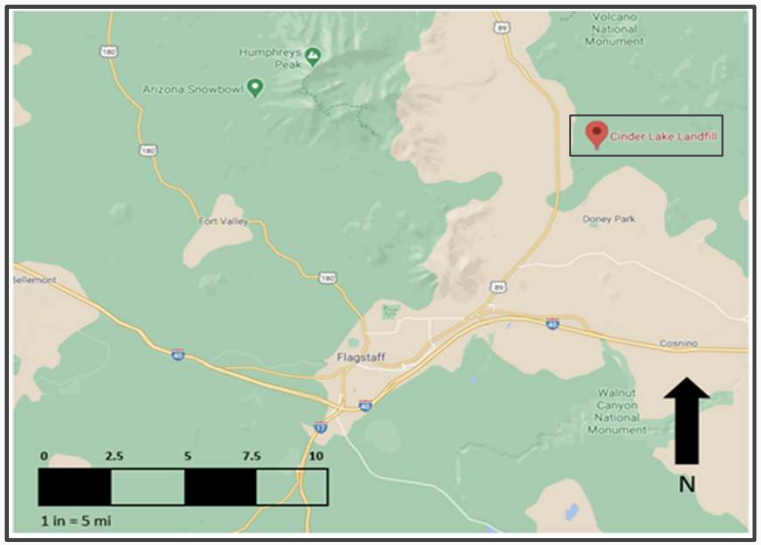


Figure 1: Map view of Flagstaff and surrounding area [1]

