Attachment C

DETERMINATION OF SEISMIC DESIGN PARAMETERS AND LIQUEFACTION POTENTIAL ANALYSIS

Summary:

The bedrock Peak Horizontal Acceleration (PHA) at the project site was obtained from USGS 2008 hazard maps located at:

http://gldims.cr.usgs.gov/nshmp2008/viewer.htm

Based on the USGS 2008 maps, the bedrock PHA associated with different design seismic events are as follows:

- 2475-year return period: PHA = 1.01g
- 475-year return period: PHA = 0.27g

According to NEHRP (2006), the site can be classified as Site Class D (Stiff Soil Profile) assuming that the contained sludge will be stabilized (Option 2b). The Peak Ground Acceleation (PGA) values at ground surface corresponding to Site Class D are:

- 2475-year return period: PGA = 1.01g x 1.0 = 1.01g
- 475-year return period: PGA = 0.27g x 1.26 = 0.34g

According to Kramer (1996), the horizontal seismic coefficient (k_h) equal to 0.5*PGA is commonly considered appropriate for pseudo static stability analyses. These values are considered applicable for comparison with IEPA and USEPA criteria. The design k_h values are:

- 2475-year return period: k_h = 0.50g
- 475-year return period: k_h = 0.17g

Based on NUREG – 1620, the horizontal seismic load coefficicent, k_h, could alternately be calculated as 67% of the PGA. NUREG 1620 is not directly applicable to the MTW project site, and therefore these larger k_h values are not directly applicable. Nonetheless, the associated k_h values are as follows, and may be considered for comparison:

- 2475-year return period: k_h = 0.67g
- 475-year return period: k_h = 0.23g

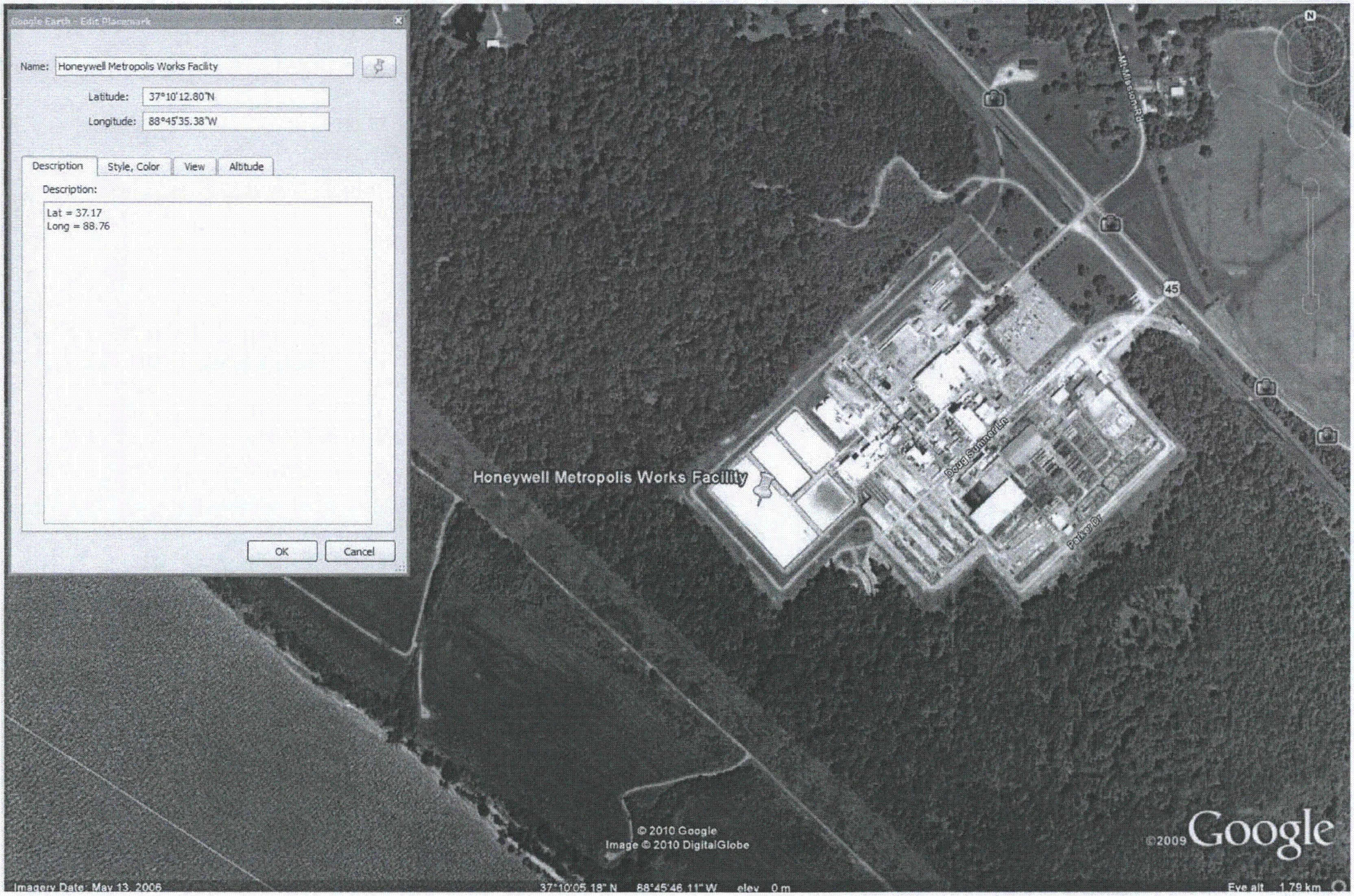


Figure C1. Project location (Latitude and Longitude)

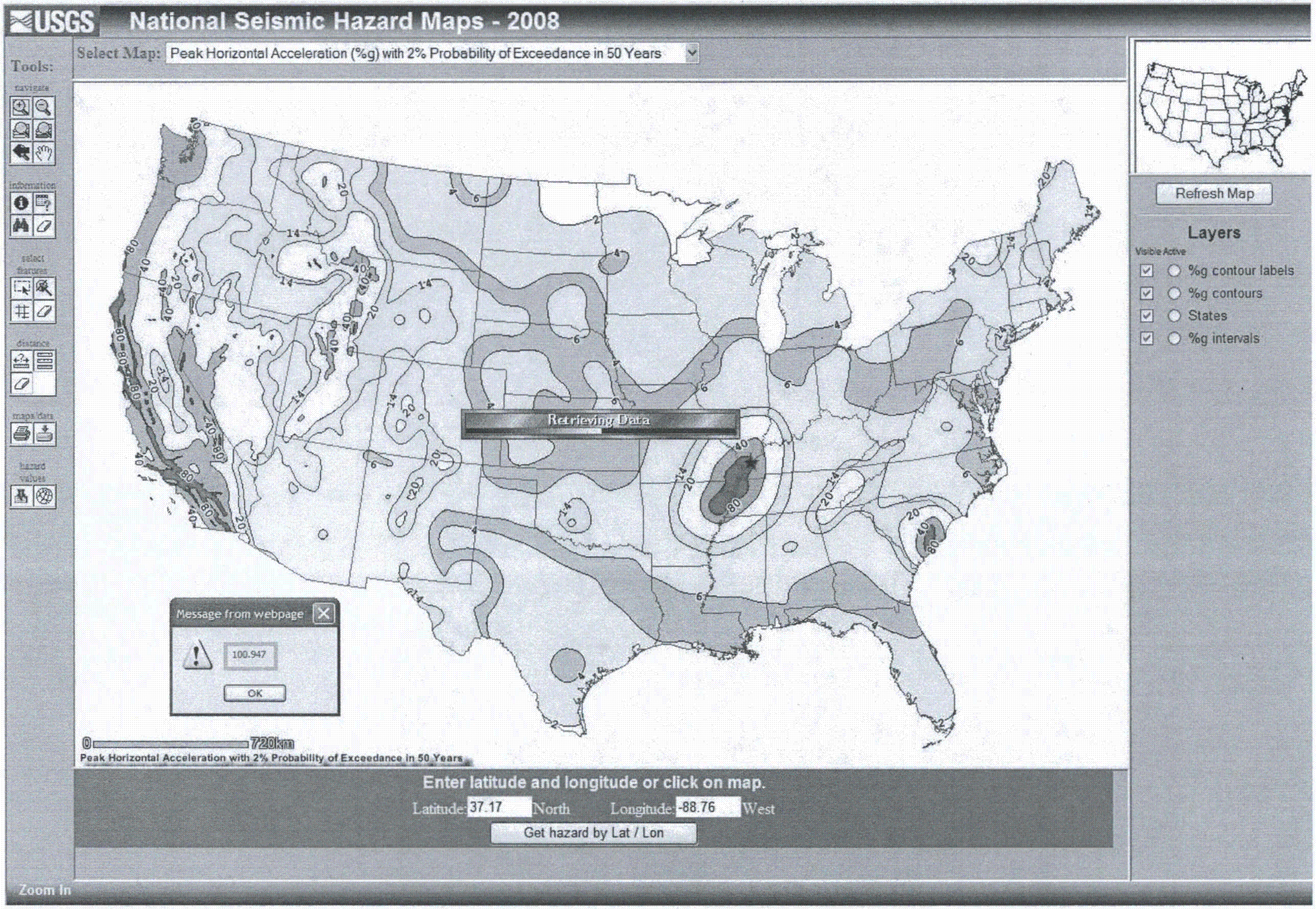


Figure C2. Peak Horizontal Acceleration (PHA) obtained from USGS 2008 hazard maps for 975-year seismic event.

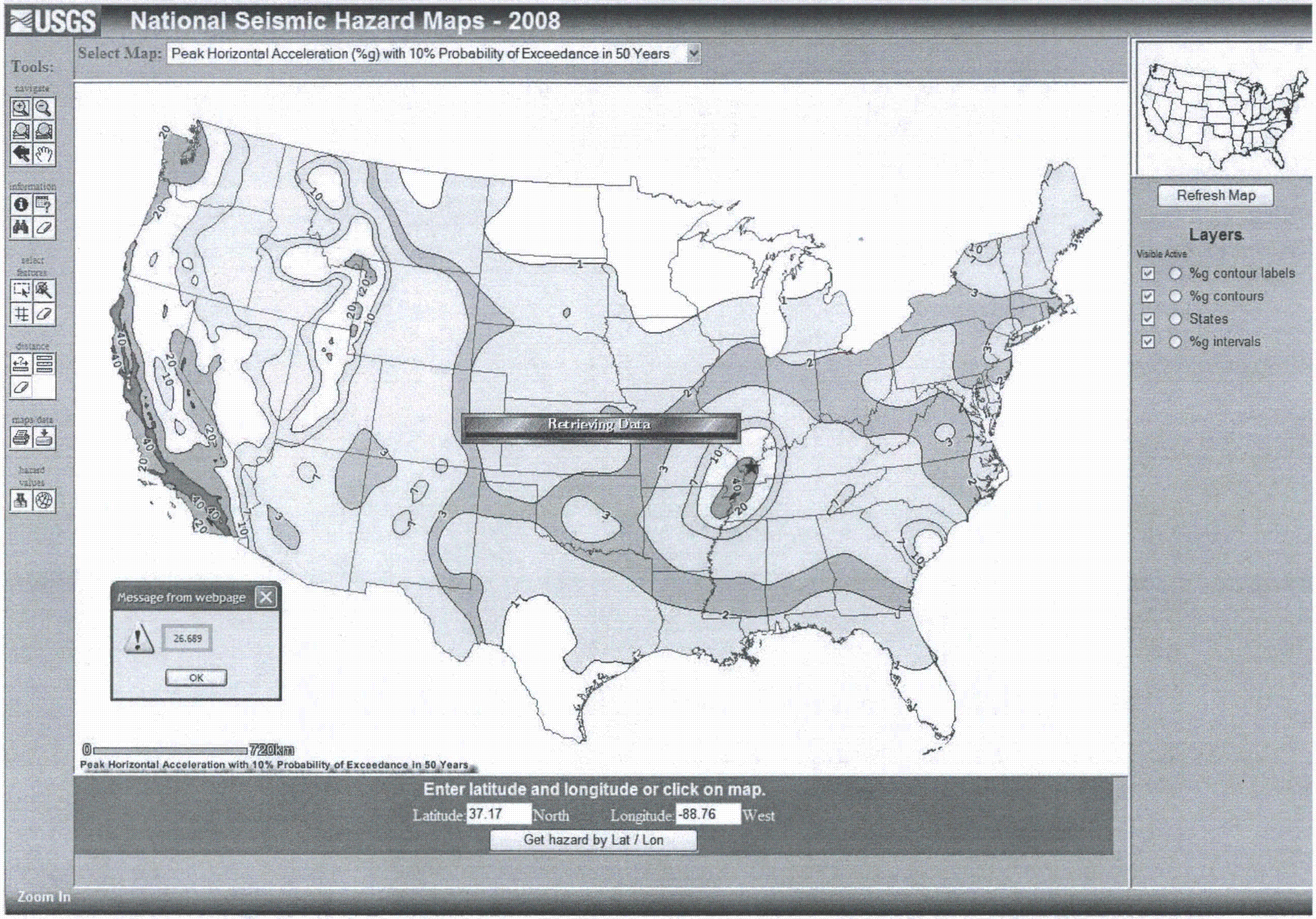


Figure C3. Peak Horizontal Acceleration (PHA) obtained from USGS 2008 hazard maps for 475-year seismic event.

Table C1. Site Class Determination Considering Native Soils Only (NEHRP 2006)

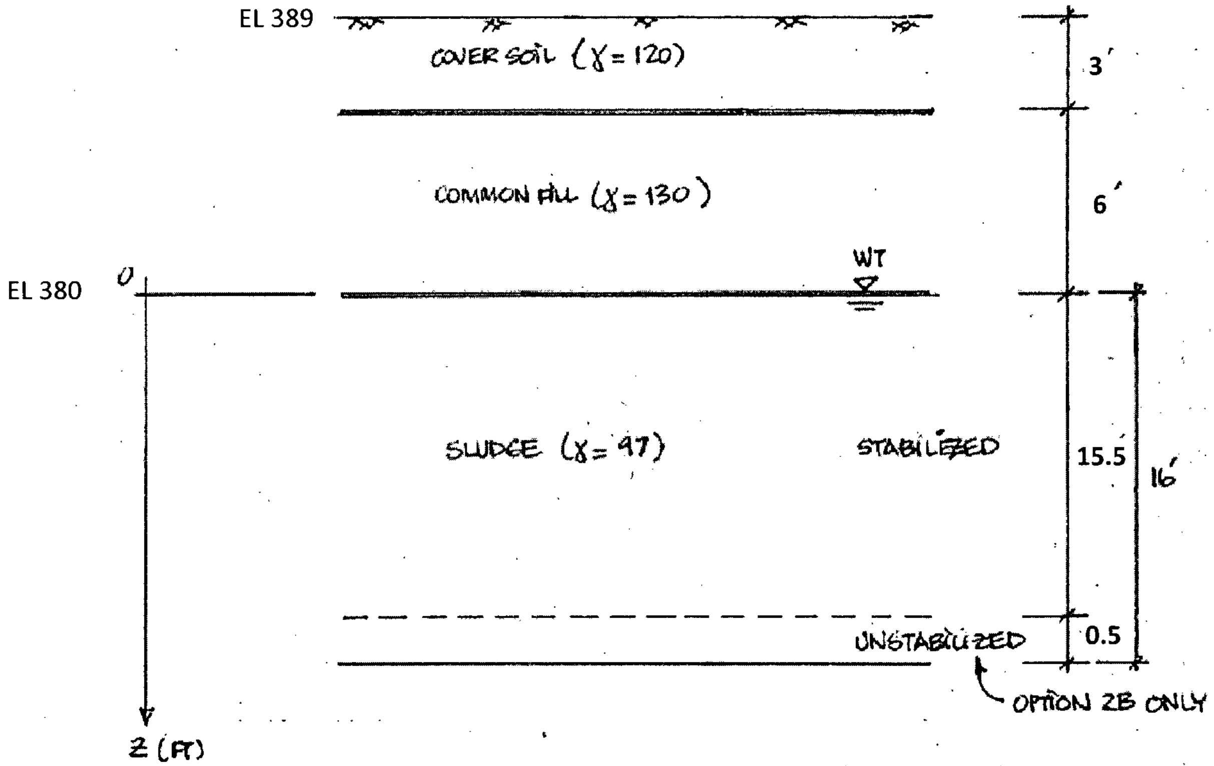
GW-107 (assumed original SPT N-values)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	363.7	11	1.0	0.09
3.5	361.2	8	2.5	0.31
6.0	358.7	15	2.5	0.17
8.5	356.2	16	2.5	0.16
11.0	353.7	32	2.5	0.08
13.5	351.2	30	2.5	0.08
16.0	348.7	48	2.5	0.05
18.5	346.2	54	2.5	0.05
21.0	343.7	100	2.5	0.03
23.5	341.2	100	2.5	0.03
26.0	338.7	100	2.5	0.03
28.5	336.2	100	2.5	0.03
33.5	331.2	14	5.0	0.36
36.0	328.7	50	2.5	0.05
38.5	326.2	16	2.5	0.16
41	323.7	14	2.5	0.18
43.5	321.2	18	2.5	0.14
46.0	318.7	26	2.5	0.10
48.5	316.2	13	2.5	0.19
51.0	313.7	24	2.5	0.10
53.5	311.2	91	2.5	0.03
60.0	304.7	82	6.5	0.08
65.0	299.7	100	5.0	0.05
70.0	294.7	100	5.0	0.05
75.0	289.7	100	5.0	0.05
80.0	284.7	100	5.0	0.05
85.0	279.7	100	5.0	0.05
90.0	274.7	100	5.0	0.05
95.0	269.7	100	5.0	0.05
100.0	264.7	100	5.0	0.05
		Sum =	100.0	2.87
	Site Class D		Nave =	35

GW-108 (assumed original SPT N-values)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	365.9	25	1.0	0.04
3.5	363.4	9	2.5	0.28
6.0	360.9	19	2.5	0.13
8.5	358.4	20	2.5	0.13
11.0	355.9	18	2.5	0.14
13.5	353.4	12	2.5	0.21
16.0	350.9	19	2.5	0.13
18.5	348.4	16	2.5	0.16
23.5	343.4	80	5.0	0.06
26.0	340.9	27	2.5	0.09
28.5	338.4	47	2.5	0.05
31.0	335.9	68	2.5	0.04
36.0	330.9	20	5.0	0.25
38.5	328.4	10	2.5	0.25
41	325.9	19	2.5	0.13
43.5	323.4	13	2.5	0.19
48.5	318.4	53	5.0	0.09
51.0	315.9	85	2.5	0.03
53.5	313.4	100	2.5	0.03
56.0	310.9	100	2.5	0.03
58.5	308.4	100	2.5	0.03
60.0	306.9	100	1.5	0.02
65.0	301.9	100	5.0	0.05
70.0	296.9	100	5.0	0.05
75.0	291.9	100	5.0	0.05
80.0	286.9	100	5.0	0.05
85.0	281.9	100	5.0	0.05
90.0	276.9	100	5.0	0.05
95.0	271.9	100	5.0	0.05
100.0	266.9	100	5.0	0.05
		Sum =	100.0	2.89
	Site Class D		Nave =	35

GW-109 (assumed original SPT N-values)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	376.9	16	1.0	0.06
3.5	374.4	10	2.5	0.25
6.0	371.9	16	2.5	0.16
8.5	369.4	11	2.5	0.23
11.0	366.9	15	2.5	0.17
13.5	364.4	15	2.5	0.17
16.0	361.9	16	2.5	0.16
18.5	359.4	13	2.5	0.19
21.0	356.9	18	2.5	0.14
23.5	354.4	15	2.5	0.17
26.0	351.9	19	2.5	0.13
28.5	349.4	27	2.5	0.09
31.0	346.9	89	2.5	0.03
33.0	344.9	26	2.0	0.08
36.0	341.9	94	3.0	0.03
38.5	339.4	23	2.5	0.11
41	336.9	62	2.5	0.04
43.5	334.4	65	2.5	0.04
46.0	331.9	100	2.5	0.03
48.5	329.4	12	2.5	0.21
51.0	326.9	12	2.5	0.21
53.5	324.4	11	2.5	0.23
56.0	321.9	18	2.5	0.14
58.5	319.4	92	2.5	0.03
61.0	316.9	65	2.5	0.04
65.0	312.9	100	4.0	0.04
70.0	307.9	100	5.0	0.05
75.0	302.9	100	5.0	0.05
80.0	297.9	100	5.0	0.05
85.0	292.9	100	5.0	0.05
90.0	287.9	100	5.0	0.05
95.0	282.9	100	5.0	0.05
100.0	277.9	100	5.0	0.05
		Sum =	100.0	3.50
	Site Class D		Nave =	29

Assumed SPT N-values

ESTIMATE Su IN THE SLUDGE (AFTER CONSOLIDATION)



@ $z = 0'$: $\sigma_v' = (120)(3) + (130)(6) = 1140$ psf

@ $z = 16'$: $\sigma_v' = (1140) + (97)(16) - (62.4)(16) = 1694$ psf

- FROM TRIAXIAL TEST RESULTS : $\frac{S_u}{P'} = \frac{S_u}{\sigma_v'}$ RANGES FROM 0.38 TO 0.56
- ASSUME AVERAGE $\frac{S_u}{P'} = 0.47 \Rightarrow S_u$ RANGES FROM $(1140)(0.47) = \underline{536}$ psf @ $z = 0$ TO $(1694)(0.47) = \underline{796 \text{ psf}}$ @ $z = 16'$
- $\frac{S_u}{P_a}$ RANGES FROM $\frac{536}{2150} = \underline{0.25}$ TO $\frac{796}{2150} = \underline{0.37}$
- FROM FIGURE 4.50 (EPRI 1990) : N_VALUE RANGES FROM 2 TO 10
- SELECT N_VALUE OF $\underline{6}$

Note: The above estimate of N is conservative, because the stabilize sludge will have Su (1800 psf) greater than the values calculated above based on Su/P ratio, and the associated N will be higher

REFERENCE: Manual on Estimating Soil Properties for Foundation Design - EPRI 1990

Table 4-10

APPROXIMATE s_u VERSUS N RELATIONSHIP

N Value (blows/ft or 305 mm)	Consistency	Approximate s_u/p_a
0 to 2	very soft	< 1/8
2 to 4	soft	1/8 to 1/4
4 to 8	medium	1/4 to 1/2
8 to 15	stiff	1/2 to 1
15 to 30	very stiff	1 to 2
> 30	hard	> 2

Source: Terzaghi and Peck (4), p. 347.

Assumed N value for consolidated sludge → (4 to 8, medium)

Su/pa ranges from 0.25 to 0.37 ← (1/4 to 1/2)

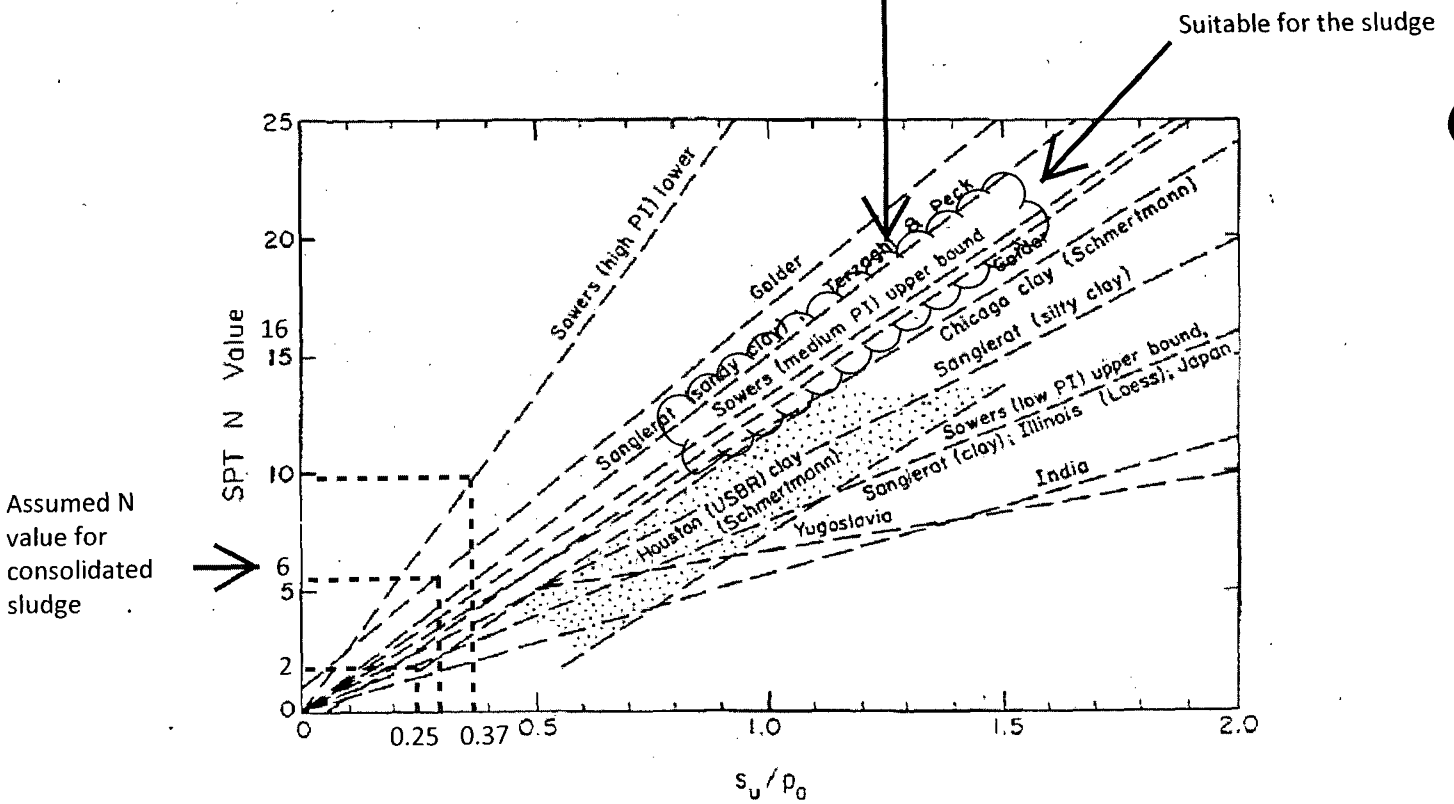


Figure 4-50. Selected Relationships Between N and s_u

Source: Djoenaidi (71), p. 5-93.

