# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 143418

PROJECT NAME: USEN – Trench 13 Design

DATE: December 3, 2014

CALCULATION NUMBER: C.03 Revision:

**CALCULATION TITLE: LCRS Infiltration Rates**

**DESCRIPTION OF CALCULATION: LCRS Infiltration Rates**

Determine infiltration rates into the Trench 13 Leachate Collection/Recovery System (LCRS)

**REFERENCES USED:**

1. Floor and Sidewall Design Plan
2. NOAA Atlas 14, Version 5, Amargosa Farms Garey Station ID: 26-0150
3. USEPA HELP Model
4. Calculation of Bubbling Pressure and Pore Size Distribution Index.

**REVIEW COMMENTS:**

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| | | | |
|---|---|---|---|
| CALCULATION MADE BY: | CWK | DATE: | 12/03/14 |
| CALCULATION CHECKED BY: | CAB | DATE: | 12/17/14 |
| CALCULATION REVISED BY: | CWK | DATE: | 02/06/15 |
| CALCULATION REVIEWED BY: | SLW | DATE: | 03/05/15 |

## Purpose of Calculation

Determine infiltration rates through the operations layer into the Trench 13 Leachate Collection and Recovery System (LCRS) that has the potential to flow in the LCRS geocomposite layer and to the LCRS sump(s). Flow in the geocomposite and transport to the sumps will be evaluated in a separate calculation

## Method

- Leachate: Assumed that after the first waste is placed all leachate collected inside Trench 13 must be managed as leachate.

- It is expected that the sidewall liner design likely will include an upper (sacrificial) HDPE (or other impermeable) layer whose function will be to protect the liner components from direct exposure to solar UV radiation (and potential material deterioration from long-term UV exposure) and possibly to reduce the temperature change range in liner materials. That HDPE layer also will prevent direct entry of precipitation into the leachate collection member (geonet) of the liner system, instead routing all incident precipitation onto the cell floor.

- Incident precipitation (falling on the cell floor and sidewalls) will infiltrate uniformly across the cell floor footprint into disposed waste or operations layer and (ultimately) to the LCRS or will be removed by evaporation (conservatively is assumed not to occur).

- The design storm is the 25-year, 24-hr storm, which is 2.26 inches, based on NOAA Atlas 14, Volume 1, Version 5, Amargosa Farms Garey Station ID: 26-0150, refer to **Reference 1** of this calculation for additional information.

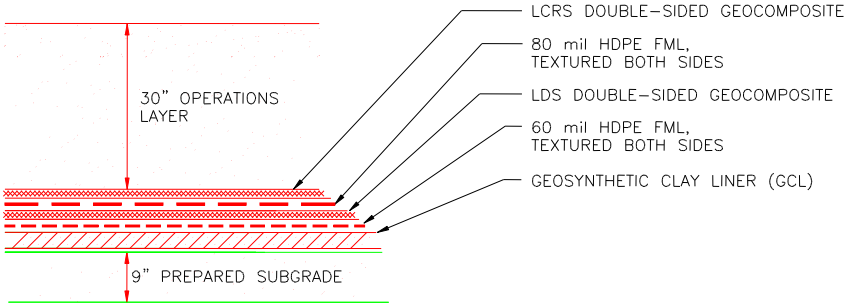
NOTE – precipitation that falls and collects within cell areas under construction (i.e., before waste placement) is not leachate, and can be managed by other means appropriate to stormwater management. Management of such stormwater is not the subject of this calculation.

## Calculation Steps

Precipitation

1. The critical period (i.e., when the greatest flow is likely to occur) for sizing the leachate collection system immediately follows placement of the 30-inch thick layer of select waste (operations layers) over the entire bottom (floor footprint) of the cell. Infiltration likely will reach the LCRS (leachate collection component) most quickly (after precipitation) and with the least loss (i.e., moisture retention within waste) at this point (i.e., before more waste is placed and the thickness of “waste” exceeds 2.5 feet).

Figure 1: Typical Base Liner System with Operations Layer




2. **Reference 2** shows the conceptual layout of the five phases and corresponding LCRS sumps of Trench 13. The horizontal area (footprint) of the five phases provided in **Table 1**

## Infiltration into the LCRS

1. No allowance is made for evaporation, so all precipitation infiltrates through the select waste (30 inch (2.5 feet) operations layer).

2. Sandy soil is assumed to comprise the select soil layer. In the Engineering Documentation for the USEPA HELP model, located in **Reference 3**, important properties of typical sandy soil types are provided. As a conservative assumption, the most permeable of the sandy soil types is considered in this calculation. Soil properties of the Operations Layer are provided in **Table 2**.

3. It is necessary to determine if saturated or unsaturated flow conditions will control infiltration through the waste. It is assumed that the soil layer contains, at most, sufficient moisture to be at field capacity (i.e. no gravity drainage occurs). A unit volume (1 ft x 1 ft x 2.5 ft thick) of the SM soil layer (based on properties in **Table 2** and provided in**Reference 3**) has available pore space of:

   2.5 cu ft x 7.48 gallons/cu ft X (0.473 – 0.222) = 4.69 gallons

4. For Trench 13, Phase A and E, total precipitation, and total water available for infiltration, is 1.86 acre-feet (**Table 1**). The rate at which the 1.86 acre-feet (i.e., 2.26" over full 9.88 acre Phase A footprint) design storm saturates the 1 ft x 1 ft unit volume of soil on the 9.88 acre cell floor during a 24 hour period is:

   1.86 ac-ft / 9.88 ac X 7.48 gal/cu ft X 1 day / 1440 min = 9.78 x $10^{-4}$ gal/min

   for each 1 ft x 1 ft unit volume

If the design storm occurs when the soil layer already is near Field Capacity (i.e., maximum moisture content without drainage), what fraction of the remaining air-filled porosity is filled by the design storm?