Site Investigation

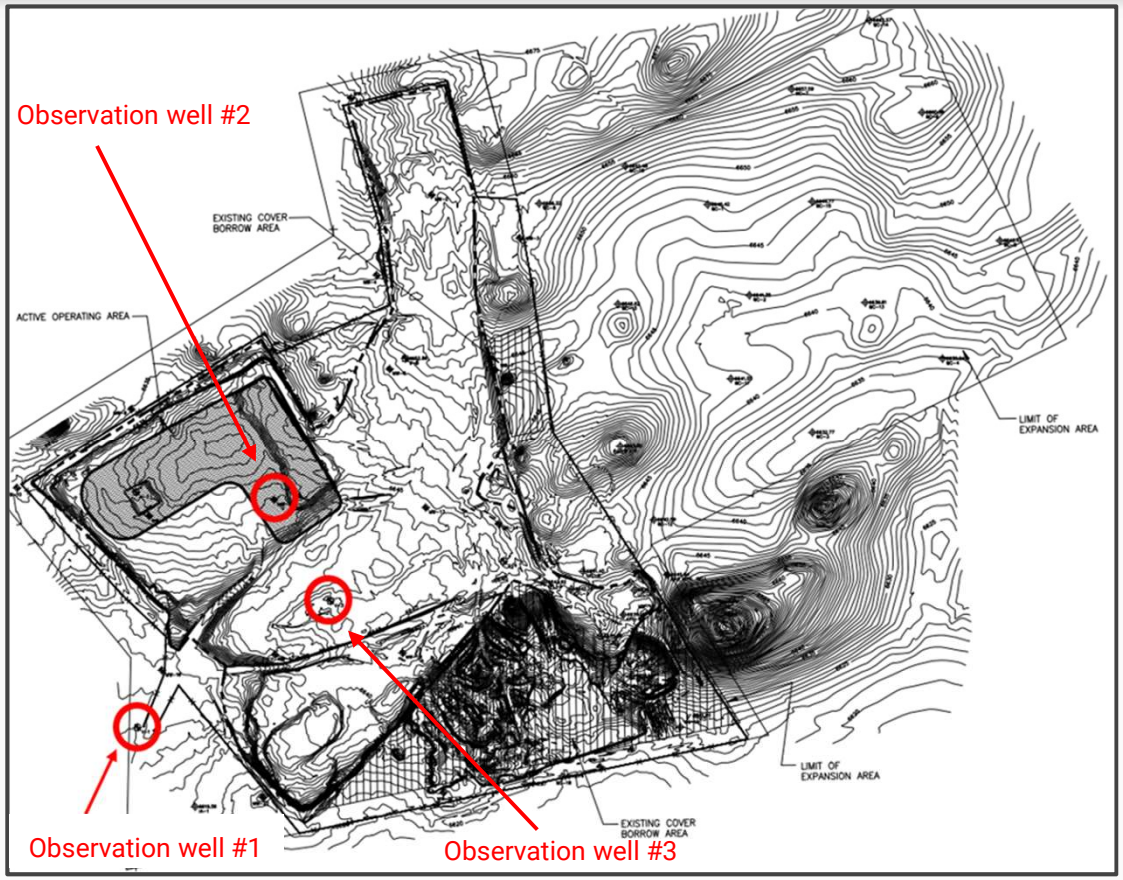


Figure 2: Topography of Cinder Lake Landfill

Figure 3: Hydroprobe Observation Well #2

Figure 4: Hydroprobe Observation Well #3

Landfill Layer Profile

- Layer 1: Cover Layer [1]
  - 2 feet thick
  - Bottom Elevation: 6648 ft
  - 3-5% slope
- Layer 2: Waste [1]
  - Current Conditions: 28 feet thick
  - Closure Conditions: 100 feet thick
  - Bottom Elevation: 6620 ft

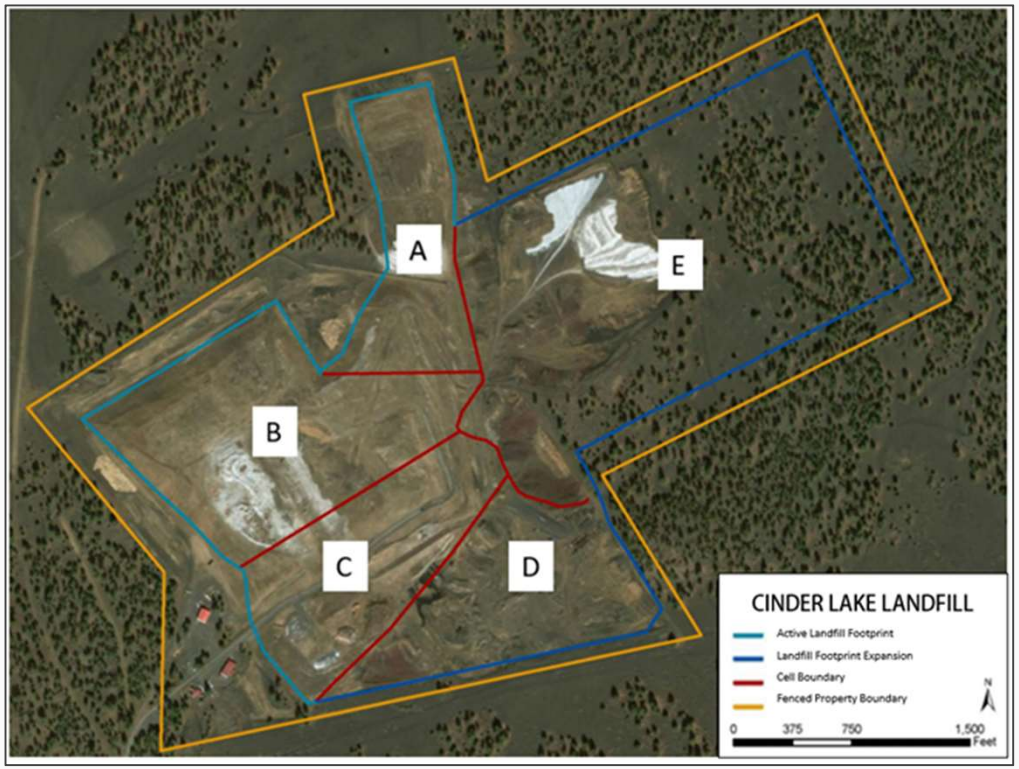


Figure 5: Landfill Site Map [2]