Table C2. Site Class Determination Considering Consolidated Sludge (NEHRP 2006)

GW-107 (assumed unstabilized sludge)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	363.7	6	1.0	0.17
3.5	361.2	6	2.5	0.42
6.0	358.7	6	2.5	0.42
8.5	356.2	6	2.5	0.42
11.0	353.7	6	2.5	0.42
13.5	351.2	6	2.5	0.42
16.0	348.7	6	2.5	0.42
18.5	346.2	54	2.5	0.05
21.0	343.7	100	2.5	0.03
23.5	341.2	100	2.5	0.03
26.0	338.7	100	2.5	0.03
28.5	336.2	100	2.5	0.03
33.5	331.2	14	5.0	0.36
36.0	328.7	50	2.5	0.05
38.5	326.2	16	2.5	0.16
41	323.7	14	2.5	0.18
43.5	321.2	18	2.5	0.14
46.0	318.7	26	2.5	0.10
48.5	316.2	13	2.5	0.19
51.0	313.7	24	2.5	0.10
53.5	311.2	91	2.5	0.03
60.0	304.7	82	6.5	0.08
65.0	299.7	100	5.0	0.05
70.0	294.7	100	5.0	0.05
75.0	289.7	100	5.0	0.05
80.0	284.7	100	5.0	0.05
85.0	279.7	100	5.0	0.05
90.0	274.7	100	5.0	0.05
95.0	269.7	100	5.0	0.05
100.0	264.7	100	5.0	0.05
		Sum =	100.0	4.59
	Site Class D		Nave =	22

GW-108 (assumed unstabilized sludge)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	365.9	6	1.0	0.17
3.5	363.4	6	2.5	0.42
6.0	360.9	6	2.5	0.42
8.5	358.4	6	2.5	0.42
11.0	355.9	6	2.5	0.42
13.5	353.4	6	2.5	0.42
16.0	350.9	6	2.5	0.42
18.5	348.4	16	2.5	0.16
23.5	343.4	80	5.0	0.06
26.0	340.9	27	2.5	0.09
28.5	338.4	47	2.5	0.05
31.0	335.9	68	2.5	0.04
36.0	330.9	20	5.0	0.25
38.5	328.4	10	2.5	0.25
41	325.9	19	2.5	0.13
43.5	323.4	13	2.5	0.19
48.5	318.4	53	5.0	0.09
51.0	315.9	85	2.5	0.03
53.5	313.4	100	2.5	0.03
56.0	310.9	100	2.5	0.03
58.5	308.4	100	2.5	0.03
60.0	306.9	100	1.5	0.02
65.0	301.9	100	5.0	0.05
70.0	296.9	100	5.0	0.05
75.0	291.9	100	5.0	0.05
80.0	286.9	100	5.0	0.05
85.0	281.9	100	5.0	0.05
90.0	276.9	100	5.0	0.05
95.0	271.9	100	5.0	0.05
100.0	266.9	100	5.0	0.05
		Sum =	100.0	4.51
	Site Class D		Nave =	22

GW-109 (assumed unstabilized sludge)				
Depth (ft)	Elev (ft)	N-value	Layer Thickness, di	di/Ni
1.0	376.9	6	1.0	0.17
3.5	374.4	6	2.5	0.42
6.0	371.9	6	2.5	0.42
8.5	369.4	6	2.5	0.42
11.0	366.9	6	2.5	0.42
13.5	364.4	6	2.5	0.42
16.0	361.9	6	2.5	0.42
18.5	359.4	13	2.5	0.19
21.0	356.9	18	2.5	0.14
23.5	354.4	15	2.5	0.17
26.0	351.9	19	2.5	0.13
28.5	349.4	27	2.5	0.09
31.0	346.9	89	2.5	0.03
33.0	344.9	26	2.0	0.08
36.0	341.9	94	3.0	0.03
38.5	339.4	23	2.5	0.11
41	336.9	62	2.5	0.04
43.5	334.4	65	2.5	0.04
46.0	331.9	100	2.5	0.03
48.5	329.4	12	2.5	0.21
51.0	326.9	12	2.5	0.21
53.5	324.4	11	2.5	0.23
56.0	321.9	18	2.5	0.14
58.5	319.4	92	2.5	0.03
61.0	316.9	65	2.5	0.04
65.0	312.9	100	4.0	0.04
70.0	307.9	100	5.0	0.05
75.0	302.9	100	5.0	0.05
80.0	297.9	100	5.0	0.05
85.0	292.9	100	5.0	0.05
90.0	287.9	100	5.0	0.05
95.0	282.9	100	5.0	0.05
100.0	277.9	100	5.0	0.05
		Sum =	100.0	4.98
	Site Class D		Nave =	20

Assumed SPT N-values

Assumed N value for consolidated sludge

PGA = Ss/2.5 = 0.2g PGA = Ss/2.5 = 0.3g PGA = Ss/2.5 > 0.5g

NEHRP (2006) Table 3.3-1 Values of Site Coefficient F_a

Site Class	Mapped MCE Spectral Response Acceleration Parameter at 0.2 Second Period[a]				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	__[b]	__[b]	__[b]	__[b]	__[b]

[a] Use straight line interpolation for intermediate values of S_S.
[b] Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

PGA = 0.27g --> Fpga = 1.4 - (1.4-1.2)/10*7 = 1.26

PGA = 1.0g --> Fpga = 1.0

Table C3

Honeywell Metropolis Facility Works - Seismic Design Parameters

8/13/2010

Ground Motion	Latitude	Longitude	PGA (B/C)	Site Class[1]	F_{pga}[2]	PGA (D)	Modal M
	deg	deg	g	(--)	(--)	g	(--)
10% in 50 yrs or 475-yr return period	37.17	-88.76	0.27	D	1.26	0.34	7.7
2% in 50 yrs or 2,475-yr return period	37.17	-88.76	1.01	D	1.00	1.01	7.7

Note:
1. Site Class D was determined based on average SPT N value obtained in the upper 100 feet of soil between 15 and 50 bps (NEHRP 2006)
2. Based on Table 3-3.1 (NEHRP 2006)

Attachment D

SEISMIC-INDUCED DEFORMATION (LURCHING) OF THE SLUDGE USING NEWMARK RIGID-BLOCK METHOD

Summary:

Magnitude of the lateral movement of the contained sludge caused by the inertial force during an earthquake is assumed to be equal to the initial shift of the soil block calculated using the Newmark method. In this analysis, a yield acceleration and a representative acceleration time history are used as inputs. The yield acceleration is determined from a pseudo-static global stability analysis in which the failure surface is forced to go through the unstabilized sludge along the bottom of the pond. The horizontal seismic load coefficient, k_h, that results in a global factor of safety of 1.0 is the yield acceleration. The Newmark analysis was performed using the program "Newmark" available from the USGS website. This program was developed by Jibson and Jibson (2003).

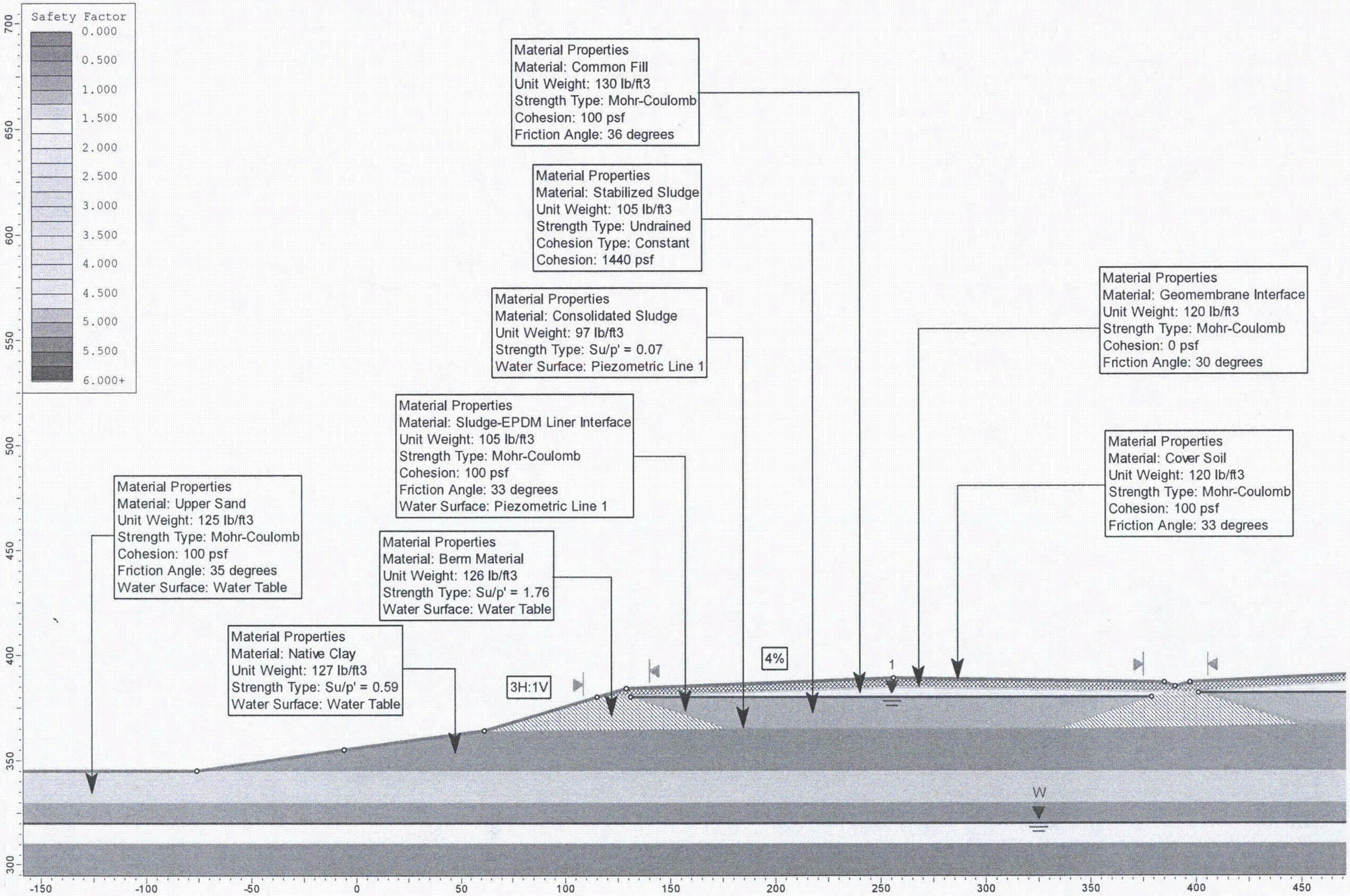


Figure D2. Soil profile and properties for pseudo static stability analysis.

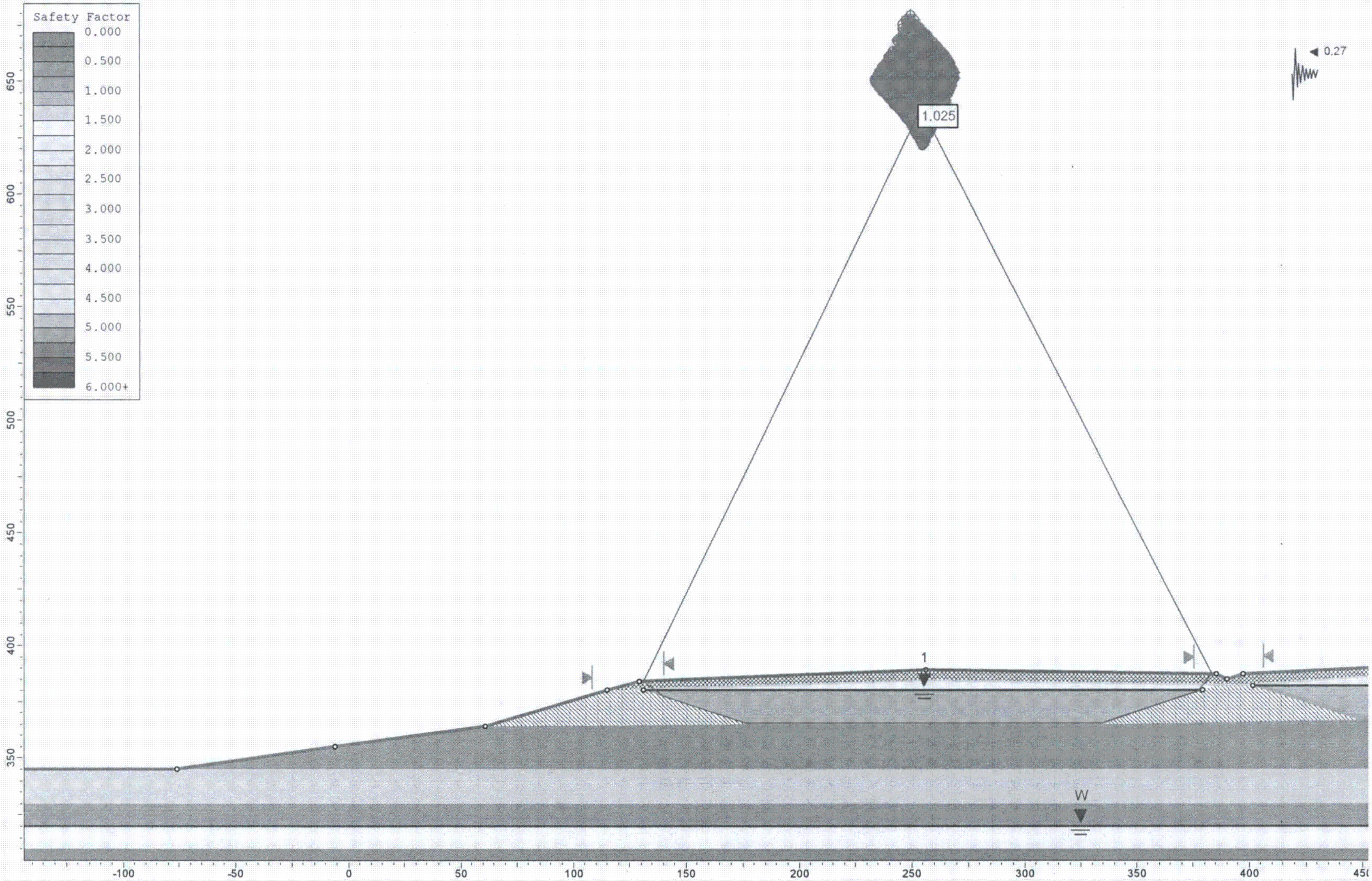


Figure D3. Determination of yield acceleration based on pseudo static stability analysis.

TABLE D1. SELECTED EARTHQUAKE TIME HISTORIES FOR NEWMARK ANALYSIS (2475-YEAR EVENT)

Newmark

Getting Started | Rigorous Rigid-Block Analysis | Simplified Analyses | Record Manager | Utilities | Help

Step 1: Select Records | Step 2: Perform Rigid-Block Analysis | Step 3: View Results

Search records by properties | Select individual records

	Greater than or equal to:	Less than or equal to:
Moment Magnitude	7	8.5
Arias Intensity (m/s)		
Duration (5-95%) (s)		
Peak Acceleration (g)	.8	1.1
Mean Period (s)		
Epicentral Distance (km)	10	30
Focal Distance (km)		
Rupture Distance (km)		

Search for records

Clear all search fields

Search complete. 5 records found.

Focal Mechanism: ☐ All ☑ Strike-slip ☑ Normal ☑ Reverse ☐ Oblique normal ☐ Oblique reverse

Site Classification: ☐ All ☑ Hard rock ☑ Soft rock ☑ Stiff soil ☐ Soft soil

Records selected (units as indicated above):

Select all for analysis | Deselect all for analysis

Sort by Earthquake then Record A/A

Display properties of: ◉ Records ○ Stations

Earthquake	Record	Magnitude	Arias Int.	Duration	PGA	Mean Per.	Epi. Dist.	Focal Dist.	Rup. Dist	Foc. Mech.	Analyze
Cape Mendocino...	CPM-090	7.1	2.389	9.8	1.039	0.35	10.5	14.6	8.5	Reverse	☑
Chi-Chi, Taiwan ...	TCU065-270	7.6	7.669	28.6	0.814	1.12	25.6	27.6	1.0	Reverse	☑
Chi-Chi, Taiwan ...	TCU129-270	7.6	9.259	27.3	1.010	0.35	13.5	17.0	1.2	Reverse	☑
Chi-Chi, Taiwan ...	WNT-090	7.6	7.886	27.1	0.958	0.34	11.9	15.8	1.2	Reverse	☑
Duzce, Turkey 19...	VO-000	7.1	9.976	12.9	0.970	0.30	23.1	25.2	8.2	Strike-slip	☑

Manage groups... | Clear table | Delete highlighted record(s) | Go to Perform Rigid-Block Analysis page

5 of 5 records selected for analysis

TABLE D2. YIELD ACCELERATION AND PGA USED IN THE ANALYSIS (2475-YEAR EVENT)

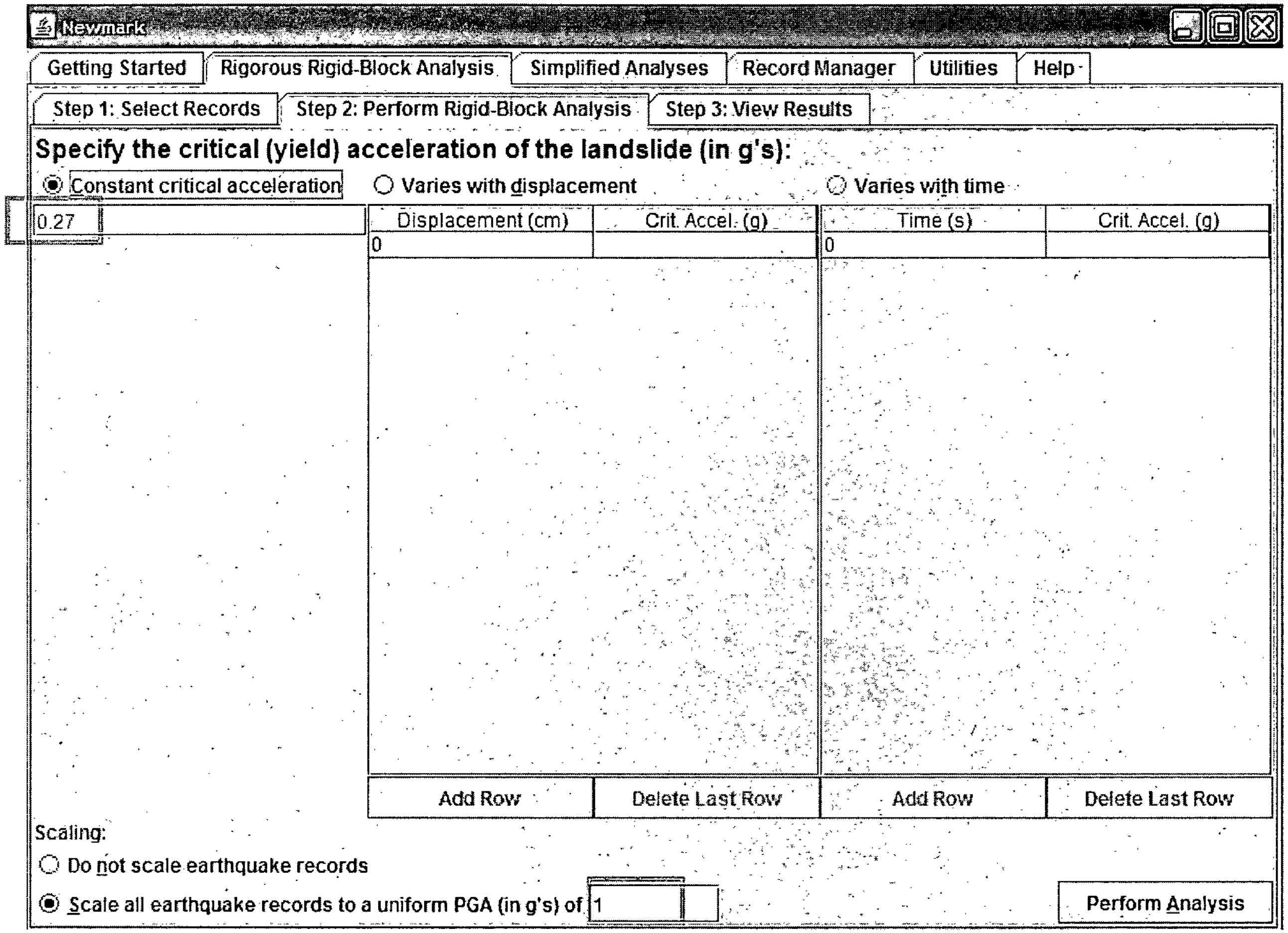


FIGURE D4. SEISMIC-INDUCED DISPLACEMENTS BASED ON NEWMARK ANALYSIS (2475-YEAR EVENT)

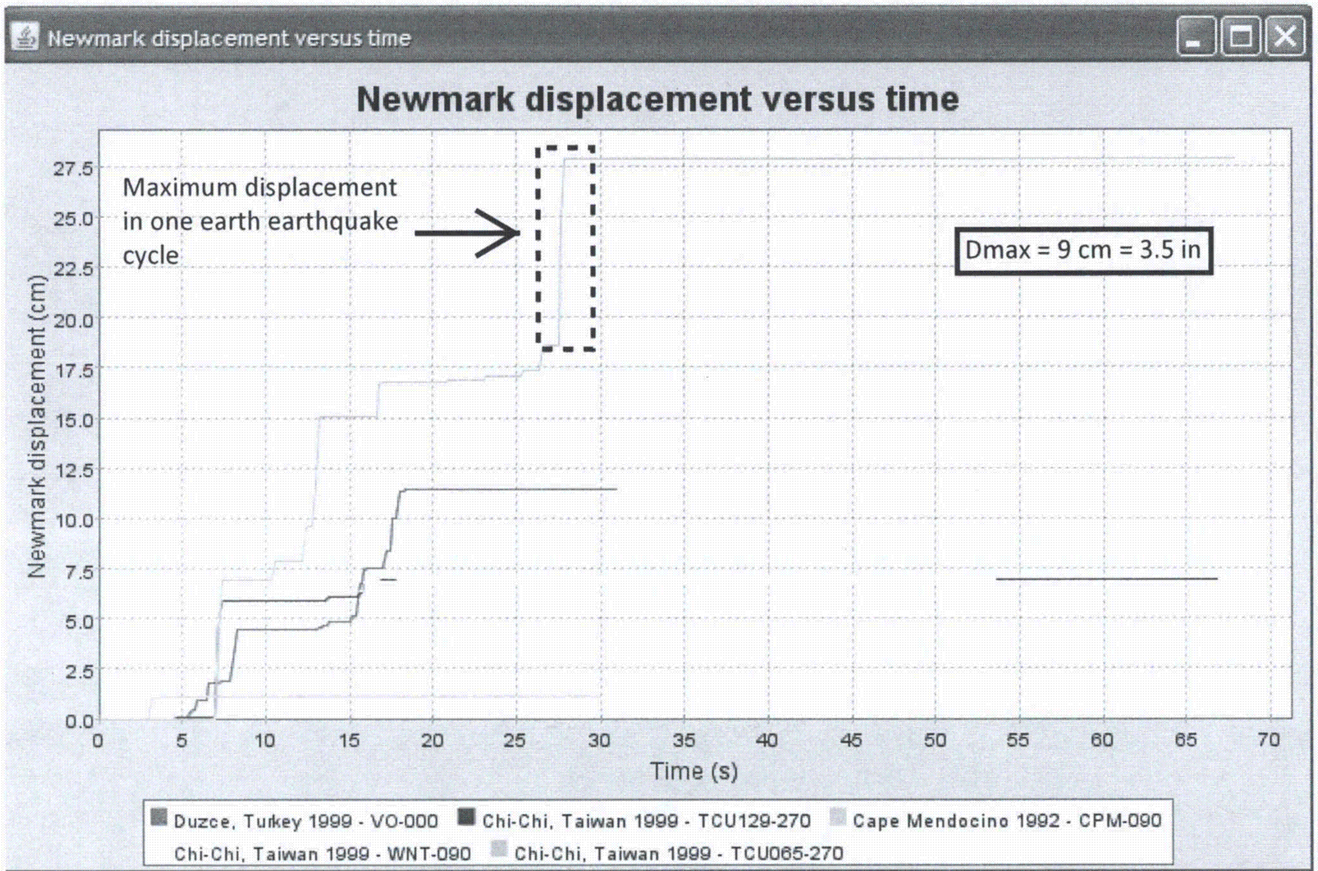


TABLE D3. SELECTED EARTHQUAKE TIME HISTORIES FOR NEWMARK ANALYSIS (475-YEAR EVENT)

Newmark

Getting Started | Rigorous Rigid-Block Analysis | Simplified Analyses | Record Manager | Utilities | Help

Step 1: Select Records | Step 2: Perform Rigid-Block Analysis | Step 3: View Results

Search records by properties | Select individual records

	Greater than or equal to:	Less than or equal to:
Moment Magnitude	7	8.5
Arias Intensity (m/s)		
Duration (5-95%) (s)		
Peak Acceleration (g)	0.3	0.5
Mean Period (s)		
Epicentral Distance (km)	10	30
Focal Distance (km)		
Rupture Distance (km)		

Search for records

Clear all search fields

Search complete. 11 records found.

Focal Mechanism: ☐ All ☑ Strike-slip ☑ Normal ☑ Reverse ☐ Oblique normal ☐ Oblique reverse

Site Classification: ☐ All ☑ Hard rock ☑ Soft rock ☑ Stiff soil ☐ Soft soil

Records selected (units as indicated above):

Select all for analysis | Deselect all for analysis

Sort by Earthquake then Record A/A

Display properties of: ◉ Records ○ Stations

Earthquake	Record	Magnitude	Arias Int.	Duration	PGA	Mean Per.	Epi. Dist.	Focal Dist.	Rup. Dist.	Foc. Mech.	Analyze
Cape Mendocino...	RIO-270	7.1	1.523	15.3	0.385	0.54	21.9	24.2	18.5	Reverse	☑
Chi-Chi, Taiwan ...	TCU067-000	7.6	2.618	23.0	0.325	0.75	27.6	29.5	0.3	Reverse	☑
Chi-Chi, Taiwan ...	TCU072-000	7.6	4.963	24.0	0.400	0.59	20.5	22.9	7.4	Reverse	☑
Chi-Chi, Taiwan ...	TCU072-270	7.6	5.768	21.9	0.489	0.62	20.5	22.9	7.4	Reverse	☑
Chi-Chi, Taiwan ...	TCU074-000	7.6	3.116	19.7	0.349	0.68	18.7	21.4	13.7	Reverse	☑
Chi-Chi, Taiwan ...	TCU075-270	7.6	2.975	27.0	0.333	0.77	19.7	22.2	1.5	Reverse	☑
Chi-Chi, Taiwan ...	TCU076-000	7.6	3.654	28.1	0.416	0.62	15.3	18.4	2.0	Reverse	☑
Chi-Chi, Taiwan ...	TCU076-270	7.6	3.515	29.5	0.303	0.50	15.3	18.4	2.0	Reverse	☑
El Centro 1940	EC9-180	7.0	1.705	24.1	0.313	0.54	11.4	19.6	8.3	Strike-slip	☑
Tabas, Iran 1978	DAY-LN	7.4	1.424	12.3	0.328	0.33	24.0	48.5	17.0	Reverse	☑
Tabas, Iran 1978	DAY-TR	7.4	1.359	12.4	0.406	0.45	24.0	48.5	17.0	Reverse	☑

Manage groups...