Porosity, $\phi$ = 0.473 or 47.3% of 30 inches = 14.19 inches

FC = 0.222 or 22.2% of 30 inches = 6.66 inches

Remaining air space before storm = 14.19 – 6.66 = 7.53 inches or

0.473 - 0.222 = 25.1% (see **Table 3**)

Design storm = 2.26 inches over the full 9.88 acres of Trench 13 - Phase A, which, when all precipitation falling on the 56,358 sq ft (1.29 ac) of the Phase A side slopes is routed to the cell floor, is equivalent to 2.60 inches of precipitation on just the 374,012 sq. ft. (8.59 ac) of cell floor. That is 2.26 inches falling directly on the cell floor and an additional 0.34 inches running off the side slopes to become evenly distributed over the cell floor. As 2.60 inches is less than 7.53 inches (**Table 4**), the design storm does not fully saturate the unit volume of select waste. The combination of field capacity and design storm moisture results in the following water-filled geometry in a 2.5 cubic feet volume of cell floor 'waste' as shown in **Table 5**:

6.66 inches + 2.60 inches = 9.26 inches

As 100% of field capacity in the 2.5 cubic feet of cell floor waste is 14.19 inches

9.26 inches / 14.19 inches = 65% of available air space.

Assuming that drainage does not begin during the design storm, 65% of the total air space is saturated following the storm. Since 65% is less than 100%, unsaturated flow controls drainage from the unit volume of soil (1 ft x 1 ft x 2.5 ft thick select waste layer) following the design storm.

Tables for the soil properties, area calculations, and volumetric moisture content are provided at the end of this calculation.

Laminar flow through a porous medium is estimated by d'Arcy's Law, or

$Q = KiA$

Where,

Q = flow (typical unit is cu ft / min
K = hydraulic conductivity (typical unit is ft / min)
i = gradient (feet / feet or unit-less)
A = area through which flow occurs (square feet)

for unsaturated flow, unsaturated hydraulic conductivity (Ku) replaces K

5. For the unsaturated flow through the select waste layer,

   K = 5.2 x $10^{-4}$ cm/sec or 1.02 x $10^{-3}$ ft / min
   i = 2.5 ft / 2.5 ft = 1.0
   A = 1 sq ft

6. Unsaturated hydraulic conductivity is estimated by Campbell's equation (**Reference 3**) and is presented in **Table 6** as:

   $Ku = Ks\ [(\theta - \theta r) / (\phi - \theta r)]^{[3 + (2 / \lambda)]}$

   Where:
   $Ku$ = unsaturated hydraulic conductivity, cm/sec
   $Ks$ = saturated hydraulic conductivity, cm/sec
   $\theta$ = actual volumetric water content, vol/vol
   $\theta r$ = residual volumetric water content, vol/vol
   $\phi$ = total porosity, vol/vol
   $\lambda$ = pore-size distribution index, dimensionless

7. The residual water content, $\theta r$, is the amount of water remaining in the soil pores under infinite capillary suction. Residual water content is estimated by Rawls (Help documentation) as follows.

   $$\theta r = 0.014 + 0.25 \text{ X Wilting Point, where WP} \geq 0.04$$

   In this case, WP = 0.104 and is ≥ 0.04 and the equation is applicable. The residual water content is:

   $$\theta r = 0.014 + 0.25 \text{ X } 0.104 = 0.040$$

8. As discussed in the HELP documentation (**Reference 3**), residual water content and pore-size distribution index, $\lambda$, are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces).

   $$(\theta - \theta r) / (\phi - \theta r) = (\varphi_b / \psi)^{**}\lambda$$

9. This equation is solved assuming that the volumetric water content is the field capacity at 0.33 bars of capillary suction, $\psi$, and equal to the wilting point at 15 bars capillary suction, $\psi b$. Solving the two equation for the values assumed for the site soil provides the following results.

| Constants | Variables |
|---|---|
| $\theta r$ = 0.040 | Field capacity = 0.222 @ $\psi$ = 0.33 |
| $\phi$ = 0.473 | Wilting point = 0.104 @ $\psi$ = 15 |

Two equations in two unknowns solved in **Reference 4**, results are:

Bubbling Pressure ($\varphi_b$)= 0.013

Pore Size Distribution Index ($\lambda$) = 0.270

10. Assuming drainage does not start during the design storm, the volumetric water content (Table 6) in a unit volume (1 cubic foot) of 'select water' following the storm is:

$$\theta = \text{Field Capacity} + 2.60 \text{ inch} / 30 \text{ inch} = 0.222 + (2.60 \text{ inch} / 30 \text{ inch})$$

$$\theta = 0.222 + 0.087$$

$$= 0.309$$

11. Based on the preceding, the unsaturated hydraulic conductivity is calculated as follows using Campbell's equation (**Table 6**).