Duplicated HELP Model

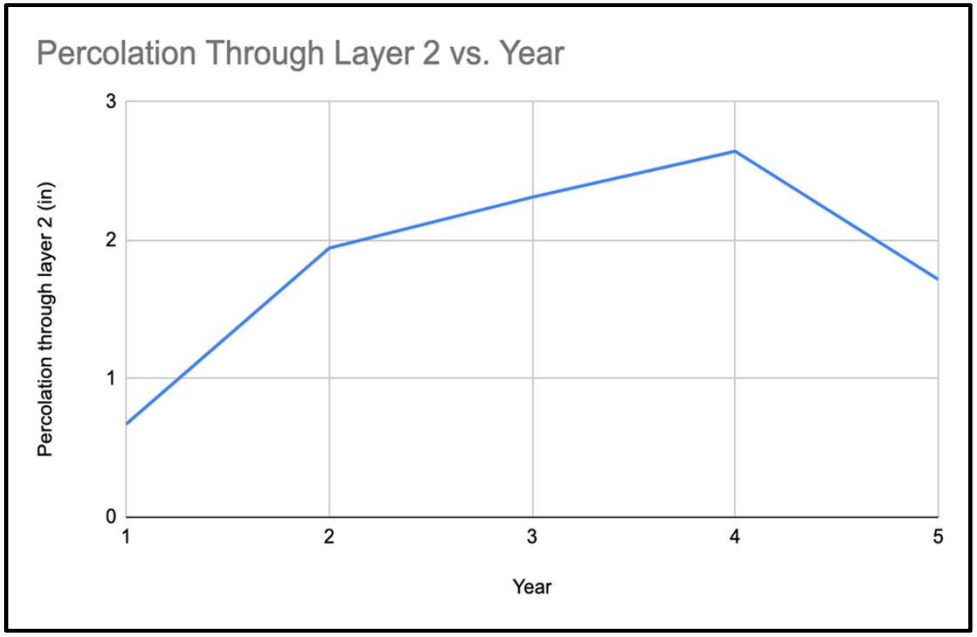
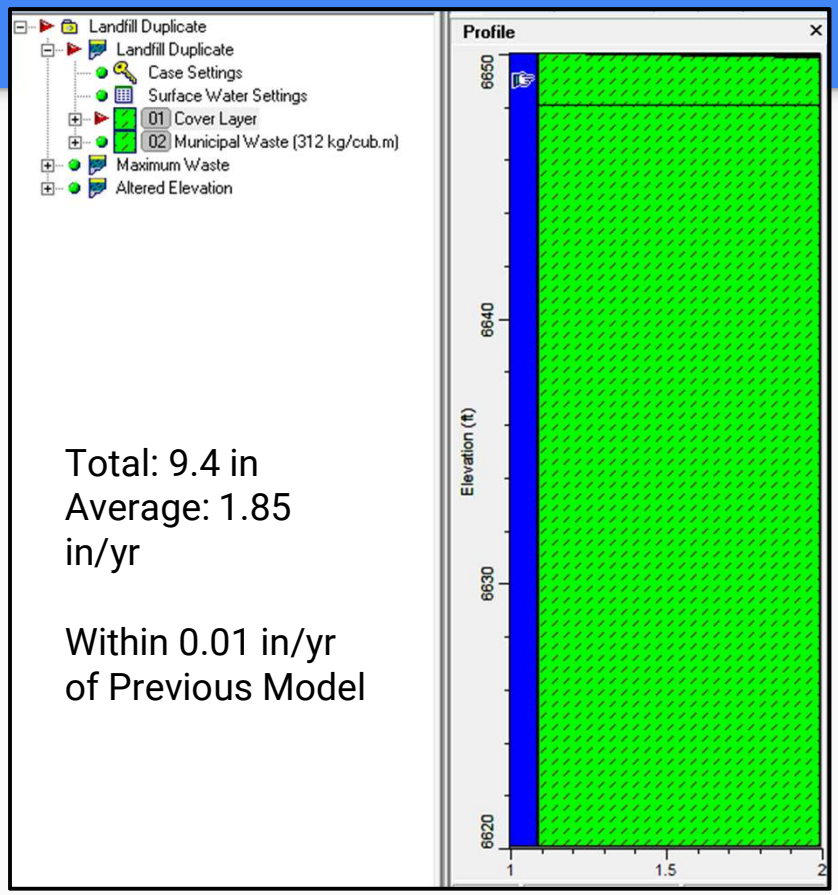