Clear table | Delete highlighted record(s) | Go to Perform Rigid-Block Analysis page

11 of 11 records selected for analysis

TABLE D4. YIELD ACCELERATION AND PGA USED IN THE ANALYSIS (2475-YEAR EVENT)

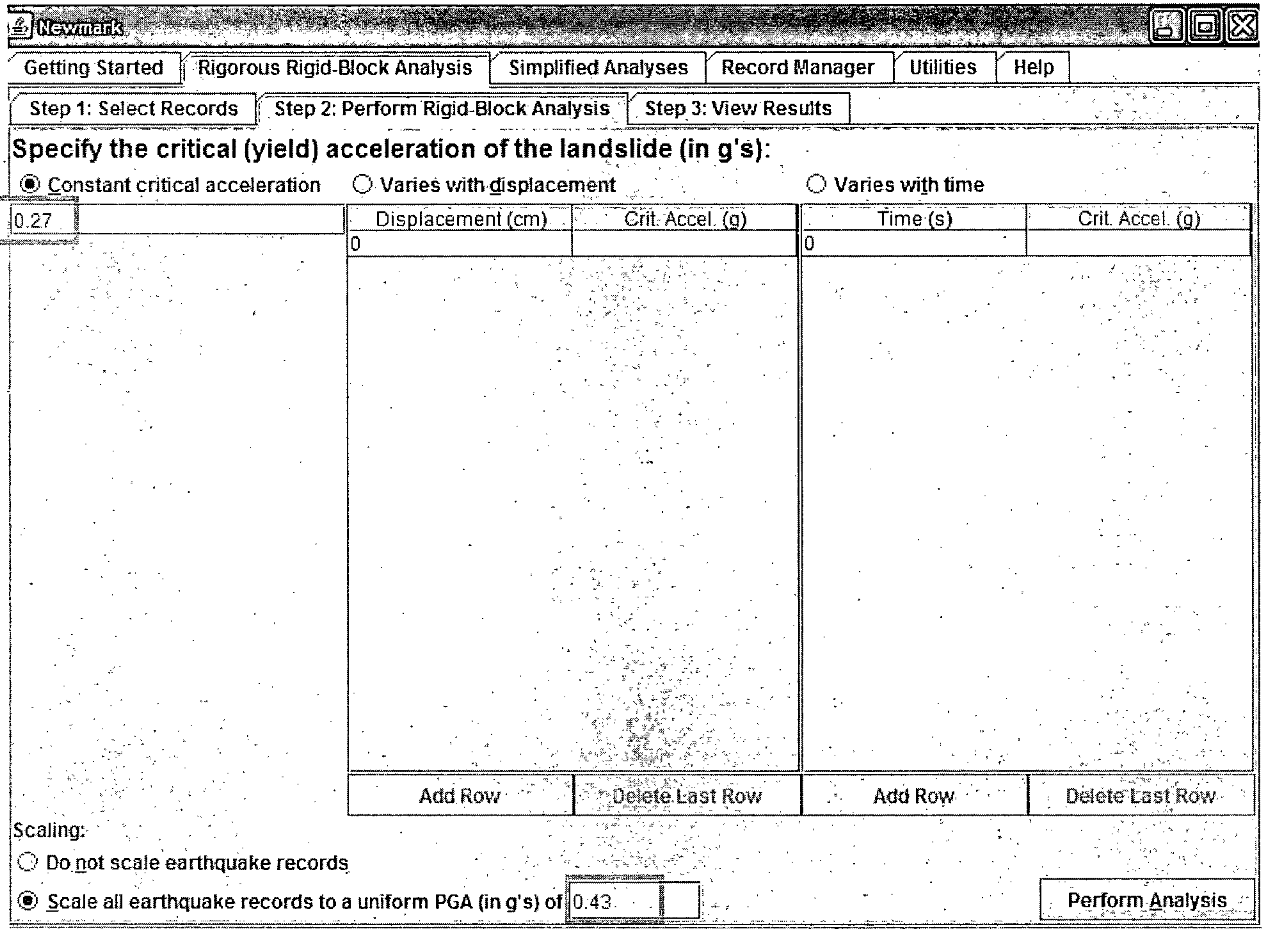
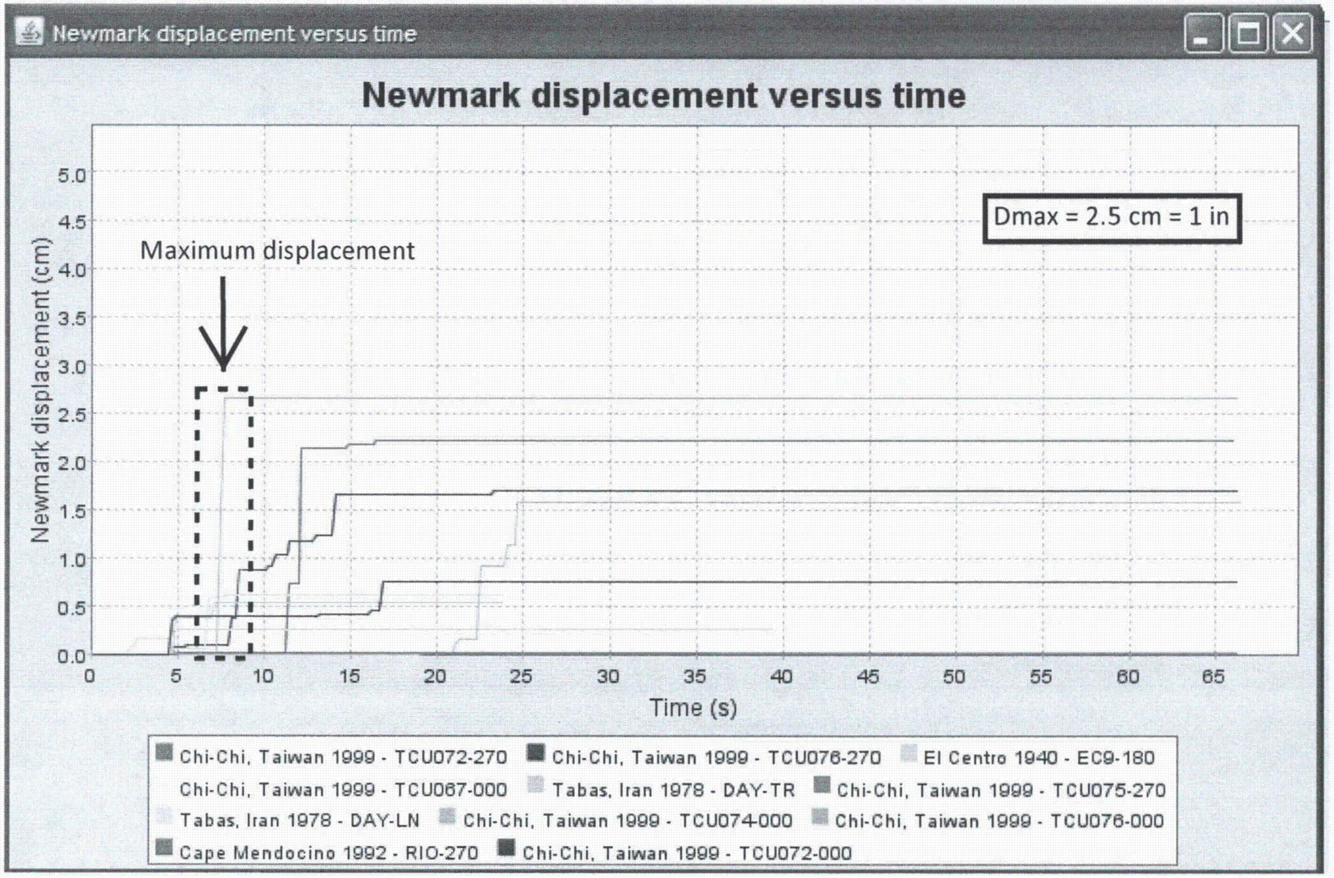


FIGURE D5. SEISMIC-INDUCED DISPLACEMENTS BASED ON NEWMARK ANALYSIS (475-YEAR EVENT)



Attachment E

ESTIMATE OF LIQUEFACTION-INDUCED SETTLEMENT OF THE SLUDGE

Summary:

In this analysis, the amount of post-liquefaction settlement was estimated using the simplified procedures developed by Tokimatsu and Seed (1987) and Ishihara and Yoshimine (1992). Inputs for the Tokimatsu and Seed (1987) and Ishihara and Yoshimine (1992) include the corrected $(N1)_{60}cs$, cyclic stress ratio, and the factor of safety against liquefaction. The liquefaction-induced settlement of a 12-inch thick unstabilized sludge layer is calculated as 0.7 inch or less.

SPT-Based Liquefaction Analysis Using Simplified Procedure and Residual Strength Estimation

475-YEAR EVENT

Project name (number):	Honeywell Metropolis Works Facility
Engineer:	H. Pham
Reviewer:	M. Gavin
Date:	09/17/10

Soil boring number:	N/A	(A)
Approximate borehole diameter (inch):	5.0	(B)
Soil boring ground surface elevation (ft):	380.0	(C)
Groundwater depth during field exploration (ft):	0.0	(D)
Design groundwater depth (ft):	0.0	(E)
Design fill/cut, H (ft): {Positive for fill, negative for cut}	12.0	(F)
Unit weight of fill/cut material (pcf):	125	(G)
SPT hammer energy ratio (ER): {Enter percentage}	60	(H)
Liner used in sampler? {Yes or No}	No	(I)
Peak horizontal ground acceleration (a_{max}/g):	0.43	(J)
Design earthquake magnitude (M):	7.7	(K)
Factor of safety criterion: {1.0 or higher}	1.0	(L)

Hammer Energy Ratios		
Hammer Type	Range[1]	Recommend[2]
Safety	42% - 72%	60%
Donut	30% - 60%	50%
Automatic-Trip	48% - 78%	80%

1) after recommendations by NCEER, 1997
2) for good-quality equipment and procedures conforming to ASTM D-1686.

(1) Interval Bottom Depth (ft)	(2) Interval Soil Type	(3) Total Unit Weight (pcf)	(4) Field SPT N Value N_m	(5) Estimated Fines Content FC (%)	(6a) Relative Density Dr (%)	(6b) Restricted Relative Density D_r (%)	(7) Interval Bottom Elevation (ft)	(8) Interval Thickness (ft)	(9) Effective Unit Weight (pcf)
0									
2	MH	97	6	99	68	68	378.0	2	34.6
4	MH	97	6	99	68	68	376.0	2	34.6
6	MH	97	6	99	68	68	374.0	2	34.6
8	MH	97	6	99	68	68	372.0	2	34.6
10	MH	97	6	99	68	68	370.0	2	34.6
12	MH	97	6	99	68	68	368.0	2	34.6
14	MH	97	6	99	68	68	366.0	2	34.6
16	MH	97	6	99	68	68	364.0	2	34.6

(1) Interval Bottom Depth (ft)	(10) Field Total Overburden (tsf)	(11) Design Total Overburden (tsf)	(12) Field Effective Overburden (tsf)	(13) Design Effective Overburden (tsf)	(14) Effective Overburden Correction C_N	(15) Hammer Energy Correction C_E	(16) Borehole Diameter Correction C_B	(17) Rod Length Correction C_R	(18) Sampling Method Correction C_S
0	0	0.750	0	0.750					
2	0.097	0.847	0.035	0.785	1.70	1.00	1.02	0.75	1.10
4	0.194	0.944	0.069	0.819	1.70	1.00	1.02	0.75	1.10
6	0.291	1.041	0.104	0.854	1.69	1.00	1.02	0.75	1.10
8	0.388	1.138	0.138	0.888	1.65	1.00	1.02	0.75	1.10
10	0.485	1.235	0.173	0.923	1.61	1.00	1.02	1.00	1.10
12	0.582	1.332	0.208	0.958	1.58	1.00	1.02	1.00	1.10
14	0.679	1.429	0.242	0.992	1.54	1.00	1.02	1.00	1.10
16	0.776	1.526	0.277	1.027	1.51	1.00	1.02	1.00	1.10

↑ Properties of the consolidated sludge

475-YEAR EVENT

(19) Energy Correction Only N_{60}	(20) No Fines Correction $(N_1)_{60}$	(21) Clean Sand $(N_1)_{60cs}$	(22) Stress Reduction Coefficient r_d	(23) Cyclic Stress Ratio CSR	(24) Cyclic Resistance Ratio $CRR_{7.5}$	(25) CRR Overburden Correction f	(26) CRR Overburden Correction K_σ	(27) CRR Static Shear Correction K_α	(28) Magnitude Scaling Factor MSF	(29) Factor of Safety FS	(30) Liquefaction Susceptibility	(31) Comments	(32) Residual Undrained Strength, S_r (tsf): Idriss (1999)	(33) Olson & Stark (2002)	(34) Idriss & Boulanger (2007)	(35) Kramer (2008)	(36) Weighted Average
6	9	15	0.97	0.292	0.163	0.66	1.00	1.00	0.93	0.52	NO	Plastic soil evaluation needed					
6	9	15	0.96	0.310	0.163	0.66	1.00	1.00	0.93	0.49	NO	Plastic soil evaluation needed					
6	9	15	0.96	0.326	0.163	0.66	1.00	1.00	0.93	0.47	NO	Plastic soil evaluation needed					
6	8	15	0.95	0.341	0.160	0.66	1.00	1.00	0.93	0.44	NO	Plastic soil evaluation needed					
6	11	18	0.95	0.355	0.193	0.66	1.00	1.00	0.93	0.51	NO	Plastic soil evaluation needed					
6	11	18	0.94	0.367	0.189	0.66	1.00	1.00	0.93	0.48	NO	Plastic soil evaluation needed					
6	10	17	0.94	0.378	0.186	0.66	1.00	1.00	0.93	0.46	NO	Plastic soil evaluation needed					
6	10	17	0.93	0.388	0.183	0.66	1.00	1.00	0.93	0.44	NO	Plastic soil evaluation needed					

Inputs for liquefaction-induced settlement calculations

SPT-Based Liquefaction Analysis Using Simplified Procedure and Residual Strength Estimation

2475-YEAR EVENT

Project name (number):	Honeywell Metropolis Works Facility
Engineer:	H. Pham
Reviewer:	M. Gavin
Date:	07/21/10

Soil boring number:	N/A	(A)
Approximate borehole diameter (inch):	5.0	(B)
Soil boring ground surface elevation (ft):	380.0	(C)
Groundwater depth during field exploration (ft):	0.0	(D)
Design groundwater depth (ft):	0.0	(E)
Design fill/cut, H (ft): {Positive for fill, negative for cut}	12.0	(F)
Unit weight of fill/cut material (pcf):	125	(G)
SPT hammer energy ratio (ER): {Enter percentage}	60	(H)
Liner used in sampler? {Yes or No}	No	(I)
Peak horizontal ground acceleration (a_{max}/g):	1.00	(J)
Design earthquake magnitude (M):	7.7	(K)
Factor of safety criterion: {1.0 or higher}	1.0	(L)

Hammer Energy Ratios

Hammer Type	Range[1]	Recommend[2]
Safety	42% - 72%	60%
Donut	30% - 60%	50%
Automatic-Trip	48% - 78%	80%

1) after recommendations by NCEER, 1997
2) for good-quality equipment and procedures conforming to ASTM D-1686.

(1) Interval Bottom Depth (ft)	(2) Interval Soil Type	(3) Total Unit Weight (pcf)	(4) Field SPT N Value N_m	(5) Estimated Fines Content FC (%)	(6a) Relative Density D_r (%)	(6b) Restricted Relative Density D_r (%)	(7) Interval Bottom Elevation (ft)	(8) Interval Thickness (ft)	(9) Effective Unit Weight (pcf)	(10) Field Total Overburden (tsf)	(11) Design Total Overburden (tsf)	(12) Field Effective Overburden (tsf)	(13) Design Effective Overburden (tsf)	(14) Effective Overburden Correction C_N	(15) Hammer Energy Correction C_E	(16) Borehole Diameter Correction C_B	(17) Rod Length Correction C_R	(18) Sampling Method Correction C_S
0										0	0.750	0	0.750					
2	MH	97	6	99	68	68	378.0	2	34.6	0.097	0.847	0.035	0.785	1.70	1.00	1.02	0.75	1.10
4	MH	97	6	99	68	68	376.0	2	34.6	0.194	0.944	0.069	0.819	1.70	1.00	1.02	0.75	1.10
6	MH	97	6	99	68	68	374.0	2	34.6	0.291	1.041	0.104	0.854	1.69	1.00	1.02	0.75	1.10
8	MH	97	6	99	68	68	372.0	2	34.6	0.388	1.138	0.138	0.888	1.65	1.00	1.02	0.75	1.10
10	MH	97	6	99	68	68	370.0	2	34.6	0.485	1.235	0.173	0.923	1.61	1.00	1.02	1.00	1.10
12	MH	97	6	99	68	68	368.0	2	34.6	0.582	1.332	0.208	0.958	1.58	1.00	1.02	1.00	1.10
14	MH	97	6	99	68	68	366.0	2	34.6	0.679	1.429	0.242	0.992	1.54	1.00	1.02	1.00	1.10
16	MH	97	6	99	68	68	364.0	2	34.6	0.776	1.526	0.277	1.027	1.51	1.00	1.02	1.00	1.10

↑ Properties of the consolidated sludge

(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
													Residual Undrained Strength, S_r (tsf)				
Energy Correction Only N_{60}	No Fines Correction $(N_1)_{60}$	Clean Sand $(N_1)_{60cs}$	Stress Reduction Coefficient r_d	Cyclic Stress Ratio CSR	Cyclic Resistance Ratio $CRR_{7.5}$	CRR Overburden Correction f	K_σ	CRR Static Shear Correction K_α	Magnitude Scaling Factor MSF	Factor of Safety FS	Liquefaction Susceptibility	Comments	Idriss (1999)	Olson & Stark (2002)	Idriss & Boulanger (2007)	Kramer (2008)	Weighted Average
6	9	15	0.97	0.679	0.163	0.66	1.00	1.00	0.93	0.22	NO	Plastic soil evaluation needed					
6	9	15	0.96	0.721	0.163	0.66	1.00	1.00	0.93	0.21	NO	Plastic soil evaluation needed					
6	9	15	0.96	0.759	0.163	0.66	1.00	1.00	0.93	0.20	NO	Plastic soil evaluation needed					
6	8	15	0.95	0.794	0.160	0.66	1.00	1.00	0.93	0.19	NO	Plastic soil evaluation needed					
6	11	18	0.95	0.825	0.193	0.66	1.00	1.00	0.93	0.22	NO	Plastic soil evaluation needed					
6	11	18	0.94	0.854	0.189	0.66	1.00	1.00	0.93	0.21	NO	Plastic soil evaluation needed					
6	10	17	0.94	0.879	0.186	0.66	1.00	1.00	0.93	0.20	NO	Plastic soil evaluation needed					
6	10	17	0.93	0.903	0.183	0.66	1.00	1.00	0.93	0.19	NO	Plastic soil evaluation needed					

Inputs for liquefaction-induced settlement calculations

LIQUEFACTION-INDUCED SETTLEMENT

Project: Honeywell Metropolis Works Facility
Boring # N/A
Date: 9/17/2010
Engineer: H. Pham

475-YEAR EVENT

Settlement (in)	3	Tokimatsu and Seed (1987)	Ave. Sett. (inch)	4
	5	Ishihara and Yosemine (1990)		

Soil Unit	Depth (ft)	N1(60)cs	FOS for Liq. Potential	CSR	Thickness (ft)	CSR Reduction Factor (rd)	I&Y Vertical Strain	I&Y Incremental Sett. (inches)	I&Y Total Sett. (inches)	T&S Vertical Strain	T&S Incremental Sett. (inches)	T&S Total Sett. (inches)
Sludge	2	15	0.52	0.29	2	1.00	0.027	0.636	4.872	0.019	0.456	3.396
Sludge	4	15	0.49	0.31	2	0.99	0.027	0.636	4.236	0.019	0.456	2.940
Sludge	6	15	0.47	0.33	2	0.99	0.027	0.636	3.600	0.019	0.456	2.484
Sludge	8	15	0.44	0.34	2	0.98	0.027	0.636	2.964	0.019	0.456	2.028
Sludge	10	18	0.51	0.35	2	0.98	0.024	0.564	2.328	0.016	0.384	1.572
Sludge	12	18	0.48	0.37	2	0.97	0.025	0.588	1.764	0.017	0.396	1.188
Sludge	14	17	0.46	0.38	2	0.97	0.025	0.588	1.176	0.017	0.396	0.792
Sludge	16	17	0.44	0.39	2	0.96	0.025	0.588	0.588	0.017	0.396	0.396

Note: Input data is highlighted in yellow. See the liquefaction-potential spreadsheet for N1(60)cs, FOS for Liquefaction Potential, and CSR values.

Note: Liquefaction-induced settlements for a 6-inch unstabilized sludge layer was estimated between 0.1 and 0.2 inch

2475-YEAR EVENT

Settlement (in)	3	Tokimatsu and Seed (1987)	Ave. Sett. (inch)	4
	5	Ishihara and Yosemine (1990)		

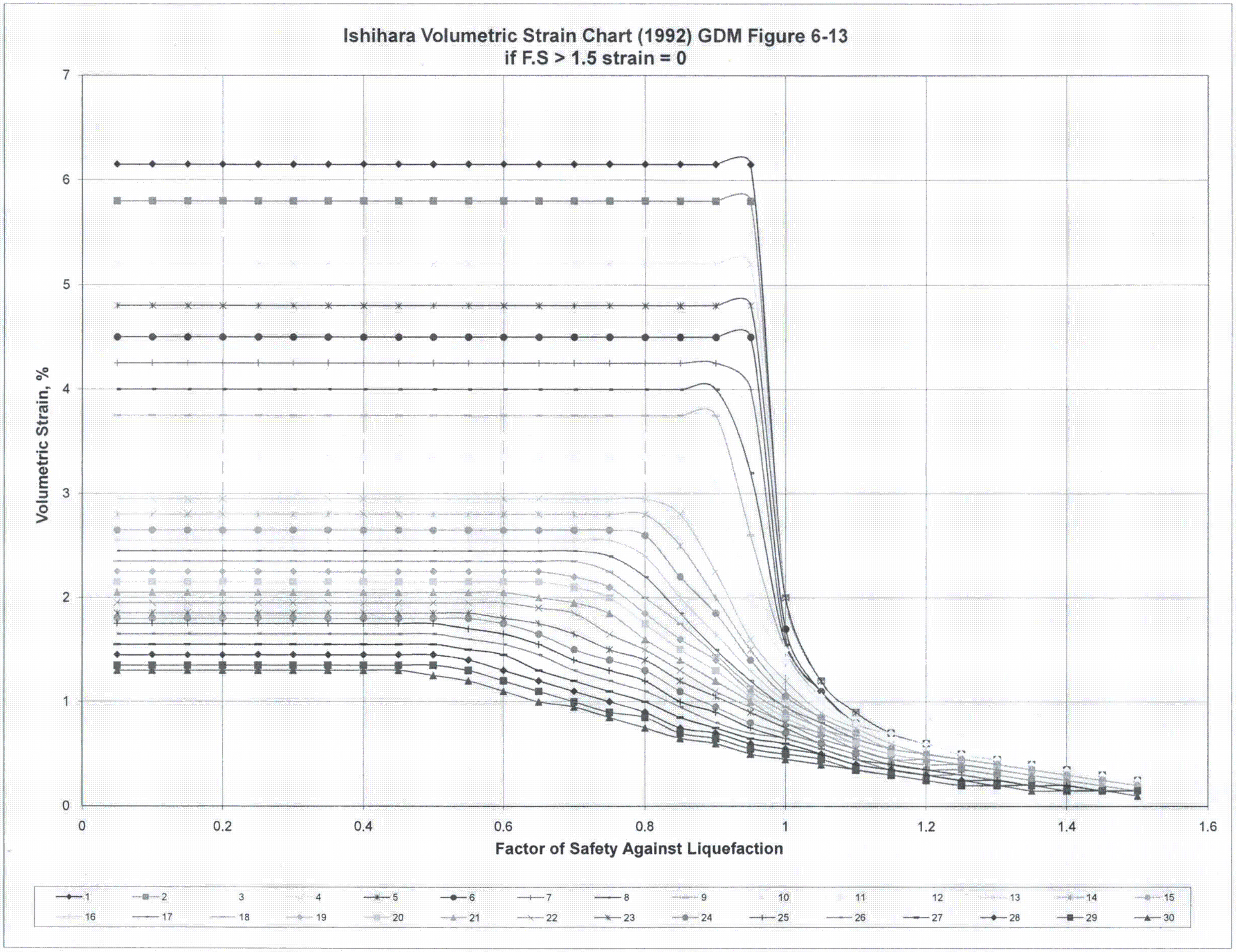
← Settlement is unchanged when FS is too low or CSR is too high (see the next 2 figures)

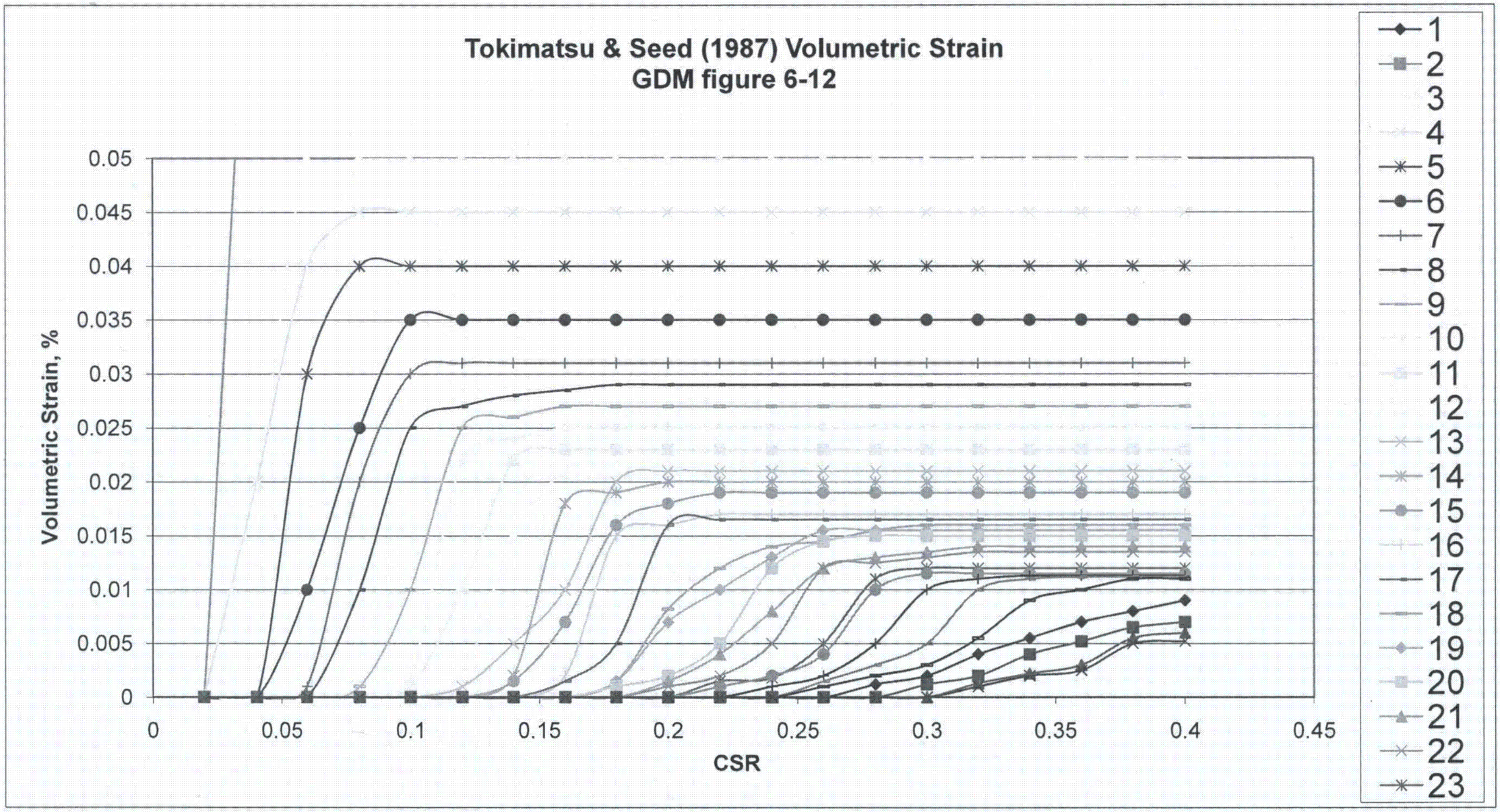
Soil Unit	Depth (ft)	N1(60)cs	FOS for Liq. Potential	CSR	Thickness (ft)	CSR Reduction Factor (rd)	I&Y Vertical Strain	I&Y Incremental Sett. (inches)	I&Y Total Sett. (inches)	T&S Vertical Strain	T&S Incremental Sett. (inches)	T&S Total Sett. (inches)
Sludge	2	15	0.22	0.68	2	1.00	0.027	0.636	4.872	0.019	0.456	3.396
Sludge	4	15	0.21	0.72	2	0.99	0.027	0.636	4.236	0.019	0.456	2.940
Sludge	6	15	0.20	0.76	2	0.99	0.027	0.636	3.600	0.019	0.456	2.484
Sludge	8	15	0.19	0.79	2	0.98	0.027	0.636	2.964	0.019	0.456	2.028
Sludge	10	18	0.22	0.83	2	0.98	0.024	0.564	2.328	0.016	0.384	1.572
Sludge	12	18	0.21	0.85	2	0.97	0.025	0.588	1.764	0.017	0.396	1.188
Sludge	14	17	0.20	0.88	2	0.97	0.025	0.588	1.176	0.017	0.396	0.792
Sludge	16	17	0.19	0.90	2	0.96	0.025	0.588	0.588	0.017	0.396	0.396

Note: Input data is highlighted in yellow. See the liquefaction-potential spreadsheet for N1(60)cs, FOS for Liquefaction Potential, and CSR values.