$$Ku = Ks\ [(\theta - \theta r) / (\phi - \theta r)]\ ^{\wedge[3 + (2 / 0.27)]}$$

$$Ku = 1.02 \times 10^{-3} \text{ ft/min} * [(0.309–0.040) / (0.473–0.040)]^{\wedge[3 + (2 / 0.27)]}$$

$$= 7.13 \times 10^{-6} \text{ ft/min}$$

12. Conservatively using a unit hydraulic gradient (i = 1.0) and assuming no evaporation, the rate at which infiltration drains through and from the 2.5 feet thick select soil layer into the LCRS per unit area (1 sq ft) is:

$$Q = Ku * i * A$$

$$Q = (7.13 \times 10^{-6} \text{ ft / min})(1.0)(1.0 \text{ sq ft})$$

$$= 7.13 \times 10^{-6} \text{ cu ft / min per square foot area}$$

$$= 5.34 \times 10^{-5} \text{ gal/ min per square foot area}$$

Drainage over the entire 9.88 acre area of the Phase A floor is:

$$Q = (5.34 \text{ gal} \times 10^{-5} \text{ gal / sq ft – min}) \text{ X } 9.88 \text{ acre X } 43{,}560 \text{ sq ft / acre}$$

Q = 22.96 gallons per minute as shown in **Table 6.**

The calculation was repeated for Phases B, C, and D, each of which includes less sideslope area, as shown in Tables below.

## Calculation Result

When the 2.5-feet thick select waste layer has been placed and before placement of any additional waste, and the new Phase of Trench 13 is subject to the 2.26-inch design storm, infiltration into the LCRS drainage geocomposite occurs under unsaturated conditions and results in the following flow.

| Phase | Infiltration ($ft^3$/min-$ft^2$) | Infiltration (gal/min-$ft^2$) | Infiltration (gal/min/phase) |
|---|---|---|---|
| A & E | 7.13E-06 | 5.34E-05 | 23.0 |
| B, C, & D | 5.58E-06 | 4.17E-05 | 16. 7 |

## Calculation Tables:

### Table 1 Trench 13 Phase Areas and Design Precipitation

| Phases | | Floor Area (sq ft) | Sidewall Area\| (sq ft) | Total Area (sq. ft.) | Total Area (acres) | Design Precipitation* (acre-feet) |
|---|---|---|---|---|---|---|
| Western most and Eastern most Phases | A & E | 374,012 | 56,358 | 430,370 | 9.88 | 1.86 |
| Internal Phases | B, C, & D | 374,012 | 25,274 | 399,286 | 9.17 | 1.73 |

** = Design Precipitation = Area (acres) x (2.26 in/12 in per ft)*

*Note: "sidewall area" is measured in the horizontal plane, representing the area 'collecting' vertically falling precipitation.*

### Table 2: Soil Properties of Operations Layer

| | | |
|---|---|---|
| Operations layer thickness | 30 | inches |
| Operations layer thickness | 2.5 | feet |
| Soil type (Unified Soil Classification System) | SM | |
| Hydraulic conductivity - saturated (Ks) | 5.20E-04 | cm/sec |
| Hydraulic conductivity - saturated (Ks) | 1.02E-03 | ft/min |
| Porosity ($\phi$) | 0.473 | |
| Field capacity | 0.222 | |
| Wilting point | 0.104 | |
| Capilary pressure ($\Psi$) | 0.33 | bars |
| Bubbling pressure ($\Psi_b$) | 0.013 | bars |
| Pore size distribution index ($\lambda$) | 0.27 | dimensionless |
| | | |
| Operations layer unit width | 1 | ft |
| Operations layer unit length | 1 | ft |
| Operations layer unit depth | 2.5 | ft |
| Operations layer unit volume | 2.5 | ft3 |
| Operations layer unit volume | 18.7 | gallons |
| Water holding capacity | 0.251 | percent |
| Operations layer pore space | 4.69 | gallons |

### Table 3: Porosity and Field Capacity

| | | |
|---|---|---|
| Porosity | 14.2 | inches |
| Field capacity | 6.66 | inches |
| Remaining air space | 7.53 | inches |

## Table 4: Precipitation distribution

| Phases | Phase A and E | Phase B, C, and D | |
|---|---|---|---|
| Precipitation on sidewalls | 10,614 | 4,760 | ft3 |
| Precipitation from sidewalls distrubuted on floor | 0.028 | 0.0127 | ft |
| Precipitation from sidewalls distrubuted on floor | 0.34 | 0.15 | inch |
| Total precipiation on floor (25 yr 24 hour storm) | 2.60 | 2.41 | inch |
| Rate of Phase floor saturation | 9.78E-04 | 9.78E-04 | gal/min |
| Amount of unit depth occupied by moisture following 25 yr 24 hour event | 9.26 | 9.07 | inches |

## Table 5: Volumetric Water Content

| Phases | Phase A and E | Phase B, C, and D |
|---|---|---|
| Moisture-occupied space following 25 yr 24 hr storm event | 0.65 | 0.64 |
| Available pore space following 25 yr 24 hour event | 0.35 | 0.36 |
| Volumetric water content (after storm, assuming drainage does not start) ($\theta$) | 0.309 | 0.302 |

## Table 6: Hydraulic Conductivity and Flow to the LCRS Drainage Layer

| Phases | Phase A and E | Phase B, C, and D | |
|---|---|---|---|
| Residual water content ($\theta r$) | 0.040 | 0.040 | |
| | 3.62E-06 | 2.84E-06 | cm/sec |
| Hydraulic conductivity using Campbell's Eqn. (Ku) | 7.13E-06 | 5.58E-06 | ft/min |
| | | | |
| Values below are for a 1x1 sq. ft. section of geocomposite | | | |
| Unsaturated flow through operations layer into LCRS | 7.13E-06 | 5.58E-06 | ft3/min-ft2 |
| Unsaturated flow through operations layer into LCRS | 5.34E-05 | 4.17E-05 | gal/min-ft2 |
| Drainage into the LCRS from phase floor | 23.0 | 16.7 | gal/min |