Figure 5: Duplicate HELP Model Percolation Rates



Total: 9.4 in
Average: 1.85 in/yr

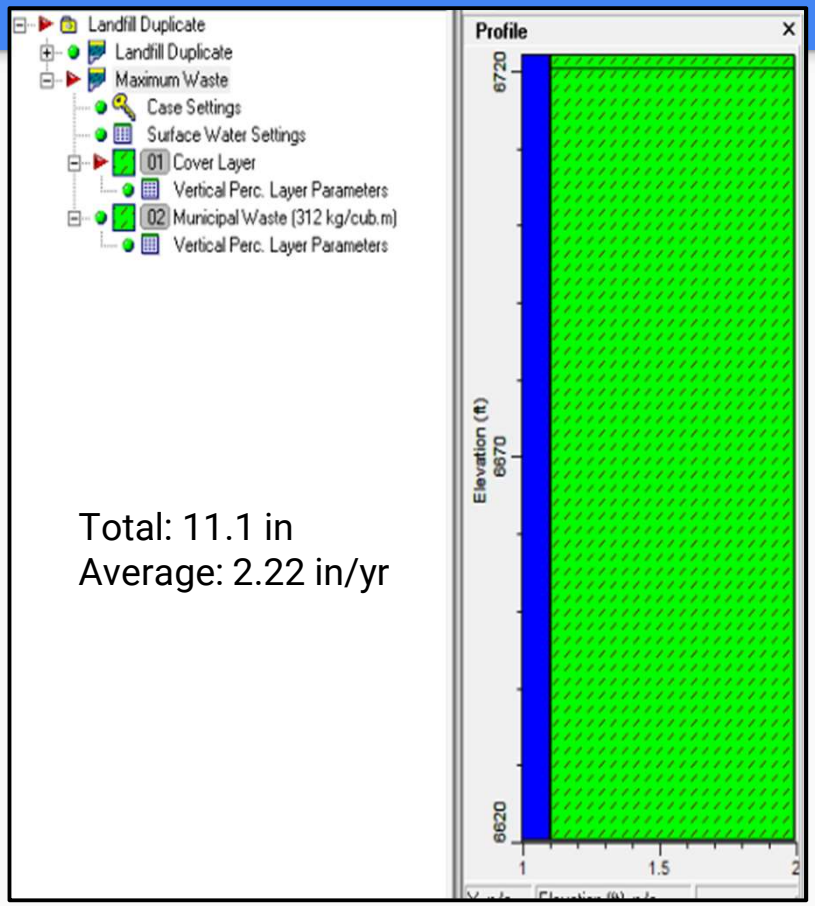
Within 0.01 in/yr of Previous Model

Figure 6: Duplicated HELP Model Layer Cross Section

HELP Model at Landfill Closure

Table 1: Leachate Percolation and Flow Rates

	Percolation Rate (in/yr)	Flow Rate (ft^3/yr)
5-yr	2.22	870,271
10-yr	2.01	787,007
50-yr	2.32	910,491
100-yr	2.48	971,410



Total: 11.1 in
Average: 2.22 in/yr

Figure 7: HELP Model at Landfill Closure

HELP Model Sensitivity Analysis

Table 2: HELP Model Sensitivity Analysis

Hydraulic Conductivity	Top Slope	Moisture Content	Resulted Percolation	% Change
cm/sec	%	%	in/yr	%
0.001	0	29.4	2.22	0
0.0001	0	29.4	0.12	-94.6
0.01	0	29.4	2.26	+1.8
0.001	3	29.4	1.37	-38.3
0.001	5	29.4	1.37	-38.3
0.001	0	18.2	5.36E-6	-99.9

Selecting a 3-D Modeling Software

Model Comparison

- TOUGH2/PetraSIM [3]
  - 2-D/3-D simulation model for water, gas and heat flow in multi-dimensional porous media
  - Cost: $2,500
- SUTRA/ModelMuse [4]
  - 2-D/3-D model for groundwater transport in unsaturated and saturated zones
  - Cost: Free
- MODFLOW-NWT/ModelMuse [5]
  - 2-D/3-D model for steady and non-steady flows in irregularly shaped flow systems
  - Cost: Free

Table 3: 3-D Model Decision Matrix

Model	Cost	User Interface Complexity	Graphical Output Capability	Total
TOUGH2/PetraSim	1	5	10	16
SUTRA/ModelMuse	10	3	10	23
MODFLOW-NWT/ModelMuse	10	5	5	20