Note: Liquefaction-induced settlements for a 6-inch unstabilized sludge layer was estimated between 0.1 and 0.2 inch

Average post-liquefaction axial strain: 4/(16*12) = 0.02


Ishihara Volumetric Strain Chart (1992) GDM Figure 6-13
if F.S > 1.5 strain = 0
Volumetric Strain, %
Factor of Safety Against Liquefaction
0
1
2
3
4
5
6
7
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

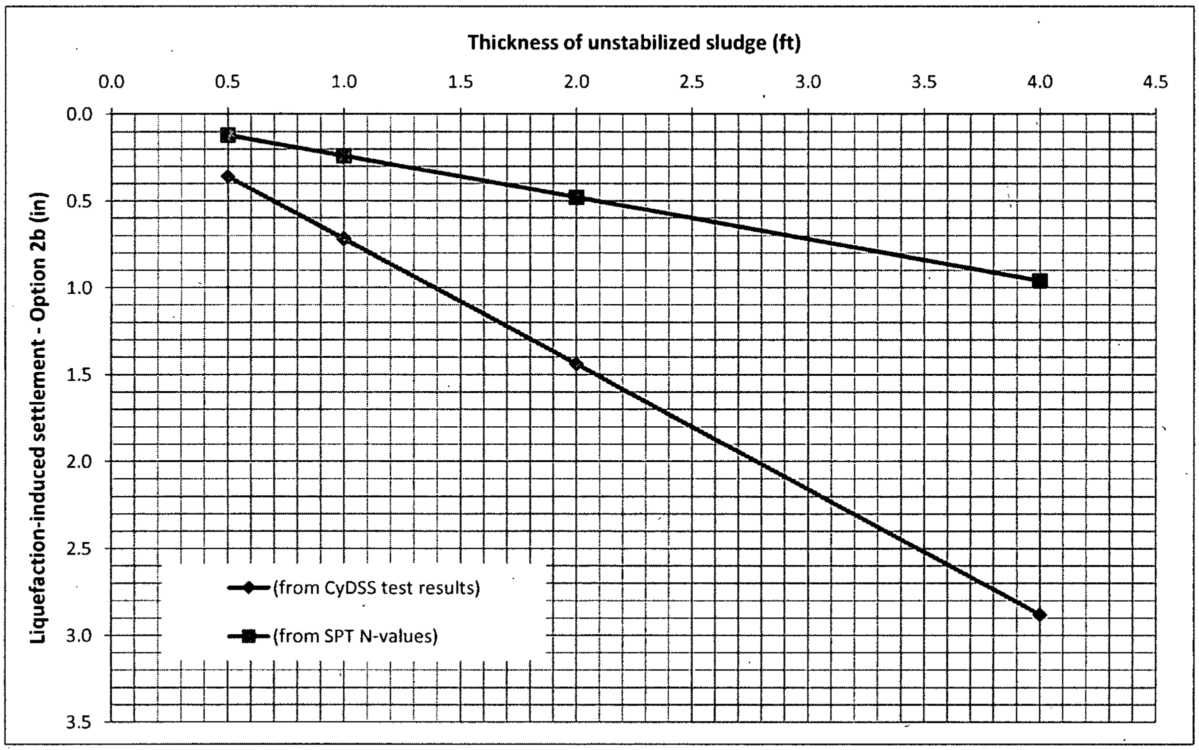


Tokimatsu & Seed (1987) Volumetric Strain
GDM figure 6-12
Volumetric Strain, %
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
CSR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Liquefaction-induced settlement

Lower bound axial strain:	0.02	(from SPT N-values)	
Upper bound axial strain:	0.06	(from CyDSS test results)	

Option	Thickness of unstabilized sludge	Upper bound liquefaction-induced settlement	Upper bound liquefaction-induced settlement
(--)	(ft)	(in)	(in)
2b	0.5	0.4	0.1
	1	0.7	0.2
	2	1.4	0.5
	4	2.9	1.0



Attachment F

ESTIMATE OF CONSOLIDATION-INDUCED SETTLEMENT OF THE SLUDGE

Summary:

Consolidation settlement of the unstabilized sludge was estimated using the Terzaghi's one-dimensional

consolidation theory. The sludge was assumed to be normally consolidated. Consolidation settlement as a function of the thickness of unstabilized sludge was developed. The consolidation (static) settlement of a 12-inch thick unstabilized sludge layer is calculated as less than 0.5 inch, which should develop prior to construction of the final cover.

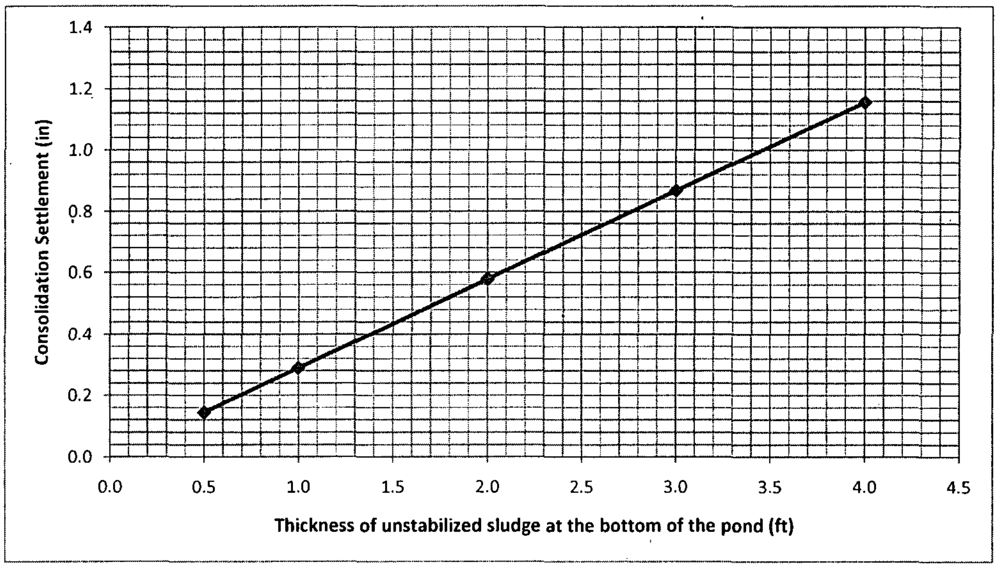
Total settlement (liquefaction-induced plus consolidation) of a 12-inch thick unstabilized sludge layer is calculated as 1 inch or less.

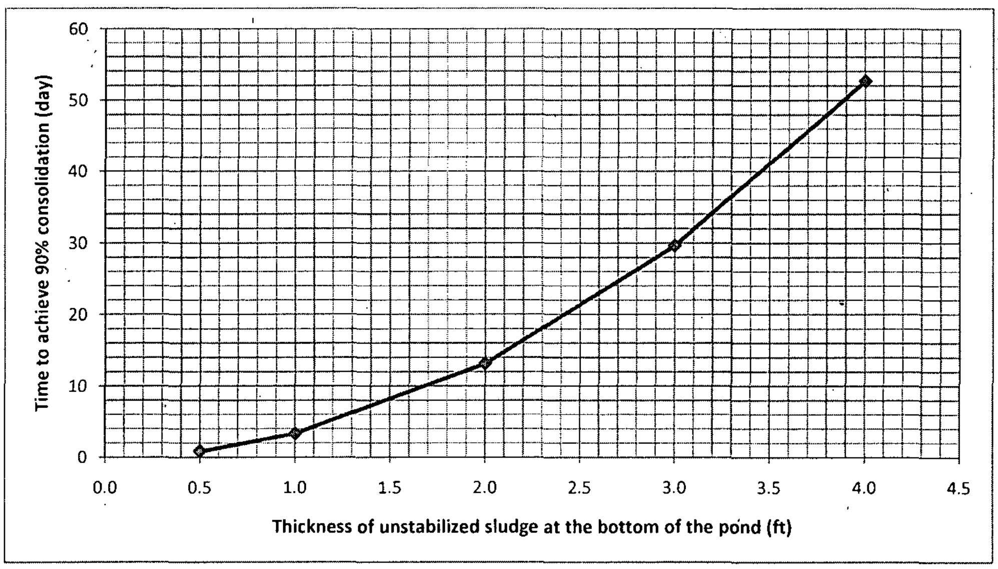
Honeywell Metropolis Works Facility

Consolidation Settlement of the Unstabilized Sludge at the Bottom of the Pond (Option 2b)

Unit Weight of Cover Soil (pcf):	125
Thickness of Cover Soil (ft):	9
Surcharge (psf):	1125
Compression Index (C_{ce}) of Sludge:	0.05
Coefficient of Consolidation (C_v - in2/sec):	4.30E-04
Initial Overburden Stress (σ'_v) at the Bottom of Pond (psf):	554

Thickness of Unstabilized Sludge (ft)	Consolidation Settlement (in)	Time to Achieve 90% Consolidation (day)
0.5	0.1	0.8
1	0.3	3.3
2	0.6	13.1
3	0.9	29.6
4	1.2	52.6





Appendix C-2
Cover System Calculations

CH2MHILL

Calculation

Calculation No.: CALC-388996-CVR-01 **Revision No.:** 1

Project: Honeywell Metropolis Works Facility (388996.HW.T6)

Engineering Discipline: Cover System Geosynthetics **Date:** 10/7/2010

Calculation Title & Description:

Title: Closure Option 2b –Geosynthetic and soil materials calculations for the cover system of the closed surface impoundments (Ponds, B, C, D, and E) at the Honeywell Metropolis Works Facility.

Description: This calculation package includes veneer stability, anchor trench pullout, wind uplift, and filter calculations for the cover system soils and geosynthetics.

Revision History:

Revision No.	Description	Date	Affected Pages
1	Previous interface friction angle for veneer stability analysis was too conservative and not representative of the actual case. Interface strength parameters have been revised. Geometry of slope was not accurate as grades have changed slightly since original calculation was performed. This has been revised.	10/7/2010	5 - 10

Document Review & Approval:

Originator: John H. Barker, P.E./Associate Engineer
NAME/POSITION

[signature]
SIGNATURE

10-7-2010
DATE

Checked: Jay Dehner, P.E./Principal Project Manager
NAME/POSITION

[signature]
SIGNATURE

10-7-2010
DATE

1. Objective:

The objective of this calculation is to evaluate the cover system components and determine the compatibility between materials (soils and geosynthetics) as well as evaluate constructability components of the cover system and determine the suitability of a particular aggregate size for use in the filter layer within the cover system.

2. Design Standards and Criteria:

The following design standards were used as main references in our analyses and development of our recommendations:

- Illinois Administrative Code 742
- Resource Recovery and Conservation Act (RCRA) Guidance Document: Surface Impoundments, Liner Systems, Final Cover, and Freeboard Control, July 1982

The following design criteria were considered in evaluating the cover system components:

- Provide long-term minimization of the migration of liquids through the closed impoundment
- Function with minimum maintenance
- Promote drainage and minimize erosion or abrasion of the final cover
- Accommodate settling and subsidence so that the integrity of the cover is maintained
- Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present.

3. Methodology and Assumptions:

The following lists assumptions made in the evaluation of the cover system:

- Common fill within the cover system will consist of borrowed on-site clay and silt, with characteristics similar to those shown in the laboratory testing results provided by Testing Service Corporation, on July 27, 2009.
- The filter layer material will be tested prior to placement such that it is free of chemicals that would leach calcium-laden fluids when wetted.
- Design for seismic deformation is under a scenario where the lower sand layer beneath the ponds is partially liquefied. Seismic deformation causes the mass (covered ponds) to act as a rigid block, meaning localized deformation is not considered but some cracks and surface deformations may occur within the mass.

4. Results and Conclusions

The following are our main findings based on the results of our analyses:

- During construction, the proposed slopes are stable from a veneer stability perspective. Meaning the interface shear strength between the soil-geosynthetics and between different geosynthetics, as well as the internal shear strength of the materials is suitable to support construction loading without slipping at the design cover slope.
- Anchor trenches for the GCL and geomembrane liner should be sized at 2 feet deep by 2 feet wide at the bottom to provide adequate pullout resistance during construction. Wind speeds in excess of 50 miles per hour may create an uplift force that will remove the geomembrane from the anchor trench if the entire slope length is exposed.
- Illinois Department of Transportation Fine Aggregate class FA1 appears to be suitable for the material to be used in the filter layer; further gradation testing of the common fill should be completed to evaluate the filter requirements.

5. List of Attachments

A. Veneer Stability

B. Anchor Trench Pullout and Wind Uplift

C. Filter Calculation

6. Additional References

The Aggregate Handbook. 1991.National Stone Association, Washington, D.C. Edited by Richard D. Barksdale

Druschel, S.J., and Underwood, E.R. (1993). Design of Lining and Cover System Sideslopes. *Geosynthetics '93. North American Conference Proceedings.* Held March 31 – April 1, 1993, Vancouver, British Columbia, Canada.

Koerner, R.M. 1986. *Designing with Geosynthetics.* 424 p. Prentice-Hall Publishing Co., Englewood Cliffs, N.J.

Richardson, G.N. (2000) "Exposed Geomembrane Covers: Part 1 - Geomembrane Stresses." *GFR Magazine.* Volume 18, Number 7.

United States Environmental Protection Agency. (1989). Requirements for Hazardous Waste Landfill Design, Construction, and Closure. *Seminar Publication, EPA/625/4-89/022, Chapter 3 Flexible Membrane Liners.*

Attachment A

VENEER STABILITY

Method Reference: Druschel, S.J., and Underwood, E.R. (1993). "Design of Lining and Cover System Sideslopes," accepted for publication and presentation, Geosynthetics '93 Conference, Industrial Fabrics Association International, Vancouver, B.C.

The purpose of this calculation is to evaluate the factor of safety (FOS) for the proposed configuration. The factor of safety of the slope may be varied so that the anchorage force (F_a) is slightly greater than or equal to zero.

Check Three Analysis Cases
Case 1 - No equipment load, no seepage force - Target FOS = 1.5
Case 2 - Equipment load, no seepage force - Target FOS = 1.3
Case 3 - Equipment load, seepage force - Target FOS = 1.1

Task: Honeywell Cover System - Case 1
Description: 4% cover slopes. Filter layer placed on geosynthetics is a fine aggregate with drainage characteristics.

Input Variables

Cover Soil Total Unit Weight	$\gamma_c := 120\text{pcf}$	*Cover Soil Thickness*	$T_c := 3\text{ft}$
Unit Weight of Water	$\gamma_w := 62.4\text{pcf}$	*Seepage Thickness*	$T_w := 0\text{ft}$
Slope Angle	$\beta := 2.3\text{deg}$	*Slope Height*	$H := 6\text{ft}$
Soil Shear Strength Angle	$\phi := 30\text{deg}$	*Interface Friction Angle*	$\delta := 30\text{deg}$
Equipment Weight	$W_e := 0\dfrac{\text{lbf}}{\text{ft}}$	*Low strength interface is residual internal soil.*	

Factor of Safety $\quad FOS := 19.2 \quad$ *Vary Friction Angle to find minimum positive anchorage force*

Mobilized Friction Angles

$$\phi_m := \text{atan}\left(\frac{\tan(\phi)}{FOS}\right) \qquad \phi_m = 1.72\cdot\text{deg} \qquad \delta_m := \text{atan}\left(\frac{\tan(\delta)}{FOS}\right) \qquad \delta_m = 1.72\cdot\text{deg}$$

Toe Buttress

$$W_1 := \frac{\gamma_c\cdot T_c^{\,2}}{2\cdot\sin(\beta)\cdot\cos(\beta)} \qquad W_1 = 1.35\times 10^4\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of toe buttress soil

Soil Cover

$$W_2 := \frac{\gamma_c\cdot T_c}{\sin(\beta)}\cdot\left(H - \frac{T_c}{2\cdot\cos(\beta)}\right) \qquad W_2 = 40356.15\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of sideslope soil

Braking Force

$F_b := 0.3 \cdot W_e$ $\qquad F_b = 0 \cdot \frac{lbf}{ft}$ $\qquad$ *braking force equal to 30% of the equipment weight*

Seepage Force

$$W_{W1} := \frac{\gamma_w \cdot T_w^2}{2 \cdot \sin(\beta) \cdot \cos(\beta)} \qquad W_{W1} = 0 \cdot \frac{lbf}{ft}$$ *weight of seepage water in toe buttress*

$$W_{W2} := \frac{\gamma_w \cdot T_w}{\sin(\beta)} \cdot \left(H - \frac{T_w}{2 \cdot \cos(\beta)}\right) \qquad W_{W2} = 0 \cdot \frac{lbf}{ft}$$ *weight of seepage water in sideslope soil*

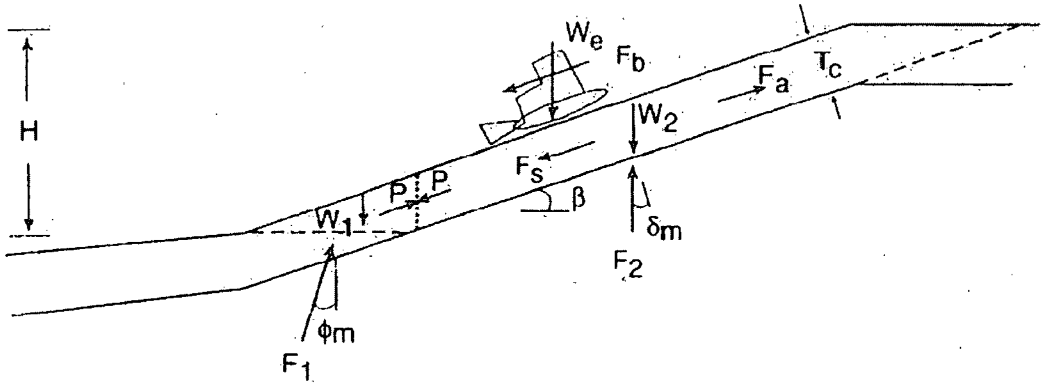
$$F_s := W_{W1} \cdot \tan(\phi_m) + W_{W2} \cdot \cos(\beta) \cdot \tan(\delta_m) \qquad F_s = 0 \cdot \frac{lbf}{ft}$$

Anchorage Force

$$F_a := F_b + F_s + \frac{(W_e + W_2) \cdot \sin(\beta - \delta_m)}{\cos(\delta_m)} - \frac{W_1 \cdot \sin(\phi_m)}{\cos(\beta + \phi_m)} \qquad F_a = 1.26 \cdot \frac{lbf}{ft} \qquad FOS = 19.2$$

Check Anchorage Force

Check := if($F_a \geq 0$, "OK" , "No Good") $\qquad$ Check = "OK"



Note: P, F_s, F_a, and F_b, are assumed to be parallel to β

Figure 1. Sideslope with Typical Forces

Method Reference: Druschel, S.J., and Underwood, E.R. (1993). "Design of Lining and Cover System Sideslopes," accepted for publication and presentation, Geosynthetics '93 Conference, Industrial Fabrics Association International, Vancouver, B.C.

The purpose of this calculation is to evaluate the factor of safety for the proposed configuration. The factor of safety of the slope may be varied so that the anchorage force (F_a) is slightly greater than or equal to zero.

<u>Check Three Analysis Cases</u>
Case 1 - No equipment load, no seepage force - Target FOS = 1.5
Case 2 - Equipment load, no seepage force - Target FOS = 1.3
Case 3 - Equipment load, seepage force - Target FOS = 1.1

<u>Task: Honeywell Cover System - Case 2</u>
Description: 4% cover slopes. Filter layer placed on geosynthetics is a fine aggregate with drainage characteristics.

<u>Input Variables</u>

Cover Soil Total Unit Weight	$\gamma_c := 120\text{pcf}$	*Cover Soil Thickness*	$T_c := 3\text{ft}$
Unit Weight of Water	$\gamma_w := 62.4\text{pcf}$	*Seepage Thickness*	$T_w := 0\text{ft}$
Slope Angle	$\beta := 2.3\text{deg}$	*Slope Height*	$H := 6\text{ft}$
Soil Shear Strength Angle	$\phi := 30\text{deg}$	*Interface Friction Angle*	$\delta := 30\text{deg}$
Equipment Weight	$W_e := 4400\dfrac{\text{lbf}}{\text{ft}}$	*Caterpillar D6 weight divided by equipment width*	

Factor of Safety $FOS := 10.8$ *Vary Friction Angle to find minimum positive anchorage force*

<u>Mobilized Friction Angles</u>

$$\phi_m := \text{atan}\left(\frac{\tan(\phi)}{FOS}\right) \quad \phi_m = 3.06\cdot\text{deg} \qquad \delta_m := \text{atan}\left(\frac{\tan(\delta)}{FOS}\right) \quad \delta_m = 3.06\cdot\text{deg}$$

<u>Toe Buttress</u>

$$W_1 := \frac{\gamma_c \cdot T_c^{\,2}}{2\cdot\sin(\beta)\cdot\cos(\beta)} \qquad W_1 = 1.35\times 10^4\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of toe buttress soil

<u>Soil Cover</u>

$$W_2 := \frac{\gamma_c\cdot T_c}{\sin(\beta)}\cdot\left(H - \frac{T_c}{2\cdot\cos(\beta)}\right) \qquad W_2 = 40356.15\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of sideslope soil

Braking Force

$F_b := 0.3 \cdot W_e$ $\quad$ $F_b = 1320 \cdot \frac{lbf}{ft}$ $\quad$ *braking force equal to 30% of the equipment weight*

Seepage Force

$$W_{W1} := \frac{\gamma_w \cdot T_w^2}{2 \cdot \sin(\beta) \cdot \cos(\beta)} \qquad W_{W1} = 0 \cdot \frac{lbf}{ft}$$ *weight of seepage water in toe buttress*

$$W_{W2} := \frac{\gamma_w \cdot T_w}{\sin(\beta)} \cdot \left(H - \frac{T_w}{2 \cdot \cos(\beta)}\right) \qquad W_{W2} = 0 \cdot \frac{lbf}{ft}$$ *weight of seepage water in sideslope soil*

$$F_s := W_{W1} \cdot \tan(\phi_m) + W_{W2} \cdot \cos(\beta) \cdot \tan(\delta_m) \qquad F_s = 0 \cdot \frac{lbf}{ft}$$

Anchorage Force

$$F_a := F_b + F_s + \frac{(W_e + W_2) \cdot \sin(\beta - \delta_m)}{\cos(\delta_m)} - \frac{W_1 \cdot \sin(\phi_m)}{\cos(\beta + \phi_m)} \qquad F_a = 3.45 \cdot \frac{lbf}{ft} \qquad FOS = 10.8$$

Check Anchorage Force

Check := if($F_a \geq 0$, "OK", "No Good") $\quad$ Check = "OK"

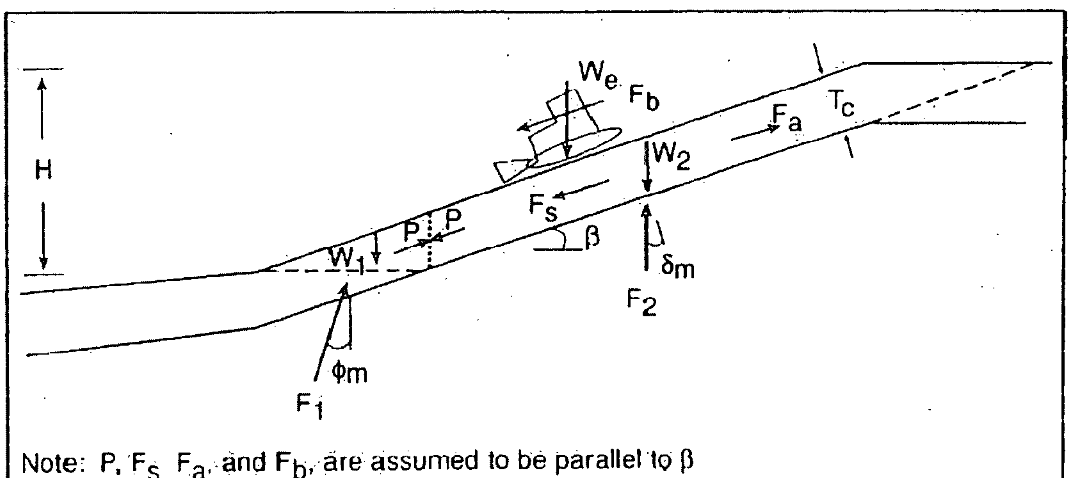


Figure 1. Sideslope with Typical Forces

Method Reference: Druschel, S.J., and Underwood, E.R. (1993). "Design of Lining and Cover System Sideslopes," accepted for publication and presentation, Geosynthetics '93 Conference, Industrial Fabrics Association International, Vancouver, B.C.

The purpose of this calculation is to evaluate the factor of safety for the proposed configuration. The factor of safety of the slope may be varied so that the anchorage force (F_a) is slightly greater than or equal to zero.

Check Three Analysis Cases
Case 1 - No equipment load, no seepage force - Target FOS = 1.5
Case 2 - Equipment load, no seepage force - Target FOS = 1.3
Case 3 - Equipment load, seepage force - Target FOS = 1.1

Task: Honeywell Cover System - Case 3
Description: 4% cover slopes. Filter layer placed on geosynthetics is a fine aggregate with drainage characteristics.

Input Variables

Cover Soil Total Unit Weight	$\gamma_c := 120\text{pcf}$	*Cover Soil Thickness*	$T_c := 3\text{ft}$
Unit Weight of Water	$\gamma_w := 62.4\text{pcf}$	*Seepage Thickness*	$T_w := 2\text{in}$
Slope Angle	$\beta := 2.3\text{deg}$	*Slope Height*	$H := 6\text{ft}$
Soil Shear Strength Angle	$\phi := 30\text{deg}$	*Interface Friction Angle*	$\delta := 30\text{deg}$
Equipment Weight	$W_e := 4400\frac{\text{lbf}}{\text{ft}}$	*Caterpillar D6 weight divided by equipment width*	
Factor of Safety	$FOS := 10.6$	*Vary Friction Angle to find minimum positive anchorage force*	

Mobilized Friction Angles

$\phi_m := \text{atan}\left(\frac{\tan(\phi)}{FOS}\right)$ $\quad \phi_m = 3.12\cdot\text{deg}$ $\qquad \delta_m := \text{atan}\left(\frac{\tan(\delta)}{FOS}\right)$ $\quad \delta_m = 3.12\cdot\text{deg}$

Toe Buttress

$$W_1 := \frac{\gamma_c \cdot T_c^{\,2}}{2\cdot\sin(\beta)\cdot\cos(\beta)} \qquad W_1 = 1.35\times10^{4}\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of toe buttress soil

Soil Cover

$$W_2 := \frac{\gamma_c \cdot T_c}{\sin(\beta)}\cdot\left(H - \frac{T_c}{2\cdot\cos(\beta)}\right) \qquad W_2 = 40356.15\cdot\frac{\text{lbf}}{\text{ft}}$$

weight of sideslope soil

Braking Force

$F_b := 0.3 \cdot W_e$ $\quad F_b = 1320 \cdot \frac{lbf}{ft}$ *braking force equal to 30% of the equipment weight*

Seepage Force

$W_{W1} := \frac{\gamma_w \cdot T_w^2}{2 \cdot \sin(\beta) \cdot \cos(\beta)}$ $\quad W_{W1} = 21.61 \cdot \frac{lbf}{ft}$ *weight of seepage water in toe buttress*

$W_{W2} := \frac{\gamma_w \cdot T_w}{\sin(\beta)} \cdot \left(H - \frac{T_w}{2 \cdot \cos(\beta)}\right)$ $\quad W_{W2} = 1533.26 \cdot \frac{lbf}{ft}$ *weight of seepage water in sideslope soil*

$F_s := W_{W1} \cdot \tan(\phi_m) + W_{W2} \cdot \cos(\beta) \cdot \tan(\delta_m)$ $\quad F_s = 84.622 \cdot \frac{lbf}{ft}$

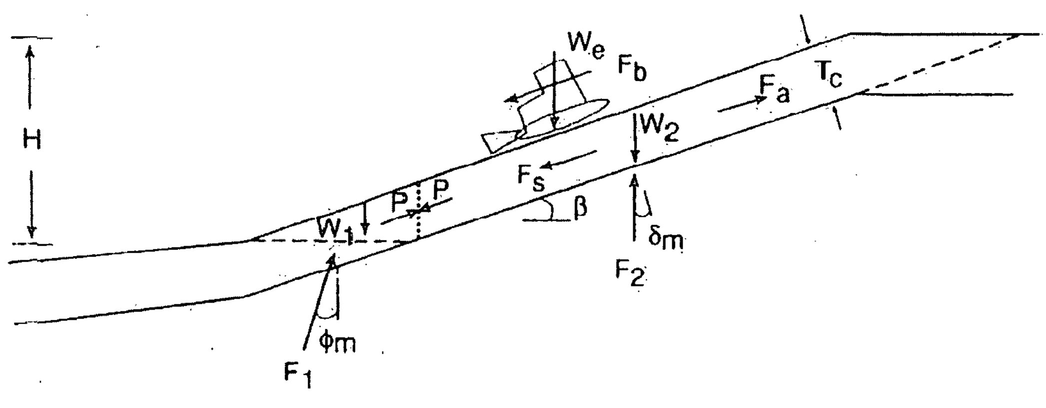
Anchorage Force

$F_a := F_b + F_s + \frac{(W_e + W_2) \cdot \sin(\beta - \delta_m)}{\cos(\delta_m)} - \frac{W_1 \cdot \sin(\phi_m)}{\cos(\beta + \phi_m)}$ $\quad F_a = 29.32 \cdot \frac{lbf}{ft}$ $\quad FOS = 10.6$

Check Anchorage Force

Check := if($F_a \geq 0$,"OK","No Good") Check = "OK"

Note: Analysis considers thickness of seepage to be 2-inches. If operations layer is saturated greater than 2-inches, equipment access should be prevented until operations layer has a chance to dry.