## REFERENCES

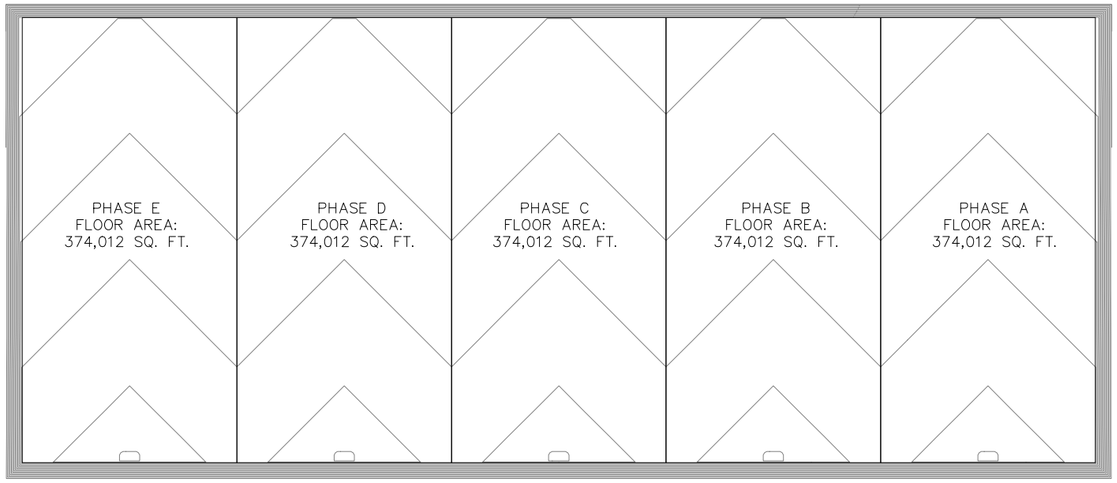
Reference 1: Trench 13 Excavation Plan and Associated Areas./

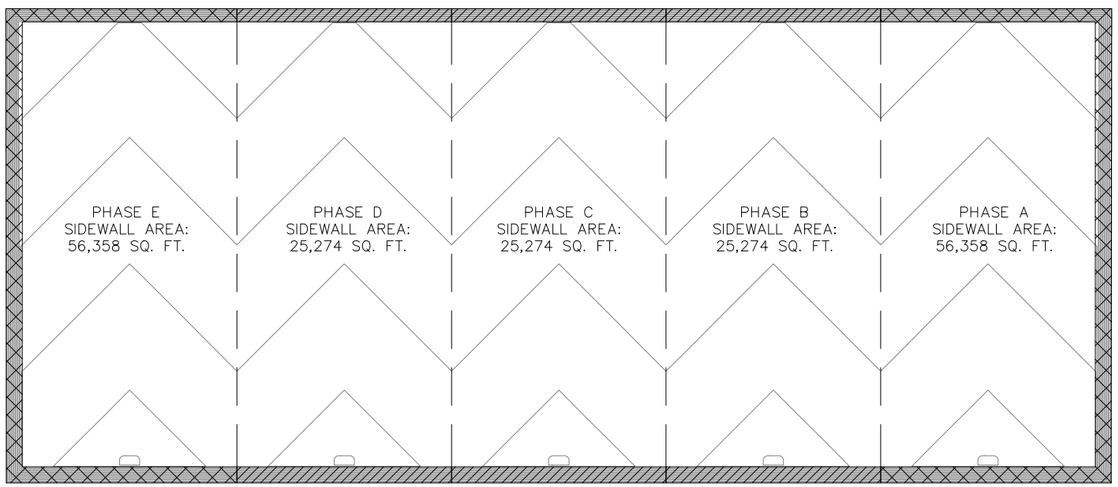
Reference 2: NOAA Atlas 14, Volume 1, Version 5, Amargosa Farms Garey Station ID: 26-0150.

Reference 3: The Hydrological Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 1. Interagency Agreement No. DW21931425. Schroeder, Paul R., Dozier, Tamsen, S., Zappi, Paul A., McEnroe, Bruce M., Sjostrom, John W., Peyton, R. Lee. US Army Corp of Engineers.

Reference 4: Calculation of Bubbling Pressure and Pore Size Distribution Index.

# REFERENCE 1

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| | |
|---|---|
| CLIENT: US ECOLOGY | REFERENCE 1<br>LCRS INFILTRATION RATE CALCULATION REFERENCE |
| LOCATION: BEATTY, NV | |
| PROJECT NUMBER: 143418 | |
| DATE: 01/02/15 | |
| DRAWN BY: CWK | |

AquAeTer

*optimizing environmental resources water, air, earth*

LEGEND:

300 0 300 600

SCALE: 1"= 300'

# REFERENCE 2

**NOAA Atlas 14, Volume 1, Version 5**
**AMARGOSA FARMS GAREY**
**Station ID: 26-0150**
**Location name: Amargosa Valley, Nevada, US***
**Latitude: 36.5717°, Longitude: -116.4619°**
**Elevation:**
**Elevation (station metadata): 2450 ft***
* source: Google Maps