Final selected model: SUTRA/ModelMuse

Unsaturated Zone Layers

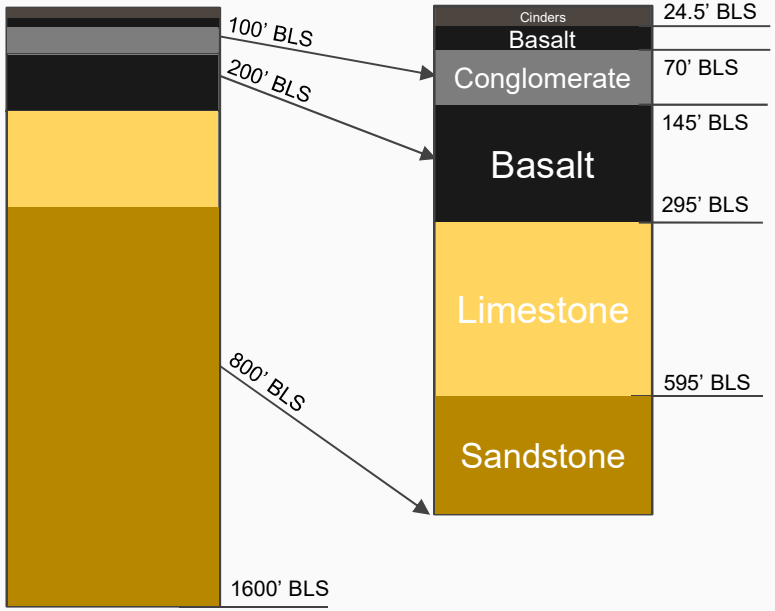
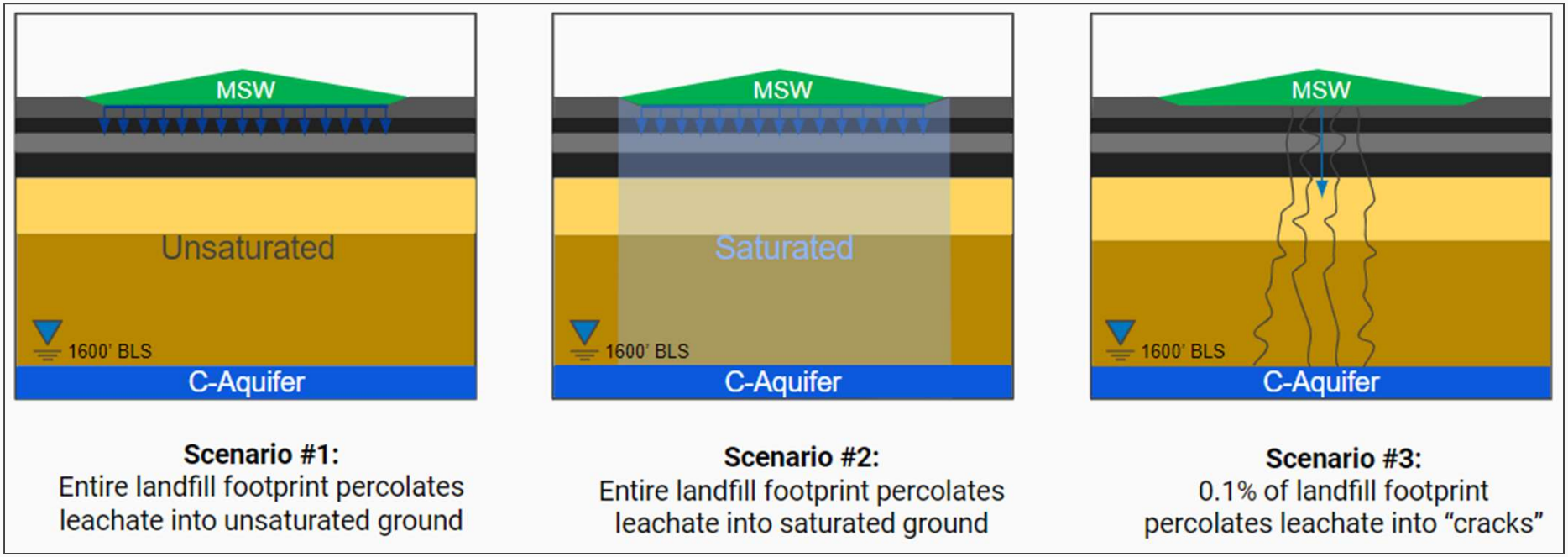


Figure 8: Simplified Borehole [2]

Table 4: Soil Strata, Porosity, and Moisture Content

Soil/Rock Type	Layer Thickness (ft)	Porosity (vol/vol)	Layer Moisture Content (%)
Cinders	24.5	0.51	17.57
Basalt	45.5	0.28	18.07
Conglomerate	75	0.38	18.94
Basalt	150	0.28	18.20
Limestone	300	0.26	18.20
Sandstone	1005	0.175	18.20

Hand Calculations: Time for Leachate to Reach Aquifer



Scenario #1:
Entire landfill footprint percolates leachate into unsaturated ground

Scenario #2:
Entire landfill footprint percolates leachate into saturated ground

Scenario #3:
0.1% of landfill footprint percolates leachate into "cracks"