Note: P, F_s, F_a, and F_b, are assumed to be parallel to β

Figure 1. Sideslope with Typical Forces

Attachment B

ANCHOR TRENCH PULLOUT AND WIND UPLIFT FORCES

Method Reference: Koerner, R.M. Prentice Hall Publishing Co., Englewood Cliffs, N.J. (1998). "Designing with Geosynthetics."

Purpose: Size the anchor trench so that the tensile strength of the liner is not exceeded. Also size the trench so that adequate resistance is provided for wind uplift force (provided in separate calculation)

Task: Honeywell Cover System
Description: 4% cover slope. Cover consists of GCL, 60-mil HDPE Geomembrane, CDN underlying 3 feet of cover soil

Input Variables

Backfill Soil

Unit weight of backfill soil: $\gamma := 110 \cdot pcf$

Friction angle of backfill soil: $\phi := 30 \cdot deg$

At rest earth pressure: $k_o := 1 - \sin(\phi)$

Interface friction angle: $\delta := 30deg$

Cover Soil

Unit weight of cover soil: $\gamma_{cs} := 120 \cdot pcf$

Trench Geometry

Depth of cover soil: $d_{cs} := 0 \cdot ft$

Length of run out section: $L_{ro} := 0 \cdot ft$

Depth of anchor trench: $d_{at} := 2 \cdot ft$

Length of anchor trench: $L_{at} := 2 \cdot ft$

Calculations

Surcharge pressure: $q := d_{cs} \cdot \gamma_{cs}$ $\quad q = 0\,psf$

Friction force below geomembrane: $F_L := q \cdot \tan(\delta) \cdot L_{ro}$ $\quad F_L = 0\,\frac{lbf}{ft}$

Friction force above geomembrane: $F_U := 0$ *assumed to be negligible*

Friction force on anchor trench side: $F_{at} := \left(d_{cs} + \frac{d_{at}}{2}\right) \cdot \gamma \cdot k_o \cdot \tan(\delta) \cdot d_{at}$ $\quad F_{at} = 63.5\,\frac{lbf}{ft}$

Friction on anchor trench bottom $F_{bot} := \left(d_{cs} + d_{at}\right) \cdot \gamma \cdot \tan(\delta) \cdot L_{at}$ $\quad F_{bot} = 254\,\frac{lbf}{ft}$

Tension on Liner

$T_A := F_L + F_U + 2 \cdot F_{at} + 2 \cdot F_{bot}$ $\quad T_A = 635\,\frac{lbf}{ft}$

Liner Strength $L_{strength} := 1512\,\frac{lbf}{ft}$ *based on test data of 126 lb/in for 60-mil geomembrane*

Conclusion

Anchor forces do not exceed liner tensile strength

Method Reference: EPA/625/4-89/022 Seminar Publication, Requirements for Hazardous Waste Landfill Design, Construction, and Closure, Chapter 3 Flexible Membrane Liners.

Method Reference: Richardson, G.N. Exposed Geomembrane Covers: Part 1 - Geomembrane Stresses. GFR Magazine. Volume 18, Number 7. September 2000.

Purpose: determine what action is required to counter the affect of wind forces on exposed geomembrane liners.

Task: Honeywell Cover System Design

Maximum Wind Velocity $V := 80\text{mph}$ $V = 117.3 \cdot \frac{ft}{s}$ *from Figure 3-20, EPA*

Wind Uplift Pressure $S_e := \left[0.00124 \cdot \left(\frac{V}{\frac{ft}{s}}\right)^2\right] \cdot psf$ $S_e = 17.1 \cdot psf$ *after Richardson, 2000*

Reduction Factors

Side Slopes: $f_{ss} := 0.7$

Reduced Pressures

Side Slopes: $f_{ss} = 0.7$ $S_{e\_ss} := S_e \cdot f_{ss}$ $S_{e\_ss} = 11.9 \cdot psf$

Calculate Wind Force on Side Slopes

Maximum Exposed Slope Length: $L_s := \begin{pmatrix} 125 \\ 50 \end{pmatrix} ft$ *check maximum slope length and minimum length to keep geomembrane anchored under maximum wind loading.*

Wind Force: $F_{wind} := S_{e\_ss} \cdot L_s$ $F_{wind} = \begin{pmatrix} 1494 \\ 597 \end{pmatrix} \cdot \frac{lbf}{ft}$ Tension on Liner from Anchor Trench: $T_A := 635 \cdot \frac{lbf}{ft}$
Established in separate calculation

$Check_1 := if\left(T_A > F_{wind_1}, \text{"OK"}, \text{"No Good"}\right)$ $Check_1 = \text{"No Good"}$

$Check_2 := if\left(T_A > F_{wind_2}, \text{"OK"}, \text{"No Good"}\right)$ $Check_2 = \text{"OK"}$

Conclusion
Sustained wind velocity of 80 mph will cause geomembrane to pull out of anchor trench at maximum slope length of 125 feet. At slope length of 50 feet, anchor trench will restrain geomembrane.

Check maximum wind sustained wind velocity that anchor trench can resist

Wind Velocity $V := 50\text{mph}$ $V = 73.3\cdot\frac{ft}{s}$

Wind Uplift Pressure $S_e := \left[0.00124\cdot\left(\frac{V}{\frac{ft}{s}}\right)^2\right]\cdot psf$ $S_e = 6.7\cdot psf$ *after Richardson, 2000*

Reduction Factors

Side Slopes: $f_{ss} := 0.7$

Reduced Pressures

Side Slopes: $f_{ss} = 0.7$ $S_{e\_ss} := S_e\cdot f_{ss}$ $S_{e\_ss} = 4.7\cdot psf$

Calculate Wind Force on Side Slopes

Maximum Exposed Slope Length: $L_s := 125ft$ *based on maximum slope height of 5 feet at 4%*

Wind Force: $F_{wind} := S_{e\_ss}\cdot L_s$ $F_{wind} = 583\cdot\frac{lbf}{ft}$ Tension on Liner from Anchor Trench: $T_A := 635\frac{lbf}{ft}$
Established in separate calculation

$Check_1 := if\left(T_A > F_{wind}, \text{"OK"}, \text{"No Good"}\right)$ $Check_1 = \text{"OK"}$

Conclusion
Anchor trench can restrain geomembrane from pullout under wind velocity of 50 mph.

Attachment C

FILTER CALCULATION

Objective: Determine the particle size requirements of a filter soil for use with clay/silt at Honeywell Metropolis site.

Reference: Aggregate Handbook, page 12-52

Filter soil is granular material to keep clay/silt from plugging composite drainage net

$D_{5\_filter} := 0.1mm$

$D_{10\_filter} := 0.15mm$

$D_{15\_filter} := 0.18mm$

filter soil is Illinois DOT FA1 fine aggregate
use lower bound sizes

$D_{50\_filter} := 0.5mm$

$D_{60\_filter} := 0.6mm$

$$CU_{filter} := \frac{D_{60\_filter}}{D_{10\_filter}} = 4$$

Protected soil is native clay/silt

$D_{15\_protected} := 0.002mm$

$D_{50\_protected} := 0.02mm$

$D_{85\_protected} := 0.05mm$

Criteria - Check to see if filter is adequate

Check1 := if$\left(D_{15_filter} \le 5 \cdot D_{85_protected}, \text{"Criteria 1 = OK"}, \text{"Criteria 1 = No Good"}\right)$

$D_{15\_filter} = 0.18 \cdot mm$ $5 \cdot D_{85\_protected} = 0.25 \cdot mm$ Check1 = "Criteria 1 = OK"

Check2 := if$\left(D_{15_filter} \ge 5 \cdot D_{15_protected}, \text{"Criteria 2 = OK"}, \text{"Criteria 2 = No Good"}\right)$

$D_{15\_filter} = 0.18 \cdot mm$ $5 \cdot D_{15\_protected} = 0.01 \cdot mm$ Check2 = "Criteria 2 = OK"

Check3 := if$\left(D_{50_filter} \le 25 \cdot D_{50_protected}, \text{"Criteria 3 = OK"}, \text{"Criteria 3 = No Good"}\right)$

$D_{50\_filter} = 0.5 \cdot mm$ $25 \cdot D_{50\_protected} = 0.5 \cdot mm$ Check3 = "Criteria 3 = OK"

Check4 := if$\left(D_{5_filter} \ge 0.074mm, \text{"Criteria 4 = OK"}, \text{"Criteria 4 = No Good"}\right)$

$D_{5\_filter} = 0.1 \cdot mm$ Check4 = "Criteria 4 = OK"

Check5 := if$\left(CU_{filter} \le 20, \text{"Criteria 5 = OK"}, \text{"Criteria 5 = No Good"}\right)$

$CU_{filter} = 4$ Check5 = "Criteria 5 = OK"

Filter soil is granular material to keep clay/silt from plugging composite drainage net

$D_{5\_filter} := 0.3mm$

$D_{10\_filter} := 0.4mm$

$D_{15\_filter} := 0.45mm$

filter soil is Illinois DOT FA1 fine aggregate
use upper bound sizes

$D_{50\_filter} := 1.2mm$

$D_{60\_filter} := 2mm$ $\quad CU_{filter} := \frac{D_{60\_filter}}{D_{10\_filter}} = 5$

Protected soil is native clay/silt

$D_{15\_protected} := 0.002mm$

$D_{50\_protected} := 0.02mm$

$D_{85\_protected} := 0.05mm$

Criteria - Check to see if filter is adequate

$Check1 := if(D_{15\_filter} \le 5 \cdot D_{85\_protected}, \text{"Criteria 1 = OK"}, \text{"Criteria 1 = No Good"})$

$D_{15\_filter} = 0.45 \cdot mm \quad 5 \cdot D_{85\_protected} = 0.25 \cdot mm$ $\quad Check1 = \text{"Criteria 1 = No Good"}$

$Check2 := if(D_{15\_filter} \ge 5 \cdot D_{15\_protected}, \text{"Criteria 2 = OK"}, \text{"Criteria 2 = No Good"})$

$D_{15\_filter} = 0.45 \cdot mm \quad 5 \cdot D_{15\_protected} = 0.01 \cdot mm$ $\quad Check2 = \text{"Criteria 2 = OK"}$

$Check3 := if(D_{50\_filter} \le 25 \cdot D_{50\_protected}, \text{"Criteria 3 = OK"}, \text{"Criteria 3 = No Good"})$

$D_{50\_filter} = 1.2 \cdot mm \quad 25 \cdot D_{50\_protected} = 0.5 \cdot mm$ $\quad Check3 = \text{"Criteria 3 = No Good"}$

$Check4 := if(D_{5\_filter} \ge 0.074mm, \text{"Criteria 4 = OK"}, \text{"Criteria 4 = No Good"})$

$D_{5\_filter} = 0.3 \cdot mm$ $\quad Check4 = \text{"Criteria 4 = OK"}$

$Check5 := if(CU_{filter} \le 20, \text{"Criteria 5 = OK"}, \text{"Criteria 5 = No Good"})$

$CU_{filter} = 5$ $\quad Check5 = \text{"Criteria 5 = OK"}$

Determination -
FA1 lower bound is adequate for filtration. The upper bound is does not satisfy Criteria 1 or Criteria 3. However, The Aggregate Handbook notes that Criteria 3 can be waived when the soil to be protected is a medium- to high-plasticity clay. Soil testing confirms that on-site soil is medium-plasiticity silt/clay. Based on this information and the above calculations, it is recommended that Illinois DOT fine aggregate class FA1 is used as the filter layer for the Honeywell cover system.

Appendix C-3
Stormwater Management Calculations

CH2MHILL

Calculation

Calculation No.: CALC-388996-SW-01 **Revision No.:** 2

Project: Honeywell Metropolis Works Facility (388996.HW.T6)

Engineering Discipline: Civil **Date:** 11/18/10

Calculation Title & Description:

Title: Civil and Stormwater Drainage Calculations Review (and HELP Model datasheets)

Description:

These calculations present the civil and stormwater drainage evaluations related to the Honeywell – Metropolis Works Surface Water Impoundment Closure Project (30% Design Level).

Revision History:

Revision No.	Description	Date	Affected Pages
0	Draft (Initial) Calculation Package	10/1/10	
1	Draft Final Calculation Package	10/11/10	Complete Package
2	Final Calculation Package	11/18/10	Calculation Narrative and Added C10 Culvert Calc

Document Review & Approval:

Originator: Elizabeth Butterfield/CH2M HILL – BOI, SW Lead

NAME/POSITION

SIGNATURE 11/18/10 DATE

Checked: Travis Pyle, P.E./CH2M HILL – BOI, SW STR

NAME/POSITION

T. A. Pyle, P.E.

SIGNATURE 11/18/10 DATE

1

1. <u>Objective:</u>

The objectives of these calculations are to size the stormwater drainage ditches and drainage features, including riprap, and check the seepage height over the cover liner with and without composite drainage net (CDN) using the HELP Model.

2. <u>Design Standards and Criteria:</u>

CIVIL DESIGN STANDARDS AND CRITERIA

Cover Slope Criteria

General criteria regarding cover slopes for in-place closure of surface impoundments were presented in above. Additional USEPA guidance on the design and construction of RCRA/CERCLA final covers (USEPA 1991) recommends "[a] top, vegetation/soil layer... with vegetation (or an armored top surface) and a minimum of 60 cm (24 inches) of soil graded at a slope between 3 and 5 percent." The specified 4 percent cover slopes at construction will result in a minimum cover slope of 3 percent after potential differential settlement.

Additional civil and site grading criteria include the following:

- Provide a minimum of 1 foot of clean common fill between the top of the stabilized CaF_2 material and the overlying final cover system. Limited CaF_2 material regrading will be required near the berm crests in some areas to meet this requirement.
- Provide positive surface water drainage from all parts of the pond covers, berm sideslopes, perimeter ditches, and access roads to the controlled discharge points, to prevent potential grade reversals or ponding.

Access Road and Security Fence Criteria

The following criteria are applicable to design of access roads and security fences:

- Provide top-of-berm perimeter access roads around the ponds for service vehicles and equipment to access the cover system and other permanent features (i.e., monitoring wells, lysimeters, power and light poles, and pond leak-detection-system sumps). Access roads may be located over the edge of the final cover system with appropriate design considerations to protect the cover system, if top-of-berm clearance is limited. Such roads will be located along the north side of Ponds B and D, and along the Pond D berms common with Ponds B, C, and E.
- Design access roads for lightweight or low-ground-pressure-type vehicles and equipment that will be used for inspection and routine maintenance, including four-wheel all-terrain vehicles, mowers, and pickup trucks.
- Temporarily remove and replace the interior security fence (i.e., during ditch construction and riprap placement) and temporarily remove and replace segments of the exterior fence (during culvert construction). The contractor will coordinate requirements for additional security with Honeywell during such construction. Aside from these conditions, ensure the double security fence surrounding the facility and project area is not disturbed.
- Maintain security access roads between the inner and outer security fences around the entire perimeter of the project area.

STORMWATER DRAINAGE DESIGN STANDARDS AND CRITERIA

Illinois EPA and USEPA Requirements

General Illinois EPA criteria regarding drainage and erosion protection for in-place closure of surface impoundments (per 35 Ill. Adm. Code 724) do not provide specific design storm requirements; however, the 25-year, 24-hour design storm is cited throughout the 40 CFR 264 regulation for run-on and runoff facilities at Subtitle C facilities.

For this project, surface water features are sized to manage the 100-year, 24-hour storm without overtopping and to tolerate larger events without damage. Vegetated top-covers and riprap-stabilized ditches, berm sideslopes, and downslope drains will be provided to protect against erosion. Run-on is not a significant concern because the impoundments are elevated above the surrounding topography. The natural topography slopes away from the ponds into various natural drainages and to Outfall 002.

NRC Requirements and Guidance

Guidance in NUREG 1623 for uranium mine tailings sites is not directly applicable to MTW, but NRC staff considers that this guidance can be used for any application where similar long-term stability is required. Therefore, various guidance in NUREG 1623 has been considered for stormwater drainage design, including the following:

- NUREG 1623, Section 2.2.1, "Selection of Design Flood and Precipitation Event": NRC cites the use of the probable maximum flood for design storm events related to mine tailing sites, which is based on the occurrence of the probable maximum precipitation (PMP). The PMP is the estimated depth of rainfall for a given duration, drainage area, and time of year for which there is virtually no risk of exceedance. The PMP approaches and approximates the maximum rainfall that is physically possible within the limits of contemporary hydrometeorological knowledge and techniques. National Oceanographic and Atmospheric Administration (NOAA) has developed methods in the form of hydrometeorological reports for specific regions. In examining Hydrometeorological Report No. 51, "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian" (NOAA, 1978), the PMP is used primarily for very large drainage areas, from 10 to 20,000 square miles. Tables and curves of flood data are also available to give the maximum floods of record in a region, such as Creager flood envelope curves.

  Consideration for design: For this project, the combined drainage basin is on the order of 10.5 acres (or 0.016 square miles), significantly less than the published charts and reports for predicting PMP events. However, for purposes of comparison to the design storm event used for this project, a maximum flow rate (generated by a PMP event) is calculated in the design analysis section below to arrive at an estimated, equivalent PMP storm event using the charts and procedures outlined in HMR 51.

- NUREG 1623, Section 2.2.2, "Gully Erosion," and Section 2.2.3, "Flow Concentrations and Drainage Network Development": These sections describe the importance of preventing concentrated drainage flows from creating gullies during a very large design storm event. By designing for a large design storm event, the more frequent smaller events will have little to no cumulative impact on the stability of the cover system. The guidance states that it is unlikely that evenly distributed sheet flow will occur from top to bottom of a slope as flow concentrations (gullies) can be caused by different actions such as differential settlement, abnormal wind erosion, and/or random flow process and that flow concentrations can develop even on carefully placed and compacted slopes and result in formation of rills and gullies, and eventually large preferential flow paths can develop.

  Consideration for design: For this project, relatively short drainage lengths (approximately 125 feet or less) for the vegetated cover system are planned with a shallow graded cover crown of 4 percent, shedding off in all directions to prevent initiation of rills and gullies. Riprap in ditches and on berm sideslopes is designed to tolerate the very large PMP flow rates without damage.

- NUREG 1623, Appendix D, "Procedures for Designing Riprap Erosion Protection": This appendix of the NUREG discusses the importance of riprap as protection from erosion and the various methods of riprap design. The Safety Factors Method, the Stephenson Method, and the Abt/Johnson Method are discussed. These studies have indicated that the Safety Factors Method is applicable for slopes less than 10 percent and that the Stephenson Method is more applicable for slopes greater than 10 percent. Historic use of the Safety Factors Method has indicated that a minimum safety factor (SF) of 1.5 for nonprobable maximum flood applications (i.e., 100-year events) provides stability and protection. It is recommended that the riprap thickness be specified as a minimum of 1.5 times the D50 of the riprap. D50 is the stone diameter for which half the material (by weight) is smaller and half is larger.

  Consideration for design: The above guidance has been incorporated for riprap design in ditches and on berm sideslopes, as described below.

Summary of Selected Design Criteria

Permanent stormwater management features have been designed based on the following criteria.

Design Flow. Typical Subtitle C design requires the use of the 25-year, 24-hour design storm event. For this project the 100-year, 24-hour storm event is used to calculate the peak flows and to size ditches and other conveyance features, thus providing a safety factor (freeboard) for the features while carrying the 25-year, 24-hour storm event. Consideration of the PMP event is made and compared for various elements of the drainage system design. Peak flows are calculated from contributing drainages using the Modified Rational Method.

Ditches. Ditches will be V-shaped with sideslopes of 2H:1V, except for the interior slope of the exterior perimeter ditches, which will have 3H:1V slopes to match the sideslopes of the berms. The design depth of stormwater ditches has been determined using the following criteria:

- Size to convey the peak 100-year, 24-hour design storm event without overtopping, providing freeboard and a safety factor to carry the conventional 25-year event. For interior ditches, design the ditches to convey the 100-year, 24-hour design storm event below the elevation of the CDN.
- Define the ditch invert elevation as the top of the riprap layer—i.e., flow within the riprap is not considered for ditch design.
- Use $n = 0.035$ for rock-lined (riprap) ditches.
- Determine required depth for new ditches using a typical slope of one percent for all interior/common berm ditches, with slopes marginally greater or less than 1 percent in select areas as necessary due to topographic and cover system design constraints.

Riprap. Ditch riprap D_{50} is designed to protect against erosion caused by the 100-year, 24-hour storm using the Safety Factors Method with a minimum SF of 1.5, or the PMP event with an SF of 1.0. Sideslope riprap is designed using the Stephenson Method. Thickness of the riprap layers is specified as a minimum of 1.5 times the D_{50}.

Downslope Drainage Ditches/Discharge Points. Downslope drains and discharge points where ditches interface with existing, natural drainage ravines and gullies (and Outfall 002) will be stabilized with riprap. Refer to discussion of riprap (above) for design criteria.

Culverts. Size culverts to convey the peak flow from the design event (100-year, 24-hour storm). Use corrugated polyethylene pipe (such as ADS N-12) with corrugated exterior and smooth interior. Provide inlet and outlet protection using riprap.

3. <u>Methodology and Assumptions:</u>

- Refer to Section 2 above.

4. <u>Results and Conclusions</u>

STORMWATER DRAINAGE

Key permanent stormwater drainage and management features include:

- Surface water will sheet flow off the top final cover from each pond and either convey into interior ditches collocated at the top of common pond berms or convey via sheet flow down the berm sideslope riprap to exterior perimeter ditches located at the toe of the berms.
- Concentrated flows from the common berm ditches will be conveyed under the perimeter access roads via culverts to the exterior perimeter ditches.
- Exterior perimeter ditches will convey flows to three discharge points, as follows:
  - Discharge point 1 (DP1) will collect surface water runoff from parts of Ponds B, C, and E.
  - Discharge point 2 (DP2) will collect surface water runoff from part of Pond E.
  - Discharge point 3 (DP3; existing Outfall 002) will collect surface water runoff from parts of Ponds B, C, and E, and all of Pond D.

Design Analyses

100-Year, 24-Hour Design Flow Calculation. The Rational Method was used to determine the peak runoff from each of the drainage basins as shown in Drawing C-4. When evaluating the time of concentration (T_c), the maximum T_c calculated using overland flow is approximately 2 minutes for these small drainage basin areas and flow lengths; the customary default T_c of 10 minutes was used in the Rational Method calculation.

A runoff coefficient of 0.95 was selected for the Rational Method stormwater runoff calculations as a conservative measure assuming frozen ground conditions with little or no infiltration and/or initial abstraction. It is assumed virtually all of the stormwater runoff generated by the design storm events will be conveyed via ditches and culverts to the three outfalls. A storm intensity of 7.49 in./hr was used in the Rational Method calculation and is from the intensity-duration-frequency (IDF) curves (and data tables) obtained from the nearby weather station for a 100-year design storm event with a minimum time of concentration of 10 minutes.

Based on the above, the peak flow for all contributing drainage areas is 74.93 cubic feet per second (cfs) for the 100-year storm event. Table 1 summarizes the flows from each of the contributing drainage basins.

TABLE 1
Drainage Basin Flow Summary: 100-Year, 24-Hour Storm Event

Area ID	Area (acre)	Peak Flow (cfs)	Runoff Coefficient	Intensity (in./hr)	Time of Concentration (min)
Pond B					
A B-1	0.49	3.51	0.95	7.49	10
A B-2	0.18	1.26	0.95	7.49	10

TABLE 1
Drainage Basin Flow Summary: 100-Year, 24-Hour Storm Event

Area ID	Area (acre)	Peak Flow (cfs)	Runoff Coefficient	Intensity (in./hr)	Time of Concentration (min)
A B-3	0.31	2.23	0.95	7.49	10
A B-4	0.11	0.81	0.95	7.49	10
A B-5	0.21	1.47	0.95	7.49	10
A B-6	0.26	1.83	0.95	7.49	10
Pond B Total	*1.56*	*11.11*			
Pond C					
A C-1	0.49	3.46	0.95	7.49	10
A C-2	0.19	1.35	0.95	7.49	10
A C-3	0.19	1.32	0.95	7.49	10
A C-4	0.15	1.08	0.95	7.49	10
A C-5	0.57	4.06	0.95	7.49	10
Pond C Total	*1.59*	*11.27*			
Pond D					
A D-1	0.24	1.70	0.95	7.49	10
A D-2	0.25	1.79	0.95	7.49	10
A D-3	0.85	6.03	0.95	7.49	10
A D-4	0.26	1.82	0.95	7.49	10
Pond D Total	*1.60*	*11.34*			
Pond E					
A E-1	0.92	6.53	0.95	7.49	10
A E-2	0.63	4.52	0.95	7.49	10
A E-3	0.37	2.62	0.95	7.49	10
A E-4	1.08	7.67	0.95	7.49	10
A E-5	0.66	4.69	0.95	7.49	10
A E-6	1.33	9.46	0.95	7.49	10
A E-7	0.80	5.72	0.95	7.49	10
Pond E Total	*5.79*	*41.21*			
Project Total	**10.54**	**74.93**			

PMP Flow Calculation. Based on NRC guidance in NUREG 1623, theoretical maximum ditch flow rates are calculated based on the PMP for comparison to the design storm event (100-year, 24-hour storm). Consideration of the PMP is not required by the Illinois EPA.

Hydrometeorological Report No. 51 (NOAA, 1978) contains PMP charts (Figures 18 through 47) for drainage basins between 10 and 20,000 square miles and for storm durations from 6 to 72 hours. For this project, the combined drainage basin is on the order of only 10.5 acres (or 0.016 square miles), which is significantly less than the published charts and reports provided for typical PMP determinations. In the absence of having a chart available for the project drainage basis size, extrapolations were made from Figures 18 through 47 to create curves to estimate the PMP for a 1-square-mile drainage area (minimum drainage basin size for extrapolation). This results in a maximum precipitation of 28 inches over the 10-minute storm event, compared to 1.25 inches over 10 minutes for the 100-year-storm event.