**POINT PRECIPITATION FREQUENCY ESTIMATES**

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

## PF tabular

**PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | 0.108 (0.072–0.109) | 0.140 (0.097–0.147) | 0.196 (0.148–0.223) | 0.244 (0.190–0.289) | 0.319 (0.257–0.396) | 0.384 (0.312–0.490) | 0.459 (0.376–0.606) | 0.543 (0.446–0.746) | 0.677 (0.557–0.976) | 0.795 (0.653–1.20) |
| 10-min | 0.165 (0.109–0.166) | 0.213 (0.148–0.224) | 0.298 (0.225–0.339) | 0.372 (0.288–0.439) | 0.485 (0.391–0.602) | 0.584 (0.474–0.746) | 0.699 (0.572–0.923) | 0.827 (0.679–1.14) | 1.03 (0.848–1.49) | 1.21 (0.995–1.82) |
| 15-min | 0.205 (0.136–0.206) | 0.265 (0.183–0.277) | 0.370 (0.279–0.421) | 0.461 (0.358–0.545) | 0.602 (0.484–0.746) | 0.724 (0.588–0.925) | 0.866 (0.709–1.14) | 1.03 (0.841–1.41) | 1.28 (1.05–1.84) | 1.50 (1.23–2.26) |
| 30-min | 0.276 (0.183–0.278) | 0.356 (0.246–0.373) | 0.498 (0.376–0.566) | 0.621 (0.482–0.734) | 0.810 (0.652–1.01) | 0.974 (0.792–1.25) | 1.17 (0.955–1.54) | 1.38 (1.13–1.90) | 1.72 (1.42–2.48) | 2.02 (1.66–3.04) |
| 60-min | 0.341 (0.226–0.344) | 0.441 (0.305–0.462) | 0.616 (0.465–0.701) | 0.768 (0.596–0.908) | 1.00 (0.807–1.24) | 1.21 (0.980–1.54) | 1.44 (1.18–1.91) | 1.71 (1.40–2.35) | 2.13 (1.75–3.07) | 2.50 (2.06–3.76) |
| 2-hr | 0.326 (0.275–0.396) | 0.438 (0.370–0.538) | 0.657 (0.545–0.801) | 0.843 (0.694–1.04) | 1.15 (0.924–1.41) | 1.42 (1.13–1.73) | 1.73 (1.36–2.15) | 2.11 (1.61–2.63) | 2.71 (2.01–3.41) | 3.25 (2.34–4.14) |
| 3-hr | 0.375 (0.314–0.446) | 0.503 (0.426–0.605) | 0.728 (0.617–0.881) | 0.923 (0.774–1.11) | 1.24 (1.02–1.49) | 1.51 (1.22–1.82) | 1.83 (1.46–2.22) | 2.20 (1.73–2.70) | 2.80 (2.13–3.49) | 3.35 (2.48–4.21) |
| 6-hr | 0.469 (0.399–0.558) | 0.628 (0.540–0.746) | 0.910 (0.778–1.08) | 1.15 (0.970–1.35) | 1.49 (1.25–1.76) | 1.79 (1.48–2.11) | 2.14 (1.74–2.54) | 2.53 (2.02–3.03) | 3.16 (2.47–3.82) | 3.72 (2.85–4.55) |
| 12-hr | 0.591 (0.502–0.678) | 0.785 (0.677–0.917) | 1.15 (0.987–1.33) | 1.43 (1.23–1.66) | 1.84 (1.57–2.13) | 2.17 (1.83–2.52) | 2.54 (2.12–2.96) | 2.94 (2.41–3.45) | 3.52 (2.83–4.17) | 4.07 (3.23–4.89) |
| 24-hr | 0.694 (0.580–0.836) | 0.944 (0.787–1.12) | 1.39 (1.15–1.66) | 1.75 (1.43–2.08) | 2.26 (1.83–2.68) | 2.68 (2.15–3.17) | 3.13 (2.48–3.74) | 3.63 (2.82–4.34) | 4.35 (3.29–5.24) | 4.95 (3.66–6.02) |
| 2-day | 0.766 (0.647–0.914) | 1.04 (0.877–1.23) | 1.54 (1.30–1.82) | 1.94 (1.62–2.28) | 2.50 (2.07–2.90) | 2.97 (2.42–3.45) | 3.47 (2.79–4.05) | 4.02 (3.14–4.74) | 4.81 (3.65–5.77) | 5.47 (4.05–6.68) |
| 3-day | 0.791 (0.670–0.943) | 1.08 (0.909–1.27) | 1.60 (1.35–1.88) | 2.01 (1.69–2.36) | 2.60 (2.15–3.02) | 3.09 (2.52–3.59) | 3.63 (2.90–4.24) | 4.21 (3.29–4.98) | 5.06 (3.84–6.09) | 5.76 (4.27–7.05) |
| 4-day | 0.816 (0.694–0.973) | 1.11 (0.941–1.31) | 1.65 (1.40–1.93) | 2.08 (1.75–2.43) | 2.70 (2.24–3.14) | 3.22 (2.62–3.73) | 3.79 (3.02–4.42) | 4.40 (3.45–5.22) | 5.30 (4.03–6.40) | 6.06 (4.48–7.43) |
| 7-day | 0.887 (0.750–1.05) | 1.21 (1.03–1.44) | 1.83 (1.55–2.14) | 2.31 (1.93–2.70) | 2.99 (2.47–3.49) | 3.56 (2.90–4.15) | 4.17 (3.33–4.89) | 4.84 (3.79–5.76) | 5.80 (4.43–7.03) | 6.60 (4.92–8.11) |
| 10-day | 0.965 (0.797–1.17) | 1.32 (1.10–1.59) | 1.99 (1.66–2.37) | 2.51 (2.08–2.98) | 3.25 (2.65–3.85) | 3.86 (3.10–4.61) | 4.52 (3.59–5.43) | 5.24 (4.08–6.35) | 6.27 (4.74–7.73) | 7.13 (5.27–8.92) |
| 20-day | 1.15 (0.950–1.38) | 1.57 (1.31–1.88) | 2.35 (1.96–2.79) | 2.95 (2.45–3.49) | 3.79 (3.13–4.48) | 4.48 (3.62–5.31) | 5.21 (4.15–6.23) | 6.00 (4.70–7.24) | 7.11 (5.42–8.72) | 8.02 (5.96–9.99) |
| 30-day | 1.32 (1.08–1.58) | 1.81 (1.48–2.16) | 2.72 (2.23–3.23) | 3.41 (2.79–4.05) | 4.39 (3.56–5.19) | 5.17 (4.17–6.14) | 6.00 (4.80–7.14) | 6.89 (5.42–8.28) | 8.14 (6.27–9.95) | 9.16 (6.93–11.3) |
| 45-day | 1.45 (1.18–1.75) | 2.00 (1.63–2.41) | 3.07 (2.51–3.67) | 3.90 (3.18–4.65) | 5.08 (4.08–6.04) | 6.03 (4.83–7.20) | 7.07 (5.59–8.49) | 8.18 (6.38–9.93) | 9.78 (7.42–12.1) | 11.1 (8.26–13.8) |
| 60-day | 1.61 (1.30–1.97) | 2.24 (1.81–2.74) | 3.48 (2.82–4.20) | 4.45 (3.59–5.34) | 5.84 (4.65–6.98) | 7.00 (5.54–8.39) | 8.26 (6.47–9.98) | 9.63 (7.42–11.7) | 11.6 (8.69–14.3) | 13.3 (9.75–16.6) |