Figure 9: Simplified Plume Visualization Scenarios

Entire Landfill Area Unsaturated					
Soil/Rock Type	Porosity (vol/vol) [7]	Percolation (in/yr)	Layer Moisture Content (%)	Layer Depth (ft) [6]	Time to pass layer (yr)
Cinders	0.51	4.86	17.57	24.5	3
Upper Basalt	0.28	8.86	18.07	45.5	3
Conglomerate	0.38	6.53	18.94	75	7
Lower Basalt	0.28	8.86	18.2	150	11
Limestone	0.26	9.54	18.2	300	21
Sandstone	0.175	14.17	18.2	1005	47
Entire Landfill Area Saturated					
Soil/Rock Type	Porosity (vol/vol) [7]	Percolation (in/yr)	Layer Moisture Content (%)	Layer Depth (ft) [6]	Time to pass layer (yr)
Cinders	0.51	4.86	100	24.5	60
Upper Basalt	0.28	8.86	100	45.5	62
Conglomerate	0.38	6.53	100	75	138
Lower Basalt	0.28	8.86	100	150	203
Limestone	0.26	9.54	100	300	377
Sandstone	0.175	14.17	100	1005	851
Crack Scenario					
Soil/Rock Type	Porosity (vol/vol) [7]	Percolation (in/yr)	Layer Moisture Content (%)	Layer Depth (ft) [6]	Time to pass layer (yr)
Cinders	0.51	4859	17.57	24.5	0.0034
Upper Basalt	0.28	8850	18.07	45.5	0.0034
Conglomerate	0.38	6521	18.94	75	0.0073
Lower Basalt	0.28	8850	18.2	150	0.0112
Limestone	0.26	9531	18.2	300	0.0208
Sandstone	0.175	14160	18.2	1005	0.0468

Table 5: Leachate Travel Time to Aquifer

Time to reach C-Aquifer:

93 years

Time to reach C-Aquifer:

1,692 years

Time to reach C-Aquifer:

0.09 years

3-D Plume Visualization Input Data

Legend
Yellow=Default Value
Orange=Input Value

Table 6: ModelMuse Input Data

Flow Angle (degrees)	0
Initial Chloride Concentration (mg/L) [8]	1073
Initial Pressure (psf) [9]	1229
Longitudinal Dispersivity (ft/yr)	0.5
Permeability (ft/yr)	$1E^{-10}$
Nodal Porosity (vol/vol)	0.1
Transverse Dispersivity (ft/yr)	0.5
Inlet Flow (kg/s)	0.872
Fluid Compressibility (psi)	$4.47E^{-10}$
Fluid Density (kg/m^3)	1000
Fluid Viscosity (poise)	0.001
Number of Nodes	250