In the event of a PMP, the drainage system designed for the pond closure system would be quickly flooded. Stormwater would overtop the interior common berm ditch crests and back up flow over the 4 percent vegetated top slopes prior to natural relief over the berm sideslope riprap. Stormwater would also overtop the berm perimeter ditches and flow into the nearby drainages. Runoff from the PMP would be expected to primarily flow overland to discharge points (DPs) 1, 2, and 3, and eventually offsite through the natural drainage ravines to the Ohio River.

Even though the PMP event would flood the drainage system, it would not be expected to cause permanent damage to the drainage features nor exposure of the stabilized CaF_2 material. As described below, riprap on the berm sideslopes and ditches is sized to withstand the PMP event.

Ditch Sizing. Ditches were sized using the design criteria presented in Section 2. The Rational Method was used to calculate the stormwater runoff peak flow rate conveyed in each ditch. The flow for each ditch was then inserted into FlowMaster, which is a software package that uses the industry-standard open-channel Manning's Equation to solve for the minimum ditch depth with given inputs of flow rate, ditch cross-section, ditch sideslope geometry, ditch slope, and Manning's *n* value (based on ditch roughness).

The associated minimum ditch depths are summarized in Table 2.

TABLE 2
Ditch Flows and Design Summary: 100-Year, 24-Hour Storm Event

Conveyance Ditch No.	Minimum Ditch Depth (ft)	Average Slope (ft/ft)	Ditch Total Flow (cfs)
DP1	**2.22**	**0.01**	**41.70**
DP1-1	1.27	0.01	9.46
DP1-2	2.02	0.01	32.24
DP1-3	1.87	0.01	26.52
DP1-4	1.23	0.01	8.58
DP1-5	1.37	0.01	11.41
DP1-6	0.85	0.01	3.18
DP1-7	0.99	0.01	4.77
DP1-8	0.68	0.01	1.26
DP2	**1.41**	**0.01**	**12.36**

TABLE 2
Ditch Flows and Design Summary: 100-Year, 24-Hour Storm Event

Conveyance Ditch No.	Minimum Ditch Depth (ft)	Average Slope (ft/ft)	Ditch Total Flow (cfs)
DP2-1	0.98	0.01	4.69
DP2-2	1.18	0.01	7.67
DP3	**1.71**	**0.01**	**20.87**
DP3-1	1.57	0.01	16.43
DP3-2	0.96	0.01	4.44
DP3-3	1.32	0.01	10.40
DP3-4	1.23	0.01	8.61
DP3-5	0.81	0.01	2.79
DP3-6	0.74	0.01	2.23
Total			**74.93**

Culverts Sizing. Culverts were sized based on the design criteria presented in Section 2 above. The culverts were sized based on the contributing ditch flows as previously described. The culvert sizing was done using the HY8 software package distributed by the Federal Highway Administration (FHWA). The calculated flow rate for each culvert was imported into the HY8 program along with the geometry of the culvert and the inlet and outlet channels. The culvert design method used in the HY8 program is based on the use of design charts and nomographs. These charts and nomographs are in turn based on data from numerous hydraulic tests and on theoretical calculations. Table 3 summarizes the associated culvert sizes.

TABLE 3
Culvert Sizing Summary

Culvert ID	Design Flow (cfs)	Design Diameter (in.)
C1	8.58	24
C2	3.18	12
C3	1.26	12
C4	4.44	18
C5	8.61	24
C6	20.87	30
C7	20.87	30
C8	12.36	24
C9	41.70	42
C10	2.23	12

Riprap Sizing. Preliminary design of the riprap slope protection was performed using the criteria presented in Section 2. The riprap sizing is summarized in Table 4.

For the interior ditches, riprap sizing in Table 4 is based on a maximum flow depth equal to the top of the ditch with no freeboard below the cover system CDN elevation (for the 100-year, 24-hour storm), and for flow depth equal to the top of the cover system for the PMP event. A SF of 1.5 is applied to the 100-year, 24-hour storm, while a SF of 1.0 is applied to the PMP event. Due to the difference in the applied SF, the ditch riprap sizes calculated for the PMP are smaller than the riprap sizes calculated for the 100-year, 24-hour storm, as shown in Table 4.

TABLE 4
Riprap Sizing Summary
Honeywell-Metropolis Works Surface Impoundment Closure Engineering Report

Location	Storm Event	D_{50} (in.)*	Riprap Layer Thickness (in.)
Interior berm ditch	100-year	16	24
	PMP	11	16.5
Exterior perimeter ditch	100-year	26	39
	PMP	18	27
Sideslopes	100-year	4	8
	PMP	12	24

* Riprap size based on a SF of 1.5 for the 100-year event and 1.0 for the PMP event.

As described in NUREG 1623, the PMP event "approximates the maximum rainfall that is physically possible within the limits of contemporary hydrometeorological knowledge and techniques." By this definition, the riprap sizing based on the PMP event and an SF of 1.0 is considered conservative for riprap design using the Safety Factors Method.

The interior berm and exterior perimeter ditch riprap sizes based on the 100-year, 24-hour storm and a SF of 1.5 are unreasonably large (Table 4). For example, the D_{50} riprap size based on the 100-year event is larger than the calculated maximum flow depth in the ditches. The PMP is the storm event for which there is essentially no risk of exceedance at any recurrence interval; therefore, the riprap sizing derived from the PMP as listed in Table 4 is considered sufficient to manage all storms at the site and is therefore used as the design basis for riprap sizing.

The ditch riprap results in Table 4 are based on the most conservative flow rate for each ditch type. Riprap size and layer thickness will be optimized on an individual basis for each ditch segment during final design. Alternate erosion control methods (other than riprap) may be considered during final design, if they can be demonstrated to provide equivalent long-term protection as riprap. Any significant modifications to the proposed closure approach, including alternatives to riprap, would be submitted to Illinois EPA and NRC for approval prior to construction.

Drainage Layer Analysis and HELP Modeling. The seepage head over the cover system geomembrane can be controlled by limiting infiltration into the cover materials and by maximizing the hydraulic capacity of the final cover drainage layer. To discourage biointrusion from burrowing mammals, the selected final cover includes a 12-inch-thick granular filter/drainage layer beneath the vegetated support layer. The underlying CDN is used in conjunction with the granular filter/drainage layer to drain the cover.

The drainage layer will have sufficient capacity to convey infiltration off the cover without allowing the maximum head buildup to exceed the thickness of the filter/drainage layer (12 inches). Modeling was performed using the U.S. Army Corps of Engineer's Hydrologic Evaluation of Landfill Performance model, version 3.07 (HELP), a quasi-two-dimensional, deterministic computer model.

Input data required for the HELP model includes climatological data representative of the site (precipitation, temperature, solar radiation, and evapotranspiration) and soil and landfill design data. Climatological information, including average annual precipitation and temperature, was obtained from a weather station in nearby Paducah, Kentucky (Station 156110), approximately 10 miles from the site. For other HELP inputs (evapotranspiration data and solar radiation intensity), the default information in the HELP model for nearest preloaded HELP model city (St. Louis, Missouri) was used. The analysis was performed using the 100-year, 24-hour storm for Paducah of 7.42 inches of rainfall.

HELP modeling was performed to determine the estimated amount of seepage head over the geomembrane liner and to verify that the head will stay below the top of the 12-inch filter/drainage layer. The analysis also compares the predicted head with and without the use of a CDN to evaluate the conservatism of the design.

Representative properties of the cover system materials were selected from the HELP model, which provides an extensive database of recommended typical soil and waste properties cross referenced to the Unified Soil Classification System. Classification and soil parameters most closely matching the anticipated or actual layer type were selected from the HELP model's soil matrix options. Table 5 presents a summary of the HELP model input parameters.

TABLE 5
HELP Modeling Parameters Summary

Layer Description	Thickness (inches)	Classification: Soil Texture No.[a]	Classification: Layer Type[b]	Total Porosity (vol/vol)	Field Capacity (vol/vol)	Wilting Point (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Topsoil/vegetation support layer[c]	24	12	1	0.417	0.342	0.210	4.2×10^{-3}
Granular filter/drainage layer	12	21	2	0.397	0.032	0.013	0.02[d]
CDN	0.25	20	2	0.850	0.010	0.000	10.0
HDPE geomembrane	0.06	35	4	—	—	—	2.0×10^{-13}
GCL	0.25	17	3	0.750	0.747	0.400	3.0×10^{-9}

[a] HELP soil texture number for standard soil and geosynthetic material characteristics. HDPE geomembrane = 35; silty clay = 12; composite drainage layer (CDN) = 20, bentonite mat = 17 (also known as a geosynthetic clay liner, GCL).
[b] HELP layer type and function: (1) vertical percolation layer, (2) lateral drainage layer, (3) barrier soils, and (4) geomembrane liners.
[c] For this analysis, the topsoil and vegetation support layer were taken to be essentially the same material in terms of soil characteristics. Soil texture no. 12 is for UCSC clayey (CL) soil types.
[d] The HELP model default for soil texture no. 21 (gravel) hydraulic conductivity was modified as explained below.

For the granular filter/drainage layer, a standard IDOT aggregate FA1 was chosen. The hydraulic conductivity of the filter/drainage layer was estimated using Hazen's equation:

$$K_{(cm/s)} = C \times (D_{10})^2$$

where:

K = hydraulic conductivity (cm/s)
C = coefficient of 0.8 to 1.2 (a value of 1.0 is commonly used)
D_{10} = diameter for which only 10 percent of the particles are finer (0.20 mm)

This resulted in a hydraulic conductivity of 0.04 cm/s. A conservative value of 0.02 cm/s was used to account for fines that may be in the material upon placement or that may migrate into the layer during the life of the cover therefore potentially reducing the permeability of the media.

Results of the HELP model indicate the head on the liner will not exceed 12 inches as a result of the 100-year, 24-hour storm. The estimated head buildup is 11.9 inches if a CDN is not included and less than 1 inch if a CDN is included. The design currently includes the use of a CDN in conjunction with the filter/drainage layer to provide system redundancy.

5. List of Attachments

- Calculations:
  - Drainage and Ditch Sizing Calculations
  - PMP Calculation Estimates
  - Riprap Sizing Calculations
  - Culvert Sizing Calculations
  - Filter Layer Hydraulic Conductivity Estimate Calculations
  - HELP Modeling Calculations (with and without CDN)

6. Additional References

NOAA (National Oceanic and Atmospheric Administration). 1978. *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian.* Hydrometeorological Report No. 51. Available at http://www.weather.gov/oh/hdsc/PMP_documents/HMR51.pdf.

NRC. 1988. *NUREG/CR-4651. Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II; Follow-up Investigations.*

NRC. 2002. *NUREG-1623. Design of Erosion Protection for Long-Term Stabilization.* Final Report.

Stormwater Drainage Calculations

Stormwater Drainage Calculations

Drainage and Ditch Sizing

Drainage Reports

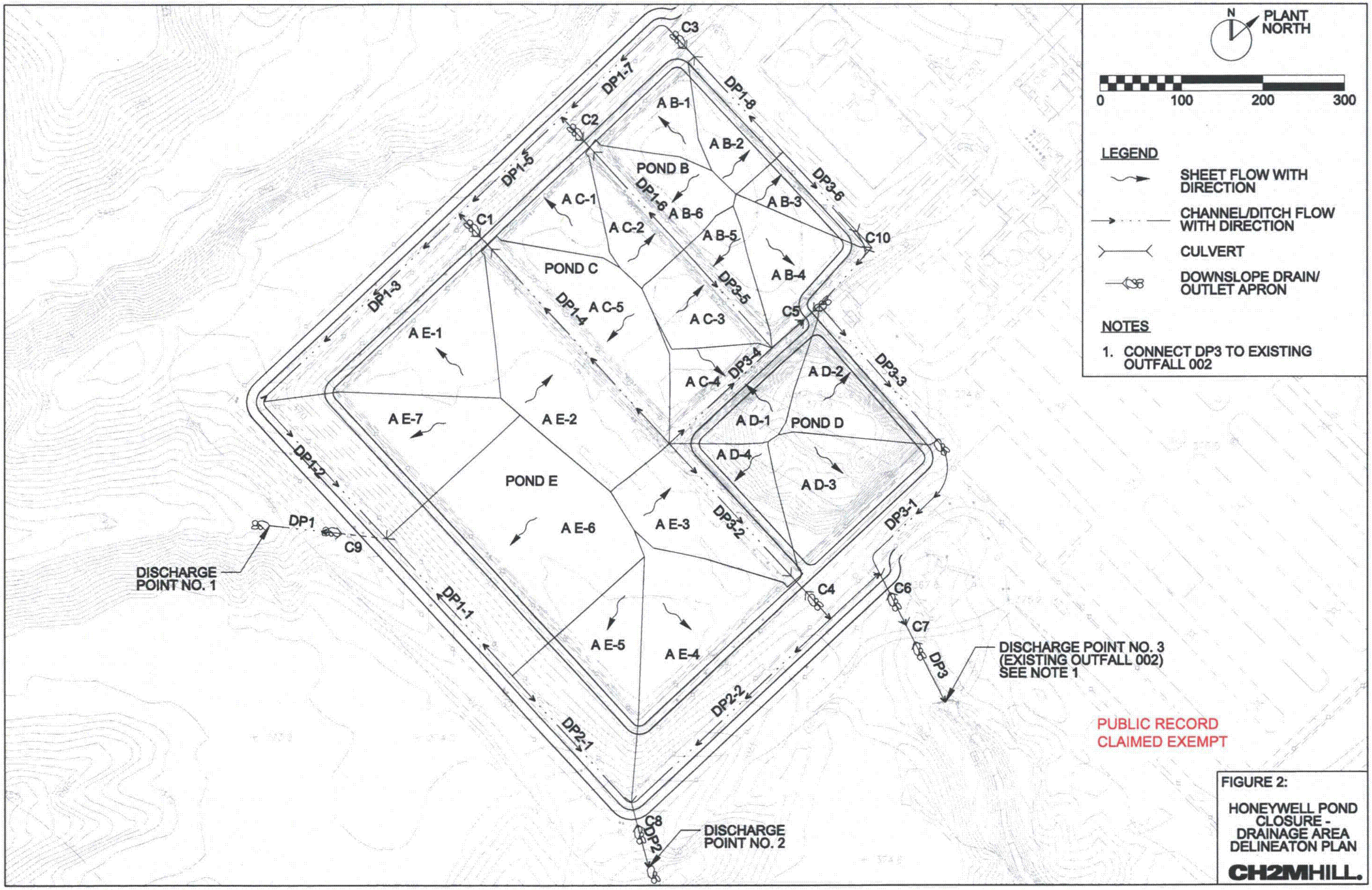
Element Type: Area

Date: Thursday, September 23, 2010 4:22:55 PM

Drainage Data File: HW_Surface_Drainage

ID	Area (ac)	Frequency	Method	PeakFlow (cfs)	RunoffCoef	Intensity (in/h)	TimeofConc (min)
A B-1	0.49	100.00	Mod. Rational	3.51	0.95	7.49	10.00
A B-2	0.18	100.00	Mod. Rational	1.26	0.95	7.49	10.00
A B-3	0.31	100.00	Mod. Rational	2.23	0.95	7.49	10.00
A B-4	0.11	100.00	Mod. Rational	0.81	0.95	7.49	10.00
A B-5	0.21	100.00	Mod. Rational	1.47	0.95	7.49	10.00
A B-6	0.26	100.00	Mod. Rational	1.83	0.95	7.49	10.00
A C-1	0.49	100.00	Mod. Rational	3.46	0.95	7.49	10.00
A C-2	0.19	100.00	Mod. Rational	1.35	0.95	7.49	10.00
A C-3	0.19	100.00	Mod. Rational	1.32	0.95	7.49	10.00
A C-4	0.15	100.00	Mod. Rational	1.08	0.95	7.49	10.00
A C-5	0.57	100.00	Mod. Rational	4.06	0.95	7.49	10.00
A D-1	0.24	100.00	Mod. Rational	1.70	0.95	7.49	10.00
A D-2	0.25	100.00	Mod. Rational	1.79	0.95	7.49	10.00
A D-3	0.85	100.00	Mod. Rational	6.03	0.95	7.49	10.00
A D-4	0.26	100.00	Mod. Rational	1.82	0.95	7.49	10.00
A E-1	0.92	100.00	Mod. Rational	6.53	0.95	7.49	10.00
A E-2	0.63	100.00	Mod. Rational	4.52	0.95	7.49	10.00
A E-3	0.37	100.00	Mod. Rational	2.62	0.95	7.49	10.00
A E-4	1.08	100.00	Mod. Rational	7.67	0.95	7.49	10.00
A E-5	0.66	100.00	Mod. Rational	4.69	0.95	7.49	10.00
A E-6	1.33	100.00	Mod. Rational	9.46	0.95	7.49	10.00
A E-7	0.80	100.00	Mod. Rational	5.72	0.95	7.49	10.00

Number of items reported: 22



PUBLIC RECORD CLAIMED EXEMPT

FIGURE 2:

HONEYWELL POND CLOSURE - DRAINAGE AREA DELINEATON PLAN

CH2MHILL.

Ditch Total Flows

Discharge Point 1

DP1-8

Flow From	A (AC)	Q (cfs)
A B-2	0.18	1.26
Totals	**0.18**	**1.26**

DP1-7

Flow From	A (AC)	Q (cfs)
DP1-8	0.18	1.26
A B-1	0.49	3.51
Totals	**0.67**	**4.77**

DP1-6

Flow From	A (AC)	Q (cfs)
A B-6	0.26	1.83
A C-2	0.19	1.35
Totals	**0.45**	**3.18**

DP1-5

Flow From	A (AC)	Q (cfs)
DP1-6	0.45	3.18
DP1-7	0.67	4.77
A C-1	0.49	3.46
Totals	**1.61**	**11.41**

DP1-4

Flow From	A (AC)	Q (cfs)
A C-5	0.57	4.06
A E-2	0.63	4.52
Totals	**1.20**	**8.58**

DP1-3

Flow From	A (AC)	Q (cfs)
DP1-4	1.20	8.58
DP1-5	1.61	11.41
A E-1	0.92	6.53
Totals	**3.73**	**26.52**

DP1-2

Flow From	A (AC)	Q (cfs)
DP1-3	3.73	26.52
A E-7	0.80	5.72
Totals	**4.53**	**32.24**

DP1-1

Flow From	A (AC)	Q (cfs)
A E-6	1.33	9.46
Totals	**1.33**	**9.46**

DP1

Flow From	A (AC)	Q (cfs)
DP1-1	1.33	9.46
DP1-2	4.53	32.24
Totals	**5.86**	**41.70**

Discharge Point 2

DP2-2

Flow From	A (AC)	Q (cfs)
A E-4	1.08	7.67
Totals	**1.08**	**7.67**

DP2-1

Flow From	A (AC)	Q (cfs)
A E-5	0.66	4.69
Totals	**0.66**	**4.69**

DP2

Flow From	A (AC)	Q (cfs)
DP2-1	0.66	4.69
DP2-2	1.08	7.67
Totals	**1.74**	**12.36**

Discharge Point 3

DP3-6

Flow From	A (AC)	Q (cfs)
A B-3	0.31	2.23
Totals	**0.31**	**2.23**

DP3-5

Flow From	A (AC)	Q (cfs)
A B-5	0.21	1.47
A C-3	0.19	1.32
Totals	**0.40**	**2.79**

DP3-4

Flow From	A (AC)	Q (cfs)
A D-1	0.24	1.70
A C-4	0.15	1.08
A B-4	0.11	0.81
DP3-5	0.40	2.79
DP3-6	0.31	2.23
Totals	**1.21**	**8.61**

DP3-3

Flow From	A (AC)	Q (cfs)
DP3-4	1.21	8.61
A D-2	0.25	1.79
Totals	**1.46**	**10.40**

DP3-2

Flow From	A (AC)	Q (cfs)
A D-4	0.26	1.82
A E-3	0.37	2.62
Totals	**0.63**	**4.44**

DP3-1

Flow From	A (AC)	Q (cfs)
DP3-3	1.46	10.40
A D-3	0.85	6.03
Totals	**2.31**	**16.43**

DP3

Flow From	A (AC)	Q (cfs)
DP3-1	2.31	16.43
DP3-2	0.63	4.44
Totals	**2.94**	**20.87**

DP1
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	41.70	cfs

Results		
Depth	2.22	ft
Flow Area	9.9	ft²
Wetted Perim	9.93	ft
Top Width	8.88	ft
Critical Depth	1.93	ft
Critical Slope	0.020948	ft/ft
Velocity	4.23	ft/s
Velocity Head	0.28	ft
Specific Energ	2.50	ft
Froude Numb	0.71	
Flow Type	Subcritical	

DP1-1
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-1
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	9.46	cfs

Results		
Depth	1.27	ft
Flow Area	3.2	ft²
Wetted Perim	5.69	ft
Top Width	5.09	ft
Critical Depth	1.07	ft
Critical Slope	0.025530	ft/ft
Velocity	2.92	ft/s
Velocity Head	0.13	ft
Specific Energ	1.41	ft
Froude Numb	0.64	
Flow Type	Subcritical	

DP1-2
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-2
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	32.24	cfs

Results		
Depth	2.02	ft
Flow Area	8.1	ft²
Wetted Perim	9.02	ft
Top Width	8.07	ft
Critical Depth	1.74	ft
Critical Slope	0.021680	ft/ft
Velocity	3.96	ft/s
Velocity Head	0.24	ft
Specific Ener	2.26	ft
Froude Numb	0.70	
Flow Type	Subcritical	

DP1-3
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-3
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	26.52	cfs

Results		
Depth	1.87	ft
Flow Area	7.0	ft²
Wetted Perim	8.38	ft
Top Width	7.50	ft
Critical Depth	1.61	ft
Critical Slope	0.022252	ft/ft
Velocity	3.77	ft/s
Velocity Head	0.22	ft
Specific Ener	2.10	ft
Froude Numb	0.69	
Flow Type	Subcritical	

DP1-4
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-4
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	8.58	cfs

Results		
Depth	1.23	ft
Flow Area	3.0	ft²
Wetted Perim	5.49	ft
Top Width	4.91	ft
Critical Depth	1.03	ft
Critical Slope	0.025865	ft/ft
Velocity	2.85	ft/s
Velocity Head	0.13	ft
Specific Ener	1.35	ft
Froude Numb	0.64	
Flow Type	Subcritical	

DP1-5
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-5
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	11.41	cfs

Results		
Depth	1.37	ft
Flow Area	3.7	ft²
Wetted Perim	6.11	ft
Top Width	5.46	ft
Critical Depth	1.15	ft
Critical Slope	0.024900	ft/ft
Velocity	3.06	ft/s
Velocity Head	0.15	ft
Specific Enerç	1.51	ft
Froude Numb	0.65	
Flow Type	Subcritical	

DP1-6
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-6
Flow Element	Triangular Char
Method	Manning's Form
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	3.18	cfs

Results		
Depth	0.85	ft
Flow Area	1.4	ft²
Wetted Perim	3.78	ft
Top Width	3.38	ft
Critical Depth	0.69	ft
Critical Slope	0.029524	ft/ft
Velocity	2.22	ft/s
Velocity Head	0.08	ft
Specific Energ	0.92	ft
Froude Numb	0.60	
Flow Type	Subcritical	

DP1-7
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-7
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	4.77	cfs

Results		
Depth	*0.99*	*ft*
Flow Area	1.9	ft²
Wetted Perim	4.41	ft
Top Width	3.94	ft
Critical Depth	0.81	ft
Critical Slope	0.027971	ft/ft
Velocity	2.46	ft/s
Velocity Head	0.09	ft
Specific Enerç	1.08	ft
Froude Numb	0.62	
Flow Type	Subcritical	

DP1-8
Worksheet for Triangular Channel

Project Description	
Worksheet	DP1-8
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	1.00	H : V
Discharge	1.26	cfs

Results		
Depth	0.68	ft
Flow Area	0.7	ft²
Wetted Perim	2.48	ft
Top Width	2.04	ft
Critical Depth	0.54	ft
Critical Slope	0.035986	ft/ft
Velocity	1.82	ft/s
Velocity Head	0.05	ft
Specific Energ	0.73	ft
Froude Numb	0.55	
Flow Type	Subcritical	

DP2
Worksheet for Triangular Channel

Project Description	
Worksheet	DP2
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	12.36	cfs

Results		
Depth	1.41	ft
Flow Area	4.0	ft²
Wetted Perim	6.30	ft
Top Width	5.63	ft
Critical Depth	1.19	ft
Critical Slope	0.024636	ft/ft
Velocity	3.12	ft/s
Velocity Head	0.15	ft
Specific Energ	1.56	ft
Froude Numb	0.66	
Flow Type	Subcritical	

DP2-1
Worksheet for Triangular Channel

Project Description	
Worksheet	DP2-1
Flow Element	Triangular Char
Method	*Manning's Forr*
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	4.69	cfs

Results		
Depth	0.98	ft
Flow Area	1.9	ft²
Wetted Perim	4.38	ft
Top Width	3.92	ft
Critical Depth	0.81	ft
Critical Slope	0.028034	ft/ft
Velocity	2.45	ft/s
Velocity Head	0.09	ft
Specific Enerç	1.07	ft
Froude Numb	0.62	
Flow Type	Subcritical	

DP2-2
Worksheet for Triangular Channel

Project Description	
Worksheet	DP2-2
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	7.67	cfs

Results		
Depth	1.18	ft
Flow Area	2.8	ft²
Wetted Perim	5.26	ft
Top Width	4.71	ft
Critical Depth	0.98	ft
Critical Slope	0.026254	ft/ft
Velocity	2.77	ft/s
Velocity Head	0.12	ft
Specific Enerç	1.30	ft
Froude Numb	0.64	
Flow Type	Subcritical	

DP3
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	20.87	cfs

Results		
Depth	1.71	ft
Flow Area	5.9	ft²
Wetted Perim	7.66	ft
Top Width	6.85	ft
Critical Depth	1.47	ft
Critical Slope	0.022974	ft/ft
Velocity	3.55	ft/s
Velocity Head	0.20	ft
Specific Energ	1.91	ft
Froude Numb	0.68	
Flow Type	Subcritical	

DP3-1
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-1
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	10.47	cfs

Results		
Depth	1.32	ft
Flow Area	3.5	ft²
Wetted Perim	5.92	ft
Top Width	5.29	ft
Critical Depth	1.11	ft
Critical Slope	0.025187	ft/ft
Velocity	2.99	ft/s
Velocity Head	0.14	ft
Specific Ener(	1.46	ft
Froude Numb	0.65	
Flow Type	Subcritical	

DP3-2
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-2
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	4.44	cfs

Results		
Depth	0.96	ft
Flow Area	1.8	ft²
Wetted Perim	4.29	ft
Top Width	3.84	ft
Critical Depth	0.79	ft
Critical Slope	0.028239	ft/ft
Velocity	2.41	ft/s
Velocity Head	0.09	ft
Specific Ener	1.05	ft
Froude Numb	0.61	
Flow Type	Subcritical	

DP3-3
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-3
Flow Element	Triangular Char
Method	Manning's Form
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	16.43	cfs

Results		
Depth	1.57	ft
Flow Area	4.9	ft²
Wetted Perim	7.00	ft
Top Width	6.27	ft
Critical Depth	1.33	ft
Critical Slope	*0.023718*	*ft/ft*
Velocity	3.35	ft/s
Velocity Head	0.17	ft
Specific Energ	1.74	ft
Froude Numb	0.67	
Flow Type	Subcritical	

DP3-4
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-4
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	8.61	cfs

Results		
Depth	1.23	ft
Flow Area	3.0	ft²
Wetted Perim	5.50	ft
Top Width	4.92	ft
Critical Depth	1.03	ft
Critical Slope	0.025853	ft/ft
Velocity	2.85	ft/s
Velocity Head	0.13	ft
Specific Enerç	1.36	ft
Froude Numb	0.64	
Flow Type	Subcritical	

DP3-5
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-5
Flow Element	Triangular Char
Method	Manning's Forr
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	2.79	cfs