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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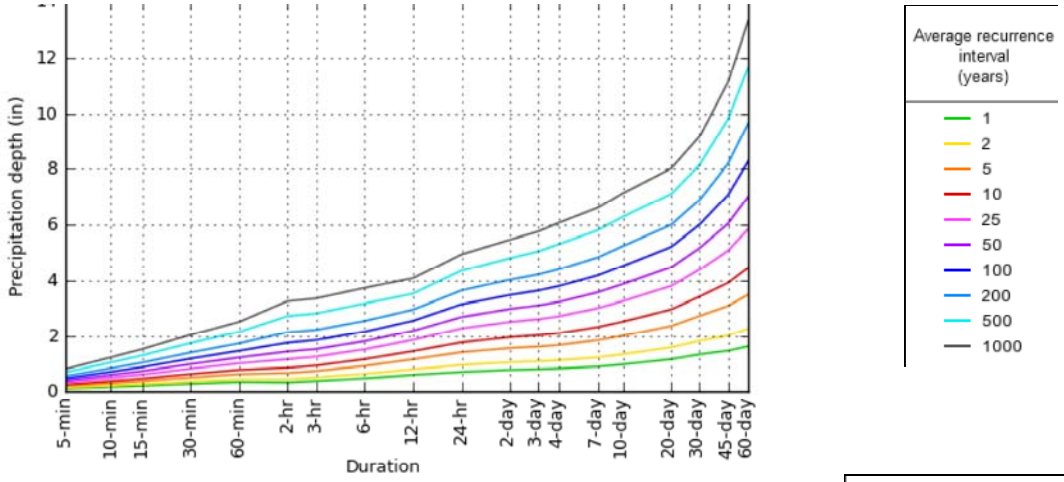
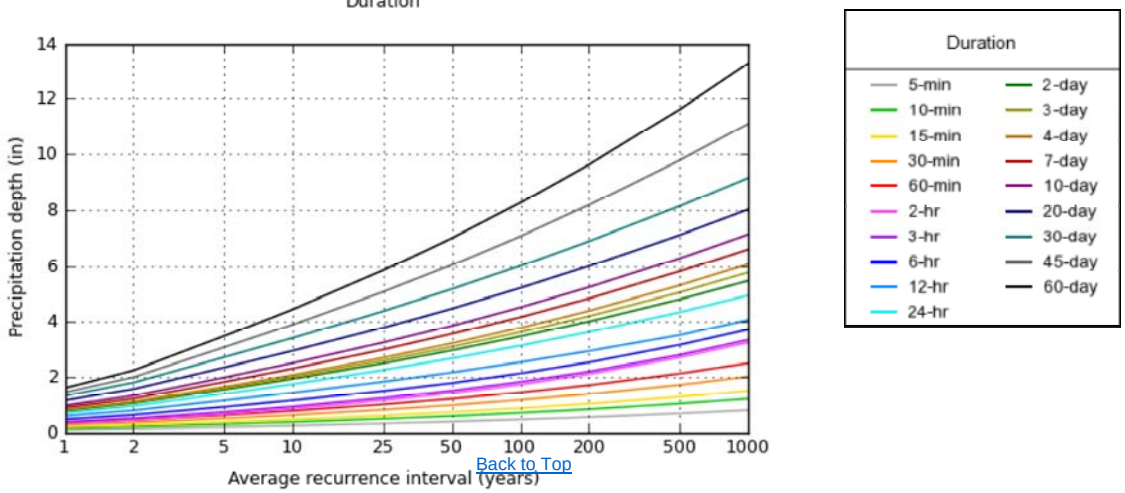
## PF graphical