ModelMuse Results

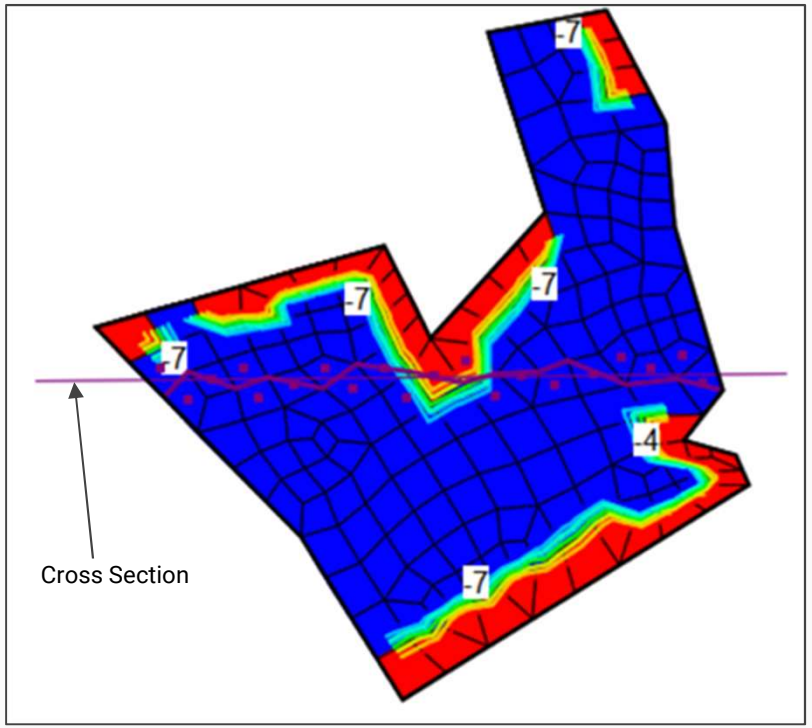


Figure 10: ModelMuse Results Top View

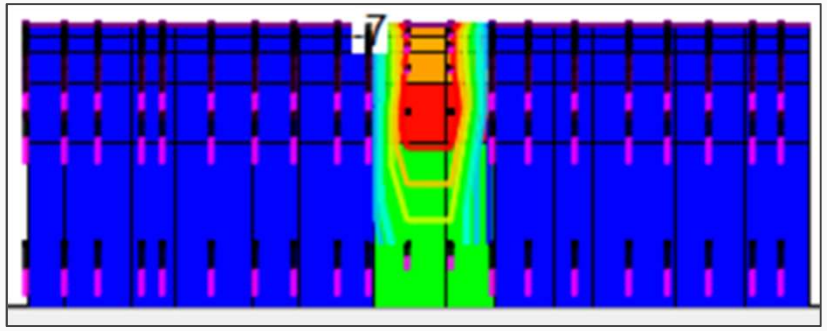


Figure 11: ModelMuse Results Cross-Section View

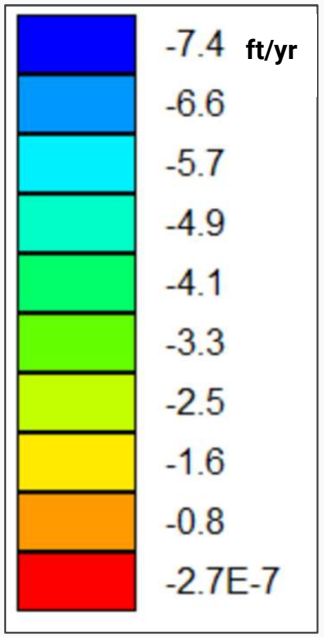


Figure 12: ModelMuse Results Color Legend

Time to reach aquifer: 216.86 years

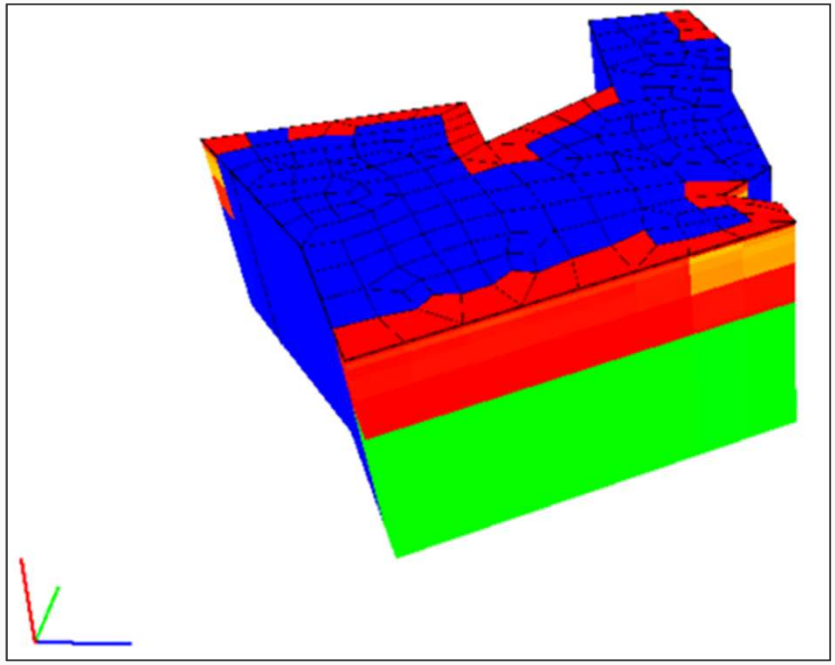


Figure 13: ModelMuse Results 3-D View

Farthest leachate distance from landfill: 1100 feet

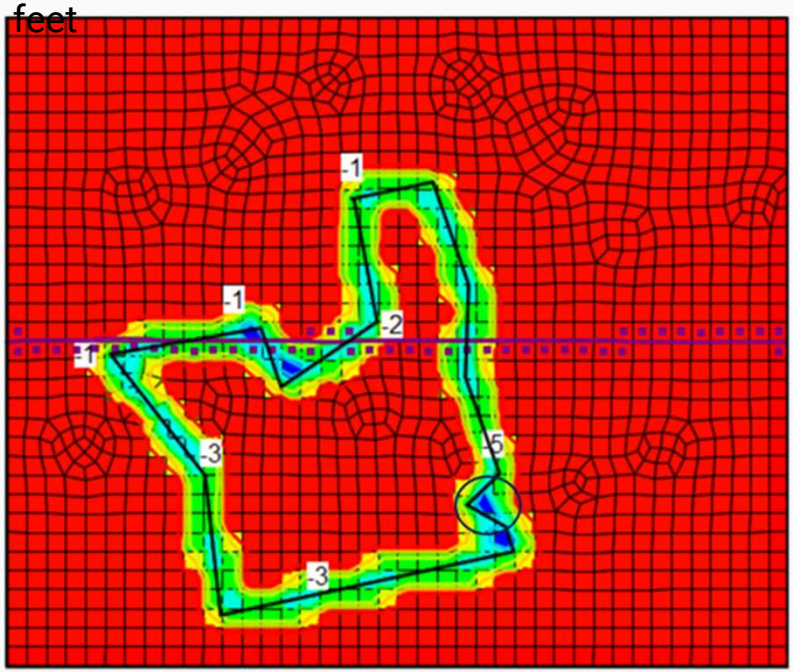


Figure 14: ModelMuse Results with Extended Area

Sensitivity Analysis for Leachate Potential to Reach Aquifer

Table 7: ModelMuse Sensitivity Analysis

Initial Concentration (mg/L)	Permeability (ft/yr)	Fluid Viscosity (poise)	Nodal Porosity (vol/vol)	Years to Reach Aquifer (yr)	Percent Change (%)
1073	1E-10	0.001	0.1	216.86	0
5000	$1E^{-10}$	0.001	0.1	190.18	-12.30
1073	$1E^{-9}$	0.001	0.1	21.68	-90.00
1073	$1E^{-10}$	0.002	0.1	433.72	+100
1073	$1E^{-10}$	0.001	0.2	433.72	+100

Final Design Recommendations

- Leachate not likely to reach aquifer
- Further data collection necessary
  - Initial Concentration
  - Permeability
  - Fluid viscosity
  - Nodal porosity
  - Pressure change with depth

Figure 15: Cinder Lake Landfill [2]

Project Impacts

Environmental

- Potential to contaminate groundwater and decrease water quality
- Land surface disturbance, loss of habitat

Social

- Increase cost of waste disposal to the public
- Peace of mind

Economic

- Increased cost of operations
- Increased cost of data collection to run better model
- Local housing and property values changes
- Potential groundwater contamination remediation

Human Health

- Abdominal pain, skin irritation, diarrhea, kidney damage, etc. from dermal contact or ingestion of contaminated groundwater