Results		
Depth	0.81	ft
Flow Area	1.3	ft^2
Wetted Perim	3.60	ft
Top Width	3.22	ft
Critical Depth	0.66	ft
Critical Slope	0.030044	ft/ft
Velocity	2.15	ft/s
Velocity Head	0.07	ft
Specific Enerç	*0.88*	*ft*
Froude Numb	0.60	
Flow Type	Subcritical	

DP3-6
Worksheet for Triangular Channel

Project Description	
Worksheet	DP3-6
Flow Element	Triangular Char
Method	Manning's Forn
Solve For	Channel Depth

Input Data		
Mannings Coeffic	0.035	
Slope	010000	ft/ft
Left Side Slope	2.00	H : V
Right Side Slope	2.00	H : V
Discharge	2.23	cfs

Results		
Depth	0.74	ft
Flow Area	1.1	ft²
Wetted Perim	3.31	ft
Top Width	2.96	ft
Critical Depth	0.60	ft
Critical Slope	0.030955	ft/ft
Velocity	2.03	ft/s
Velocity Head	0.06	ft
Specific Enerç	0.80	ft
Froude Numb	0.59	
Flow Type	Subcritical	

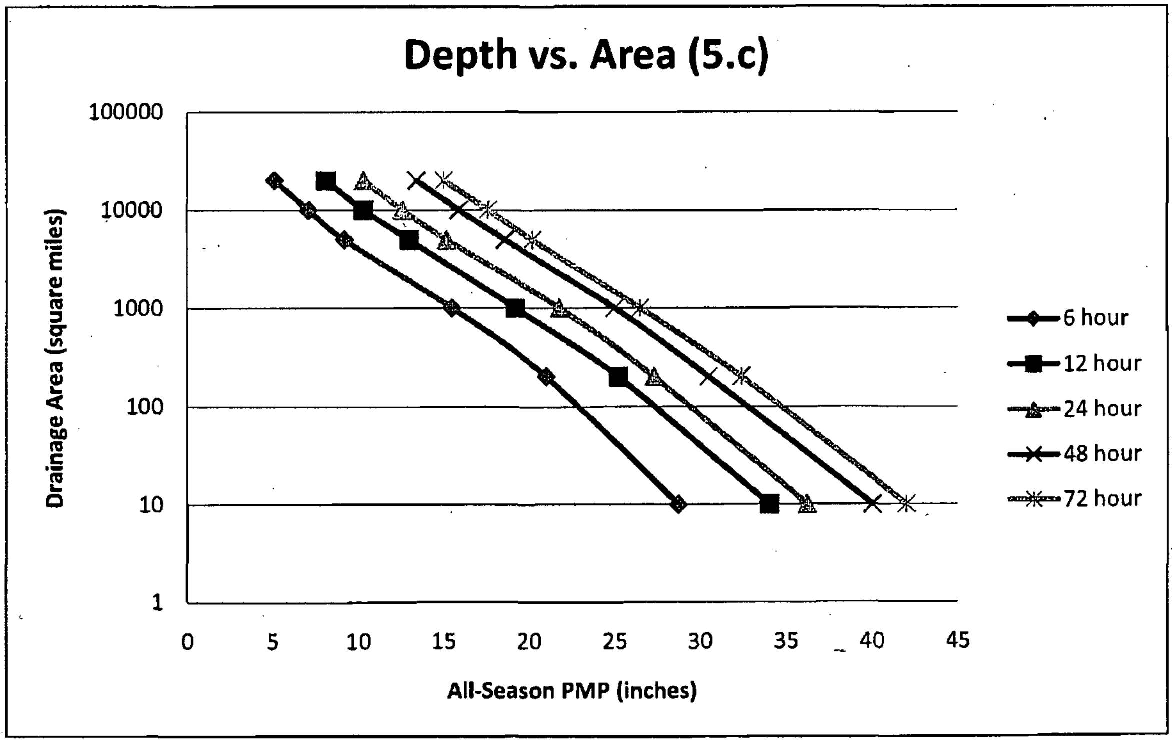
Stormwater Drainage Calculations

PMP *Calculation Estimate*

PMP Calculation Using the charts in HMR 51 (Steps from Section 5)

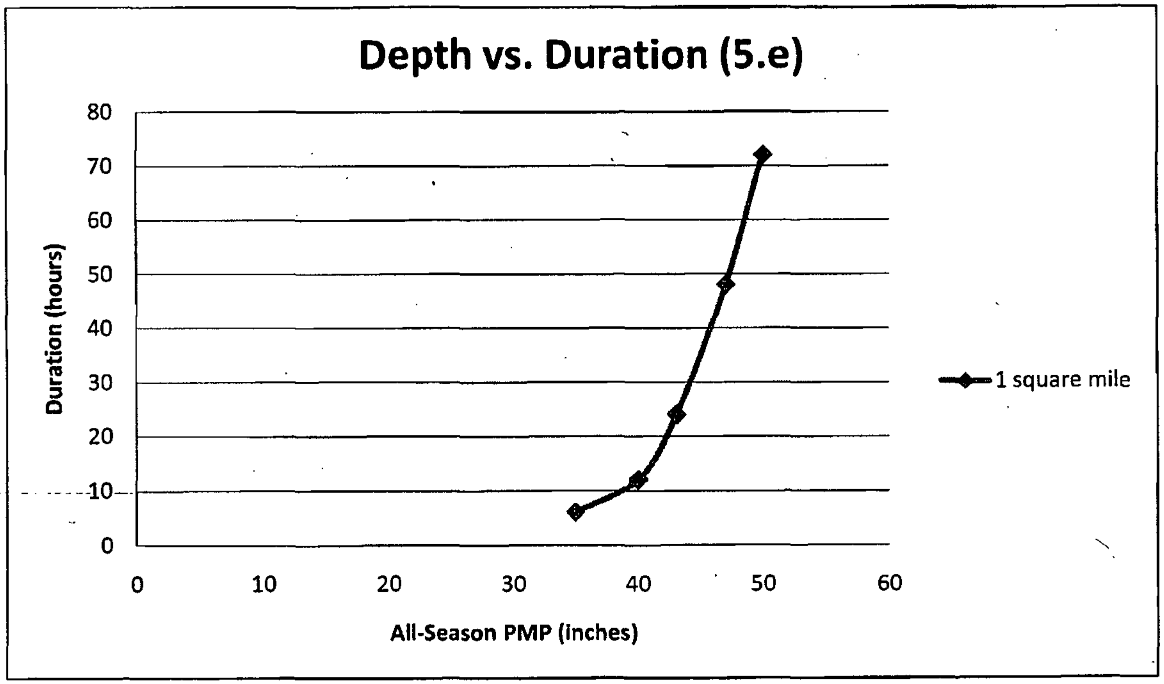
All-season PMP (inches) for Metropolis, Illinois (5.a & b)						
Duration (hours)	Drainage Area (square miles)					
	10	200	1000	5000	10000	20000
6	28.7	21	15.5	9.2	7.1	5.1
12	34	25.2	19.2	13	10.3	8.1
24	36.2	27.3	21.8	15.2	12.6	10.3
48	40	30.5	25	18.6	15.9	13.4
72	42	32.4	26.5	20.2	17.6	15

Ref: Hydrometorological Report No. 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian (HMR 51)



Interpolated from the Depth vs. Area graph:
All-season PMP (inches) for 1 square mile Drainage Area (5.d)

Duration (hours)	PMP (inches)
6	35
12	40
24	43
48	47
72	50



Interpolation from the Depth vs. Duration graph for Metropolis, Illinois for a 10 minute storm over 1 square mile, gives us a PMP of approximately 28 inches. Compare this to the 100-year 10 minute storm of 1.25 inches. At a tc of 10 min, the 100-year storm has an intensity of 7.49 in/hr. Using a simple ratio, the PMP has an intensity of 168 in/hr.

Stormwater Drainage Calculations

Riprap Sizing

Rock Slope Protection - 100-year event - Interior Dike Ditch

Ref: Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Safety Factors Method

1.0 Determine the Safety Factor (SF) for a given D_{50}

Use $$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta}$$ Equation 3.5

Where:

$$\eta' = \eta \frac{1+\sin(\lambda+\beta)}{2}$$ Equation 3.6

$$\eta = \frac{21\tau_0}{(G_s-1)\gamma D_{50}}$$ Equation 3.7

$$\tau_0 = \gamma DS$$ Equation 3.8

$$\beta = \arctan\left[\frac{\cos\lambda}{\frac{2\sin\theta}{\eta\tan\phi}+\sin\lambda}\right]$$ Equation 3.9

λ	=	as shown in Fig. 3.1; the angle between a horizontal line and the velocity vector component, V_r, measured in the plane of the side slope
θ	=	the side slope angle shown in Fig. 3.1
β	=	the angle between the vector component of the weight, W_s, directed down the side slope and the direction of particle movement
ϕ	=	the angle of repose of the riprap
τ_0	=	the bed shear stress
D_{50}	=	the representative median stone size
G_s	=	the specific weight of the rock
D	=	the depth of flow
γ	=	the specific weight of the liquid
S	=	the slope of the channel
η' and η	=	stability numbers
F_l and F_d	=	the lift and drag forces in Fig. 3.1

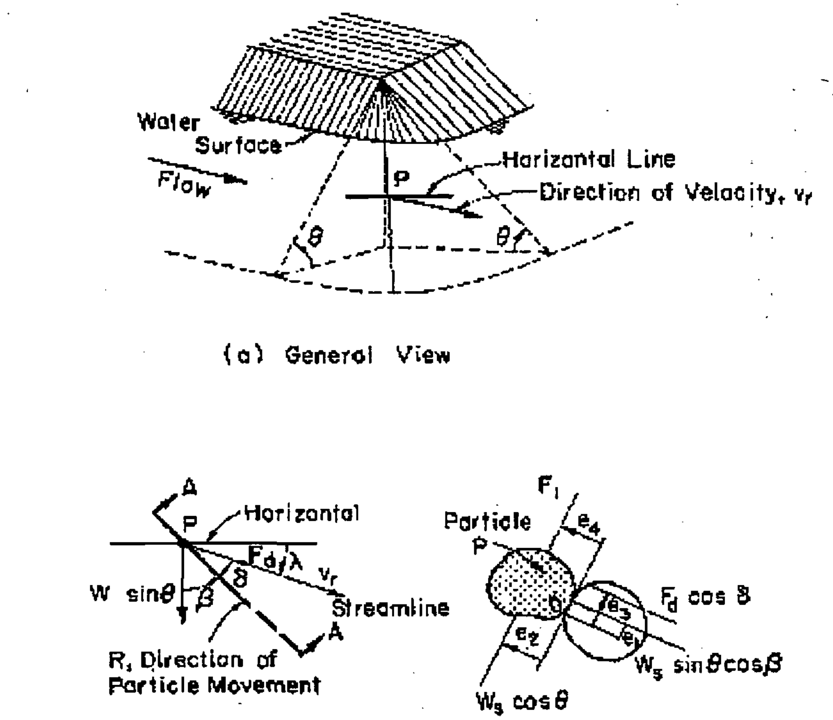


Figure 5.1. Riprap stability conditions as described in the Safety Factors Method.

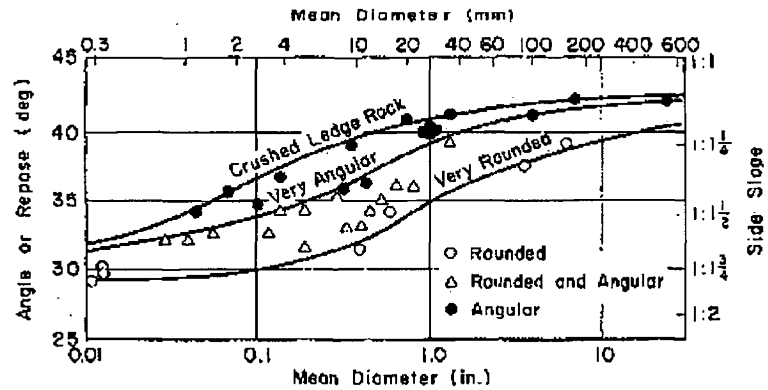


Figure 3.2. Angle of repose as a function of median stone diameter and shape.

Riprap within a conveyance ditch

Given Data:

S	=	1.00%		
λ	=	0.010000		
Ditch Sideslopes	=	2 : 1		(H:V)
θ	=	0.463648	radians	
ϕ	=	40	degrees	Figure 3.2 (Assumptions: very rounded 10" riprap)
	=	0.698132	radians	
D_{50}	=	16	inches	
	=	1.333333	feet	
G_s	=	2.66		
D	=	1.23	feet	(largest depth of flow from interior dike ditch sizing calculations)
γ	=	62.43	pounds/cubic foot (water)	

Calculations:

τ_0	=	0.767889
η	=	0.116702
β	=	0.108925
η'	=	0.065274
SF	=	1.503028

2.0 Determine the Riprap Size and Layer Thickness

Historic use of the Safety Factors Method has indicated that a minimum SF of 1.5 for non-probable maximum flood applications (i.e., 100-year events) provides a side slope with reliable stability and protection. However, an SF of slightly greater than 1.0 is recommended for probable maximum flood or maximum credible flood circumstances. It is recommended that the riprap thickness be a minimum of 1.5 times the D50.

Minimum D_{50} Riprap Size	=	16	inches
Minimum Riprap Layer Thickness	=	24	inches

Rock Slope Protection - PMP Event - Interior Dike Ditch

Ref: Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Safety Factors Method

1.0 Determine the Safety Factor (SF) for a given D_{50}

Use $$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta}$$ Equation 3.5

Where:

$$\eta' = \eta \frac{1 + \sin(\lambda + \beta)}{2}$$ Equation 3.6

$$\eta = \frac{21\tau_0}{(G_s - 1)\gamma D_{50}}$$ Equation 3.7

$$\tau_0 = \gamma DS$$ Equation 3.8

$$\beta = \arctan\left[\frac{\cos\lambda}{\frac{2\sin\theta}{\eta\tan\phi} + \sin\lambda}\right]$$ Equation 3.9

λ	=	as shown in Fig. 3.1, the angle between a horizontal line and the velocity vector component, V_r, measured in the plane of the side slope
θ	=	the side slope angle shown in Fig. 3.1
β	=	the angle between the vector component of the weight, W_s, directed down the side slope and the direction of particle movement
ϕ	=	the angle of repose of the riprap
τ_0	=	the bed shear stress
D_{50}	=	the representative median stone size
G_s	=	the specific weight of the rock
D	=	the depth of flow
γ	=	the specific weight of the liquid
S	=	the slope of the channel
η' and η	=	stability numbers
F_l and F_d	=	the lift and drag forces in Fig. 3.1

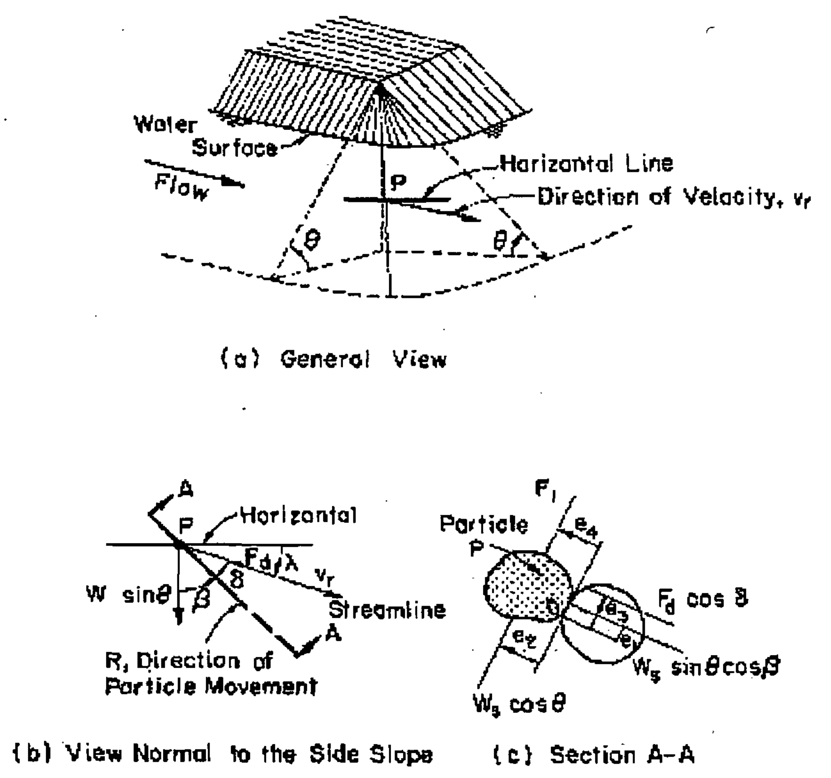


Figure 5.1. Riprap stability conditions as described in the Safety Factors Method.

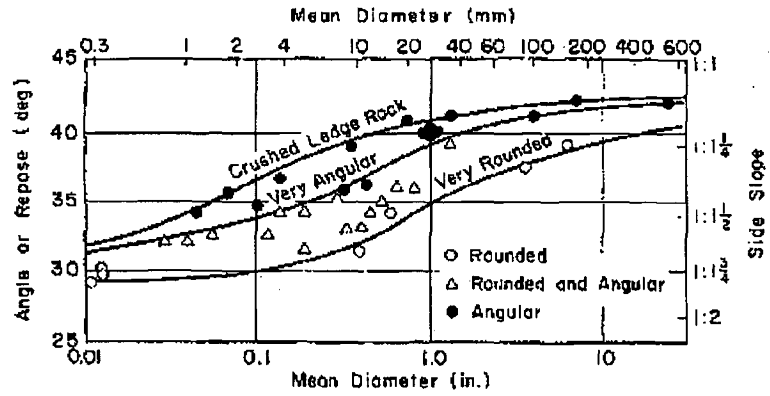


Figure 3.2. Angle of repose as a function of median stone diameter and shape.

Riprap within a conveyance ditch

Given Data:				
S	=	1.00%		
λ	=	0.010000		
Ditch Sideslopes	=	2 : 1		(H:V)
θ	=	0.463648	radians	
ϕ	=	40	degrees	Figure 3.2 (Assumptions: very rounded 10" riprap)
	=	0.698132	radians	
D_{50}	=	11	inches	
	=	0.916667	feet	
G_s	=	2.66		
D	=	3.93	feet	(largest depth of flow from interior dike ditch sizing calculations)
γ	=	62.43	pounds/cubic foot (water)	
Calculations:				
τ_0	=	2.453499		
η	=	0.542366		
β	=	0.468607		
η'	=	0.396074		
SF	=	1.026204		

2.0 Determine the Riprap Size and Layer Thickness

Historic use of the Safety Factors Method has indicated that a minimum SF of 1.5 for non-probable maximum flood applications (i.e., 100-year events) provides a side slope with reliable stability and protection. However, an SF of slightly greater than 1.0 is recommended for probable maximum flood or maximum credible flood circumstances. It is recommended that the riprap thickness be a minimum of 1.5 times the D50.

Minimum D_{50} Riprap Size	=	11	inches
Minimum Riprap Layer Thickness	=	16.5	inches

Rock Slope Protection - 100-year event - Perimeter Ditch

<u>Ref:</u> Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Safety Factors Method

<u>1.0 Determine the Safety Factor (SF) for a given D_{50}</u>

Use $$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta}$$ Equation 3.5

Where:

$$\eta' = \eta \frac{1+\sin(\lambda+\beta)}{2}$$ Equation 3.6

$$\eta = \frac{21\tau_0}{(G_s-1)\gamma D_{50}}$$ Equation 3.7

$$\tau_0 = \gamma DS$$ Equation 3.8

$$\beta = \arctan\left[\frac{\cos\lambda}{\frac{2\sin\theta}{\eta\tan\phi}+\sin\lambda}\right]$$ Equation 3.9

λ	=	as shown in Fig. 3.1, the angle between a horizontal line and the velocity vector component, V_r, measured in the plane of the side slope
θ	=	the side slope angle shown in Fig. 3.1
β	=	the angle between the vector component of the weight, W_s, directed down the side slope and the direction of particle movement
ϕ	=	the angle of repose of the riprap
τ_0	=	the bed shear stress
D_{50}	=	the representative median stone size
G_s	=	the specific weight of the rock
D	=	the depth of flow
γ	=	the specific weight of the liquid
S	=	the slope of the channel
η' and η	=	stability numbers
F_l and F_d	=	the lift and drag forces in Fig. 3.1

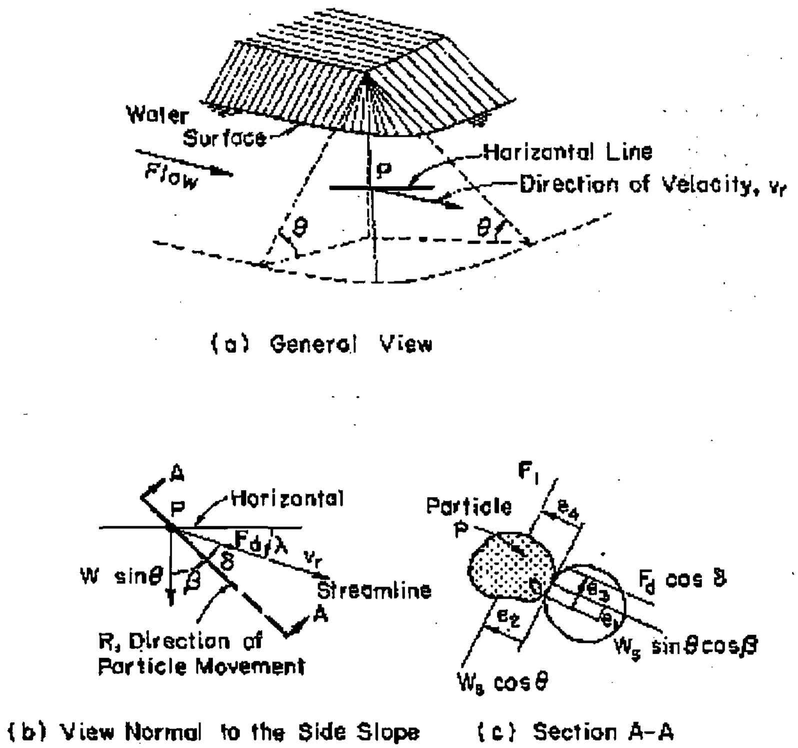


Figure 3.1. Riprap stability conditions as described in the Safety Factors Method.

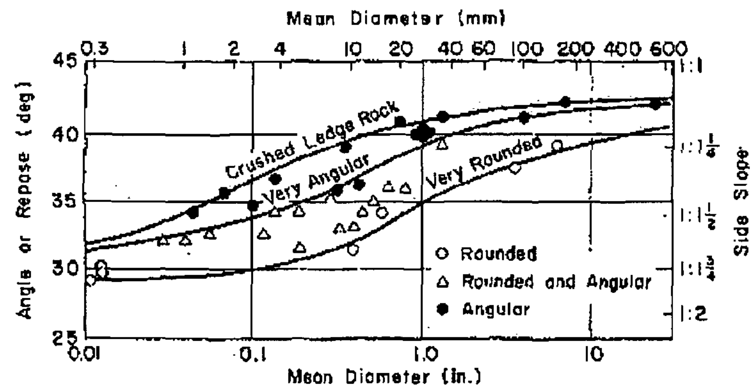


Figure 3.2. Angle of repose as a function of median stone diameter and shape.

Riprap within a conveyance ditch

Given Data:			
S	=	1.00%	
λ	=	0.010000	
Ditch Sideslopes	=	2 : 1	(H:V) worst case of ditch side slope
θ	=	0.463648	radians
ϕ	=	40	degrees Figure 3.2 (Assumptions: very rounded 10" riprap)
	=	0.698132	radians
D_{50}	=	26	inches
	=	2.166667	feet
G_s	=	2.66	
D	=	2.02	feet (largest depth of flow from interior dike ditch sizing calculations)
γ	=	62.43	pounds/cubic foot (water)
Calculations:			
τ_0	=	1.261086	
η	=	0.117943	
β	=	0.110072	
η'	=	0.066035	
SF	=	1.501276	

2.0 Determine the Riprap Size and Layer Thickness

Historic use of the Safety Factors Method has indicated that a minimum SF of 1.5 for non-probable maximum flood applications (i.e., 100-year events) provides a side slope with reliable stability and protection. However, an SF of slightly greater than 1.0 is recommended for probable maximum flood or maximum credible flood circumstances. It is recommended that the riprap thickness be a minimum of 1.5 times the D50.

Minimum D_{50} Riprap Size	=	26	inches
Minimum Riprap Layer Thickness	=	39	inches

Rock Slope Protection - PMP event - Perimeter Ditch

Ref: Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Safety Factors Method

1.0 Determine the Safety Factor (SF) for a given D_{50}

Use

$$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta}$$ Equation 3.5

Where:

$$\eta' = \eta \frac{1+\sin(\lambda+\beta)}{2}$$ Equation 3.6

$$\eta = \frac{21\tau_0}{(G_s-1)\gamma D_{50}}$$ Equation 3.7

$$\tau_0 = \gamma DS$$ Equation 3.8

$$\beta = \arctan\left[\frac{\cos\lambda}{\frac{2\sin\theta}{\eta\tan\phi}+\sin\lambda}\right]$$ Equation 3.9

λ	=	as shown in Fig. 3.1, the angle between a horizontal line and the velocity vector component, V_r, measured in the plane of the side slope
θ	=	the side slope angle shown in Fig. 3.1
β	=	the angle between the vector component of the weight, W_s, directed down the side slope and the direction of particle movement
ϕ	=	the angle of repose of the riprap
τ_0	=	the bed shear stress
D_{50}	=	the representative median stone size
G_s	=	the specific weight of the rock
D	=	the depth of flow
γ	=	the specific weight of the liquid
S	=	the slope of the channel
η' and η	=	stability numbers
F_l and F_d	=	the lift and drag forces in Fig. 3.1

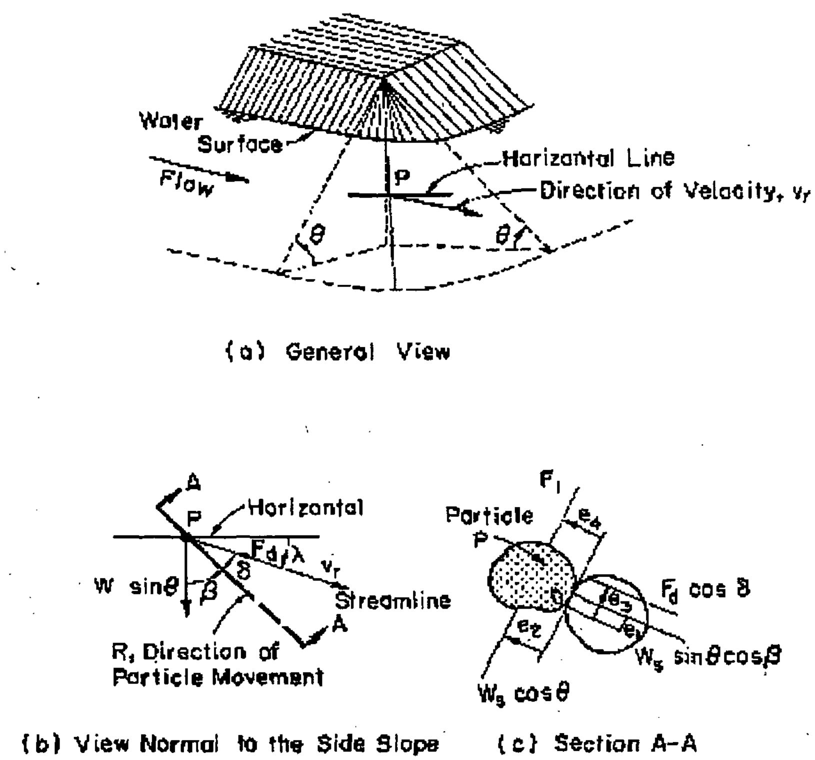


Figure 3.1. Riprap stability conditions as described in the Safety Factors Method.