REFERENCE 2

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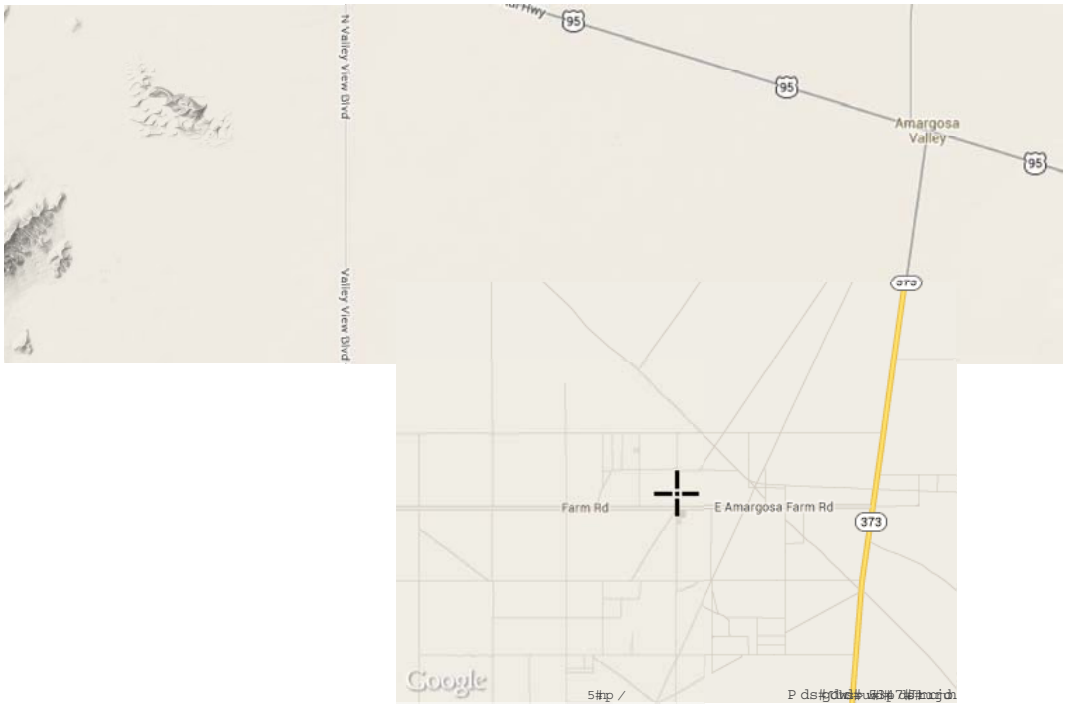
## Maps & aerials

NOAA Atlas 14, Volume 1, Version 5 Created (GMT): Fri Jul 25 17:05:28 2014

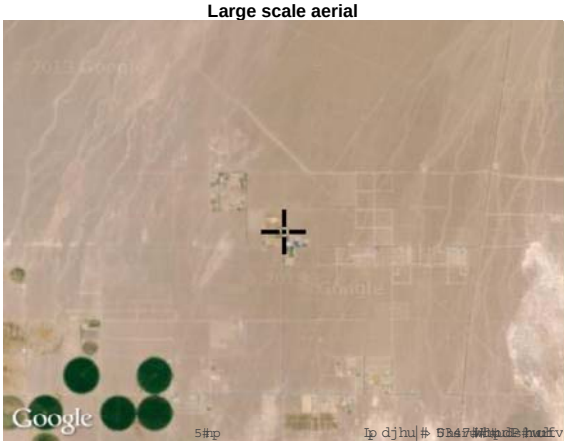
**Small scale terrain**

**Large scale terrain**

REFERENCE 2




**Large scale aerial**

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REFERENCE 3

# THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

## *ENGINEERING DOCUMENTATION FOR VERSION 3*

by

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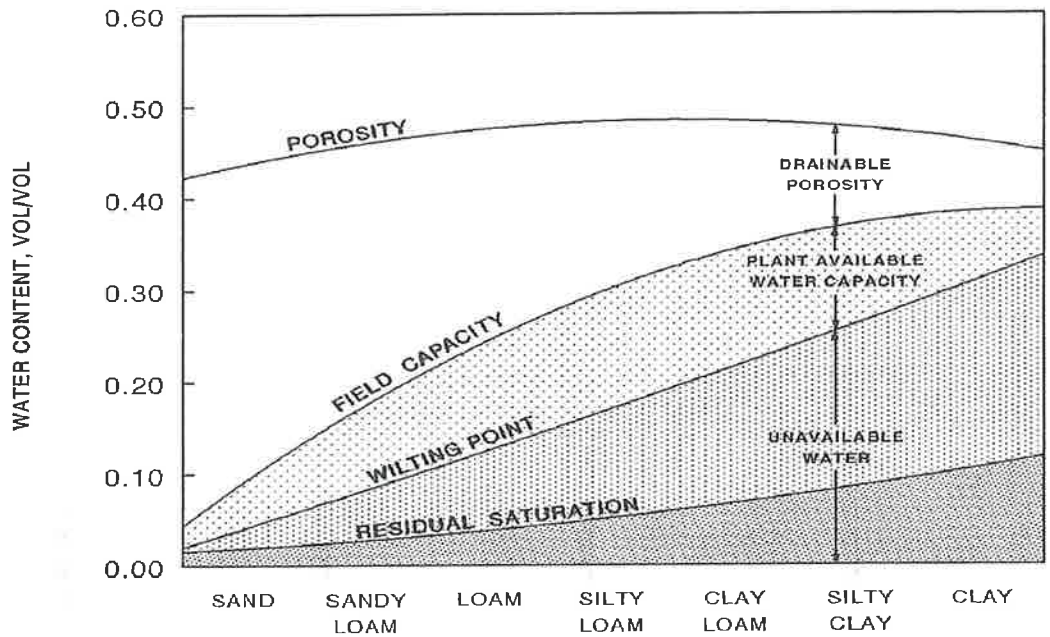


Figure 2. Relation Among Moisture Retention Parameters and Soil Texture Class

are not specified, the program assumes values near the steady-state values (allowing no long-term change in moisture storage) and runs a year of simulation to initialize the moisture contents closer to steady state. The soil water contents at the end of this year are substituted as the initial values for the simulation period. The program then runs the complete simulation, starting again from the beginning of the first year of data. The results of the volumetric water content initialization period are not reported in the output.