References

[1] Google Maps, "Cinder Lake Landfill," [Online]. Available: https://www.google.com/maps/place/Cinder+Lake+Landfill/@35.2870724,-111.6941764,11.75z/data=!4m5!3m4!1s0x872d8a5f04e1fa95:0x21c811654031dea3!8m2!3d35.304864!4d-111.520972. . [Accessed 7 September 2020].

[2] Woodward-Clyde, "Cinder Lake Landfill Facility Plan," Cinder Lake Landfill, Flagstaff, 1997.

[3] K. Pruess, C. Oldenburg and M. George, "TOUGH2 User's Guide, Version 2," Lawrence Berkeley National Laboratory, Berkley, 2012.

[4] A. Provost and C. Voss, "SUTRA, a Model for Saturated-Unsaturated, Variable-Density Groundwater Flow with Solute of Energy Transport-Documentation of Generalized Boundary Conditions, a Modified Implementation of Specified Pressures and Concentrations or Temperatures," USGS, Reston, 2019.

[5] R. Niswonger, P. Sorab and M. Ibaraki, "MODFLOW-NWT, A Newton formulation for MODFLOW02005," U.S. Geological Survey Techniques and Methods, 2011. [Online]. [Accessed 17 February 2021].

[6] HydroSystems, Inc., "City of Flagstaff Cinder Lake Landfill Geophysical Survey and Drilling Program," Phoenix, 2011.

[7] J. Macy, L. Amoroso, J. Kennedy and J. Unema, "Depth of Cinder Deposits and WAter-Storage Capacity at Cinder Lake, Coconino County, Arizona," U.S. Geological Survey, 2012.

[8] K. Robinson, "Characterizing Hydrologic and Contaminant Transport Attributes of Scoriated Lapillistone for Emplacement of Municipal Solid Waste," Northern Arizona University, Flagstaff, 2011.

[9] R. Kadambala, T. Townsend, P. Jain and K. Singh, "Temporal and Spatial Pore Water Pressure Distribution Surrounding a Vertical Landfill Leachate Recirculation Well," *International Journal of Environmental Research and Public Health,* vol. 8, pp. 1692-1706, 2011.

Questions?