### 3.3.2 Unsaturated Hydraulic Conductivity

Darcy's constant of proportionality governing flow through porous media is known quantitatively as hydraulic conductivity or coefficient of permeability and qualitatively as permeability. Hydraulic conductivity is a function of media properties, such as particle size, void ratio, composition, fabric, degree of saturation, and the kinematic viscosity of the fluid moving through the media. The HELP program uses the saturated and unsaturated hydraulic conductivities of soil and waste layers to compute vertical drainage, lateral drainage and soil liner percolation. The vapor diffusivity for geomembranes is specified as a saturated hydraulic conductivity to compute leakage through geomembranes by vapor diffusion.

### *Saturated Hydraulic Conductivity*

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

### *Unsaturated Hydraulic Conductivity*

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

$$K_u = K_s \left[ \frac{\theta - \theta_r}{\phi - \theta_r} \right]^{3 + \left(\frac{2}{\lambda}\right)} \tag{5}$$

where

$K_u$ = unsaturated hydraulic conductivity, cm/sec

$K_s$ = saturated hydraulic conductivity, cm/sec

$\theta$ = actual volumetric water content, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\phi$ = total porosity, vol/vol

$\lambda$ = pore-size distribution index, dimensionless

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & \text{for } WP \geq 0.04 \\ 0.6\,WP & \text{for } WP < 0.04 \end{cases} \tag{6}$$

where

$WP$ = volumetric wilting point, vol/vol

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \tag{7}$$

where

$\psi$ = capillary pressure, bars

$\psi_b$ = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retention and matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions).

The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

### 3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

| Soil Texture Class | | | Total Porosity vol/vol | Field Capacity vol/vol | Wilting Point vol/vol | Saturated Hydraulic Conductivity cm/sec |
|---|---|---|---|---|---|---|
| HELP | USDA | USCS | | | | |
| 1 | CoS | SP | 0.417 | 0.045 | 0.018 | $1.0 \times 10^{-2}$ |
| 2 | S | SW | 0.437 | 0.062 | 0.024 | $5.8 \times 10^{-3}$ |
| 3 | FS | SW | 0.457 | 0.083 | 0.033 | $3.1 \times 10^{-3}$ |
| 4 | LS | SM | 0.437 | 0.105 | 0.047 | $1.7 \times 10^{-3}$ |
| 5 | LFS | SM | 0.457 | 0.131 | 0.058 | $1.0 \times 10^{-3}$ |
| 6 | SL | SM | 0.453 | 0.190 | 0.085 | $7.2 \times 10^{-4}$ |
| 7 | FSL | SM | 0.473 | 0.222 | 0.104 | $5.2 \times 10^{-4}$ |
| 8 | L | ML | 0.463 | 0.232 | 0.116 | $3.7 \times 10^{-4}$ |
| 9 | SiL | ML | 0.501 | 0.284 | 0.135 | $1.9 \times 10^{-4}$ |
| 10 | SCL | SC | 0.398 | 0.244 | 0.136 | $1.2 \times 10^{-4}$ |
| 11 | CL | CL | 0.464 | 0.310 | 0.187 | $6.4 \times 10^{-5}$ |
| 12 | SiCL | CL | 0.471 | 0.342 | 0.210 | $4.2 \times 10^{-5}$ |
| 13 | SC | SC | 0.430 | 0.321 | 0.221 | $3.3 \times 10^{-5}$ |
| 14 | SiC | CH | 0.479 | 0.371 | 0.251 | $2.5 \times 10^{-5}$ |
| 15 | C | CH | 0.475 | 0.378 | 0.251 | $2.5 \times 10^{-5}$ |
| 21 | G | GP | 0.397 | 0.032 | 0.013 | $3.0 \times 10^{-1}$ |

$a$ = constant representing the effects of various fluid constants and gravity, 21 $cm^3/sec$

$\phi$ = total porosity, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\psi_b$ = bubbling pressure, cm

$\lambda$ = pore-size distribution index, dimensionless

A more detailed explanation of Equation 11 can be found in Appendix A of the HELP program Version 3 User's Guide and the cited references.

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$A = \Psi_b \qquad B = \lambda$

$$\left(\frac{A}{0.33}\right)^B = 0.42 \qquad \left(\frac{A}{15}\right)^B = 0.15$$

$$B \log A - B \log 0.33 = \log 0.42$$
$$B \log A - B \log 15 = \log 0.15$$

$$B \log A = \log 0.42 + B \log 0.33$$
$$B \log A = \log 0.15 + B \log 15$$

$$\log 0.42 + B \log 0.33 = \log 0.15 + B \log 15$$
$$B \log 0.33 - B \log 15 = \log 0.15 - \log 0.42$$
$$B (\log 0.33 - \log 15) = \log 0.15 - \log 0.42$$

$$B = \frac{\log 0.15 - \log 0.42}{\log 0.33 - \log 15} = \frac{-0.447}{-1.658} = 0.27$$

$$(0.27) \log A = \log 0.42 + (0.27) \log 0.33$$

$$\log A = \frac{-0.507}{+0.27} = -1.877$$

$$A = 10^{-1.877} = 0.013$$

$\Psi_b = 0.013$

$\lambda = 0.27$