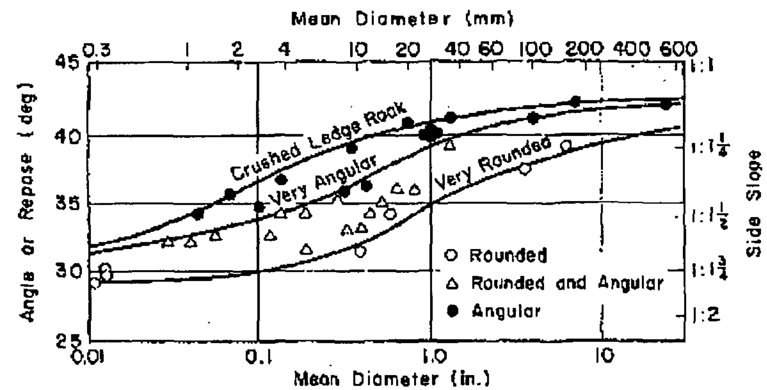


Figure 3.2. Angle of repose as a function of median stone diameter and shape.

Riprap within a conveyance ditch

Given Data:				
S	=	1.00%		
λ	=	0.010000		
Ditch Sideslopes	=	2 : 1		(H:V) worst case of ditch side slope
θ	=	0.463648	radians	
ϕ	=	40	degrees	Figure 3.2 (Assumptions: very rounded 10" riprap)
	=	0.698132	radians	
D_{50}	=	18	inches	
	=	1.5	feet	
G_s	=	2.66		
D	=	6.47	feet	(largest depth of flow from interior dike ditch sizing calculations)
γ	=	62.43	pounds/cubic foot (water)	
Calculations:				
τ_0	=	4.039221		
η	=	0.545663		
β	=	0.471041		
η'	=	0.399071		
SF	=	1.023375		

2.0 Determine the Riprap Size and Layer Thickness

Historic use of the Safety Factors Method has indicated that a minimum SF of 1.5 for non-probable maximum flood applications (i.e., 100-year events) provides a side slope with reliable stability and protection. However, an SF of slightly greater than 1.0 is recommended for probable maximum flood or maximum credible flood circumstances. It is recommended that the riprap thickness be a minimum of 1.5 times the D50.

Minimum D_{50} Riprap Size	=	18	inches
Minimum Riprap Layer Thickness	=	27	inches

Rock Slope Protection - 100-year event

Ref: Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Stephenson Method

1.0 Determine the D_{50}

Use

$$D_{50} = \left[\frac{q(\tan\theta)^{\frac{7}{6}} n_p^{\frac{1}{6}}}{C g^{\frac{1}{2}} \left[(1-n_p)(G_s-1)\cos\theta(\tan\phi - \tan\theta)\right]^{\frac{5}{3}}} \right]^{\frac{2}{3}}$$

Equation 3.15

Where:

q	=	the maximum flow rate per unit width
n_p	=	the rockfill porosity
g	=	the acceleration of gravity
G_s	=	the relative density of the rock
θ	=	the angle of the slope measured from the horizontal
ϕ	=	the angle of friction
C	=	the empirical factor (varies from 0.22 for gravel and pebbles to 0.27 for crushed granite)
D_{50}	=	the representative median stone size

Riprap along a side slope

Given Data:			
Q	=	7.67	cubic feet per second
Average width of contributing area	=	177.00	feet
q	=	0.043333	cubic feet per second/foot (maximum at A E-4)
n_p	=	50.00%	(to be conservative)
g	=	32.2	feet per second squared
G_s	=	2.66	
Sideslopes	=	2 : 1	(H:V)
θ	=	0.463648	radians
ϕ	=	40	degrees (figure 3.2, Safety Factors Method)
	=	0.698132	radians
C	=	0.220	(to be conservative)
Calculations:			
D_{50}	=	0.266078	feet
	=	3.192939	inches

2.0 Determine the Riprap Size and Layer Thickness

NUREG/CR-4651 recommends that the riprap thickness be a minimum of 2 times the D50.

Minimum D_{50} Riprap Size	=	4	inches
Minimum Riprap Layer Thickness	=	8	inches

Rock Slope Protection - PMP Event

<u>Ref:</u> Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II
Division of Low Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
NUREG/CR-4651, ORNL/TM-10100/V2
Obtained from National Technical Information Service: U.S. Department of Commerce

Stephenson Method

1.0 Determine the D_{50}

Use

$$D_{50} = \left[\frac{q(\tan\theta)^{\frac{7}{6}} n_p^{\frac{1}{6}}}{Cg^{\frac{1}{2}}\left[(1-n_p)(G_s-1)\cos\theta(\tan\phi-\tan\theta)\right]^{\frac{5}{3}}} \right]^{\frac{2}{3}}$$

Equation 3.15

Where:

q	=	the maximum flow rate per unit width
n_p	=	the rockfill porosity
g	=	the acceleration of gravity
G_s	=	the relative density of the rock
θ	=	the angle of the slope measured from the horizontal
ϕ	=	the angle of friction
C	=	the empirical factor (varies from 0.22 for gravel and pebbles to 0.27 for crushed granite)
D_{50}	=	the representative median stone size

Riprap along a side slope

Given Data:			
Q	=	172.14	cubic feet per second
Average width of contributing area	=	177.00	feet
q	=	0.972542	cubic feet per second/foot (maximum of all contributing areas)
n_p	=	50.00%	(to be conservative)
g	=	32.2	feet per second squared
G_s	=	2.66	
Sideslopes	=	3 : 1	(H:V)
θ	=	0.321751	radians
ϕ	=	40	degrees (figure 3.2, Safety Factors Method)
	=	0.698132	radians
C	=	0.220	(to be conservative)
Calculations:			
D_{50}	=	0.927773	feet
	=	11.13328	inches

<u>2.0 Determine the Riprap Size and Layer Thickness</u>

NUREG/CR-4651 recommends that the riprap thickness be a minimum of 2 times the D50.

Minimum D_{50} Riprap Size	=	12	inches
Minimum Riprap Layer Thickness	=	24	inches

Stormwater Drainage Calculations

Culvert Sizing

HY-8 Culvert Analysis Report

Table 1 - Summary of Culvert Flows at Crossing: C1

Headwater Elevation (ft)	Total Discharge (cfs)	C1 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
378.11	8.48	8.48	0.00	1
378.11	8.50	8.50	0.00	1
378.11	8.52	8.52	0.00	1
378.11	8.54	8.54	0.00	1
378.11	8.56	8.56	0.00	1
378.12	8.58	8.58	0.00	1
378.12	8.60	8.60	0.00	1
378.12	8.62	8.62	0.00	1
378.12	8.64	8.64	0.00	1
378.12	8.66	8.66	0.00	1
378.13	8.68	8.68	0.00	1
381.00	29.19	29.19	0.00	Overtopping

Rating Curve Plot for Crossing: C1

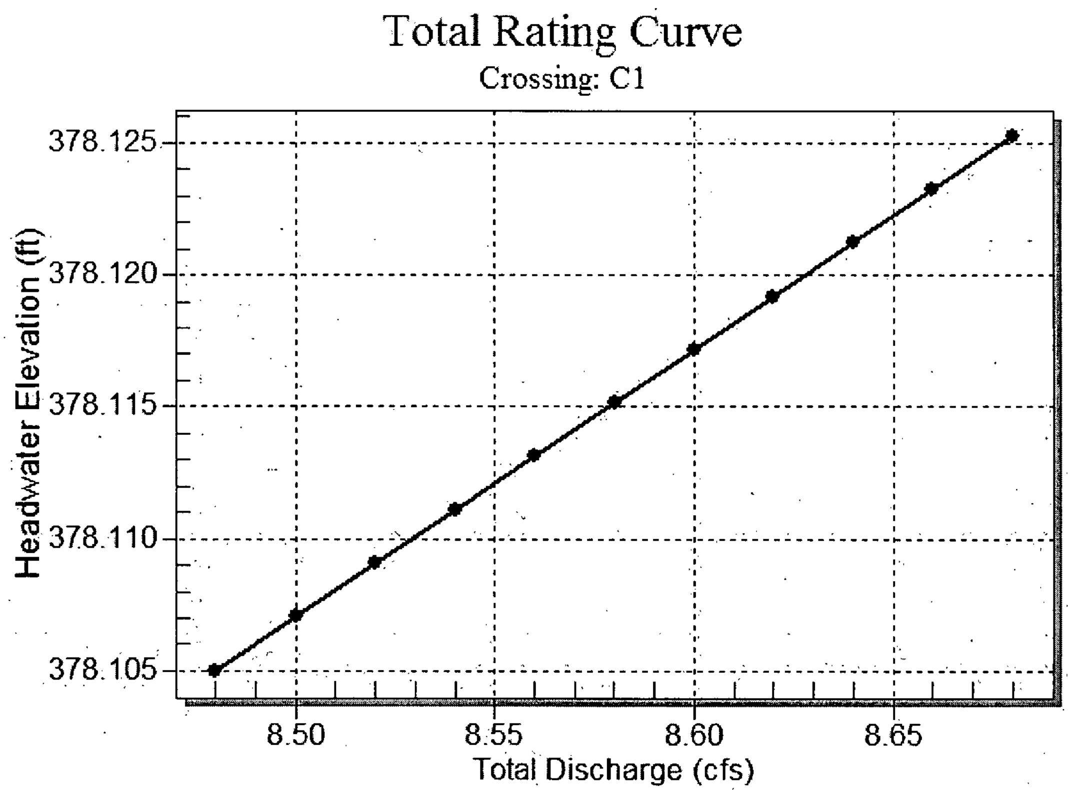


Table 2 - Culvert Summary Table: C1

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
8.48	8.48	378.11	1.435	0.0*	1-S2n	0.701	1.035	0.704	1.222	8.555	2.838
8.50	8.50	378.11	1.437	0.0*	1-S2n	0.702	1.036	0.705	1.223	8.556	2.840
8.52	8.52	378.11	1.439	0.0*	1-S2n	0.703	1.038	0.707	1.224	8.556	2.842
8.54	8.54	378.11	1.441	0.0*	1-S2n	0.704	1.039	0.708	1.225	8.556	2.843
8.56	8.56	378.11	1.443	0.0*	1-S2n	0.705	1.040	0.709	1.227	8.556	2.845
8.58	8.58	378.12	1.445	0.0*	1-S2n	0.706	1.041	0.710	1.228	8.556	2.847
8.60	8.60	378.12	1.447	0.0*	1-S2n	0.707	1.043	0.712	1.229	8.557	2.848
8.62	8.62	378.12	1.449	0.0*	1-S2n	0.708	1.044	0.713	1.230	8.557	2.850
8.64	8.64	378.12	1.451	0.0*	1-S2n	0.708	1.045	0.714	1.231	8.557	2.852
8.66	8.66	378.12	1.453	0.0*	1-S2n	0.709	1.046	0.715	1.232	8.557	2.853
8.68	8.68	378.13	1.455	0.0*	1-S2n	0.710	1.047	0.716	1.233	8.557	2.855

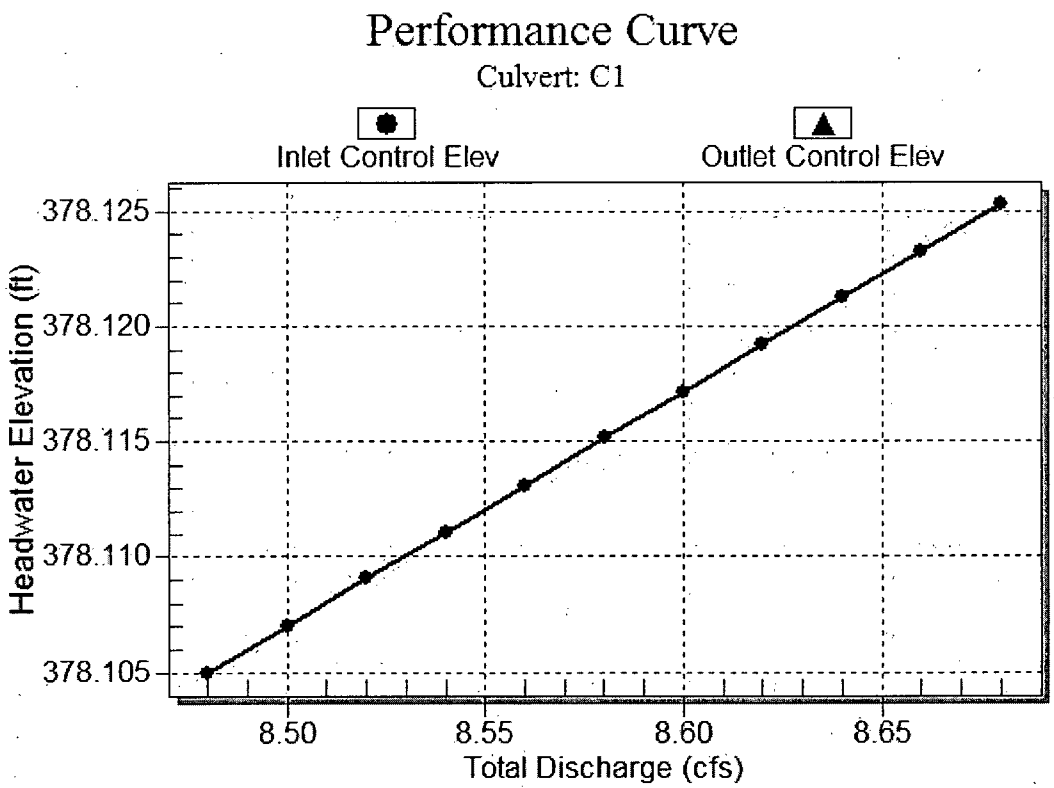
****

Inlet Elevation (invert): 376.67 ft, Outlet Elevation (invert): 374.00 ft

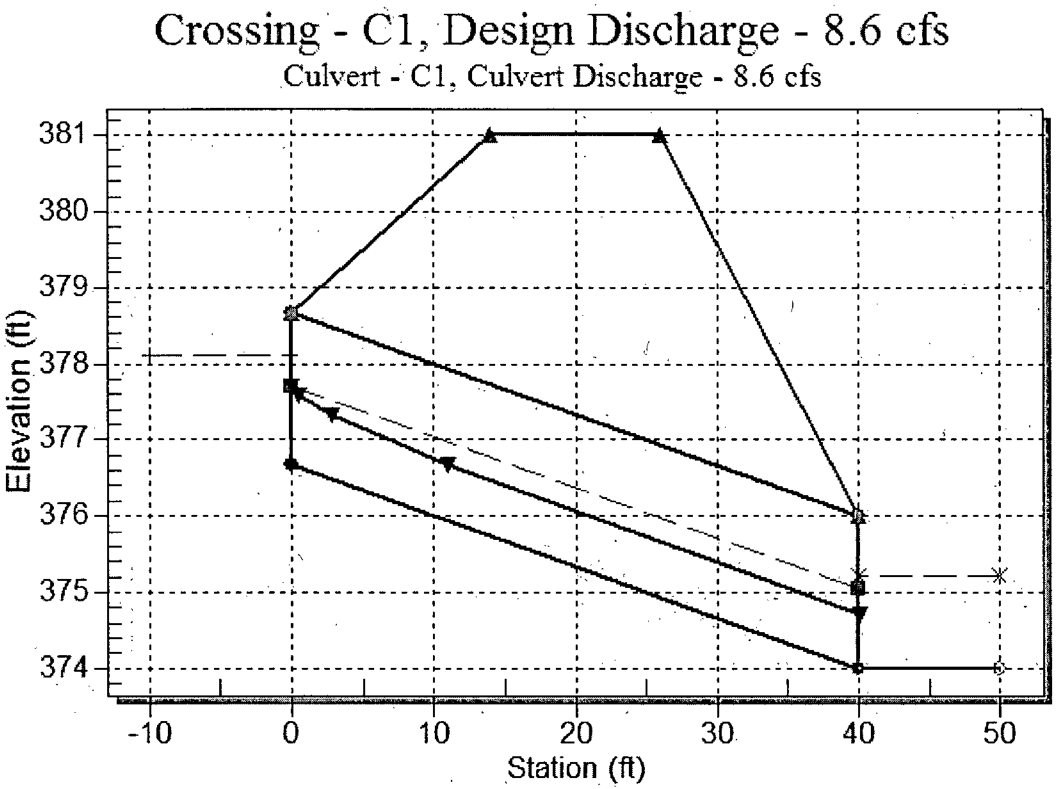
Culvert Length: 40.09 ft, Culvert Slope: 0.0668

****

Culvert Performance Curve Plot: C1



Water Surface Profile Plot for Culvert: C1



Site Data - C1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 376.67 ft

Outlet Station: 40.00 ft

Outlet Elevation: 374.00 ft

Number of Barrels: 1

Culvert Data Summary - C1

Barrel Shape: Circular

Barrel Diameter: 2.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 3 - Downstream Channel Rating Curve (Crossing: C1)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
8.48	375.22	1.22	2.84	0.76	0.64
8.50	375.22	1.22	2.84	0.76	0.64
8.52	375.22	1.22	2.84	0.76	0.64
8.54	375.23	1.23	2.84	0.76	0.64
8.56	375.23	1.23	2.84	0.77	0.64
8.58	375.23	1.23	2.85	0.77	0.64
8.60	375.23	1.23	2.85	0.77	0.64
8.62	375.23	1.23	2.85	0.77	0.64
8.64	375.23	1.23	2.85	0.77	0.64
8.66	375.23	1.23	2.85	0.77	0.64
8.68	375.23	1.23	2.85	0.77	0.64

Tailwater Channel Data - C1

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 374.00 ft

Roadway Data for Crossing: C1

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 381.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 4 - Summary of Culvert Flows at Crossing: C2

Headwater Elevation (ft)	Total Discharge (cfs)	C2 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
381.19	3.08	3.08	0.00	1
381.19	3.10	3.10	0.00	1
381.20	3.12	3.12	0.00	1
381.21	3.14	3.14	0.00	1
381.22	3.16	3.16	0.00	1
381.22	3.18	3.18	0.00	1
381.22	3.18	3.18	0.00	1
381.24	3.22	3.22	0.00	1
381.24	3.24	3.24	0.00	1
381.25	3.26	3.26	0.00	1
381.26	3.28	3.28	0.00	1
383.00	6.48	6.48	0.00	Overtopping

Rating Curve Plot for Crossing: C2

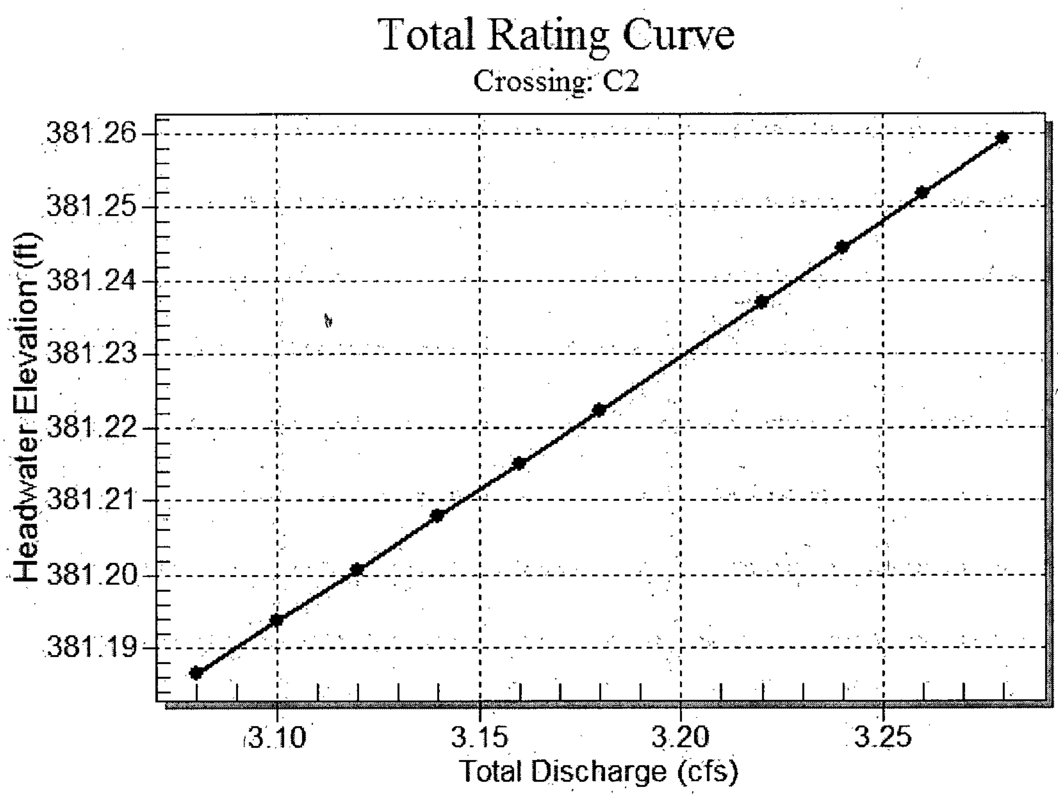


Table 5 - Culvert Summary Table: C2

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
3.08	3.08	381.19	1.117	0.0*	5-S2n	0.411	0.749	0.412	0.836	10.120	2.203
3.10	3.10	381.19	1.124	0.0*	5-S2n	0.412	0.752	0.413	0.838	10.154	2.207
3.12	3.12	381.20	1.131	0.0*	5-S2n	0.414	0.754	0.414	0.840	10.179	2.211
3.14	3.14	381.21	1.138	0.0*	5-S2n	0.415	0.756	0.415	0.842	10.198	2.214
3.16	3.16	381.22	1.145	0.0*	5-S2n	0.416	0.759	0.418	0.844	10.188	2.218
3.18	3.18	381.22	1.152	0.0*	5-S2n	0.418	0.761	0.418	0.846	10.240	2.221
3.18	3.18	381.22	1.152	0.0*	5-S2n	0.418	0.761	0.418	0.846	10.240	2.221
3.22	3.22	381.24	1.167	0.0*	5-S2n	0.421	0.766	0.421	0.850	10.282	2.228
3.24	3.24	381.24	1.174	0.0*	5-S2n	0.422	0.768	0.422	0.852	10.302	2.232
3.26	3.26	381.25	1.182	0.0*	5-S2n	0.424	0.771	0.424	0.854	10.323	2.235
3.28	3.28	381.26	1.189	0.0*	5-S2n	0.425	0.773	0.425	0.856	10.343	2.238

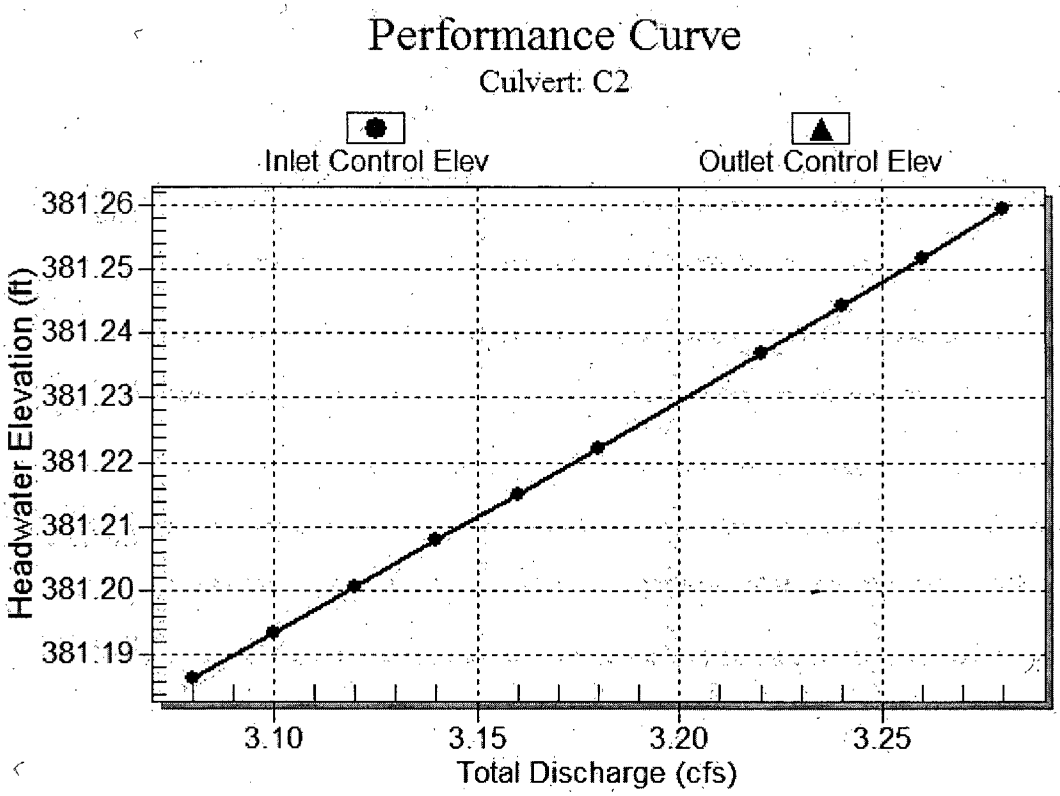
****

Inlet Elevation (invert): 380.07 ft, Outlet Elevation (invert): 372.00 ft

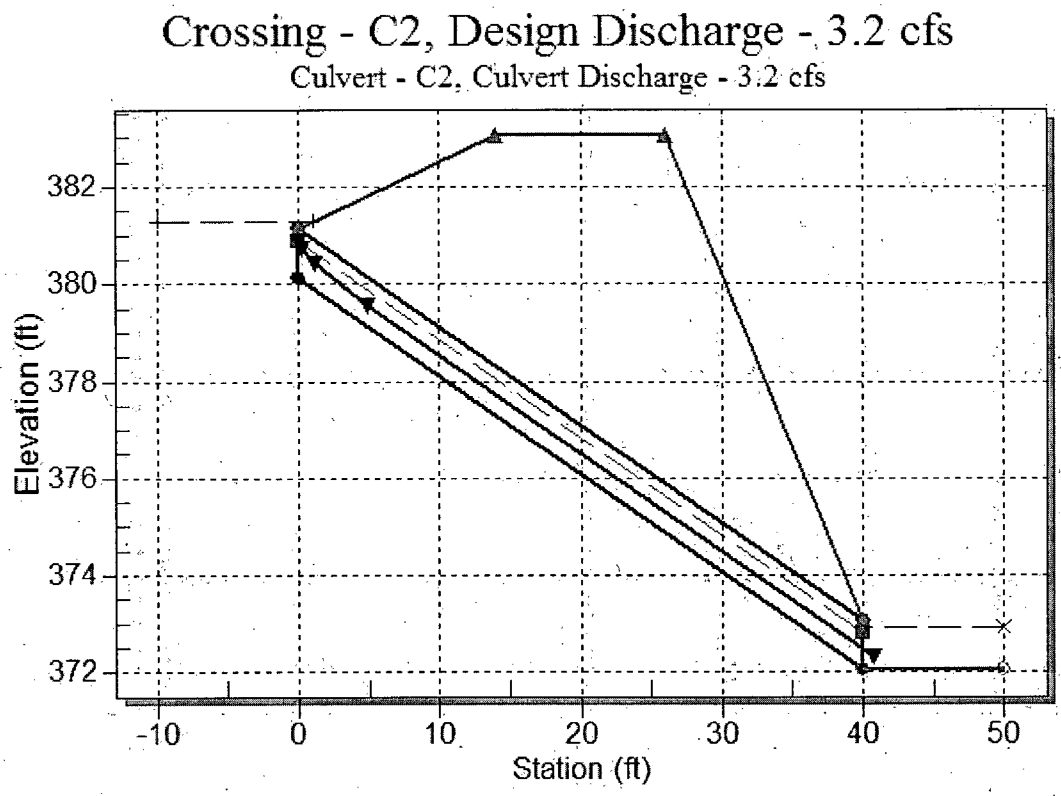
Culvert Length: 40.81 ft, Culvert Slope: 0.2017

****

Culvert Performance Curve Plot: C2



Water Surface Profile Plot for Culvert: C2



Site Data - C2

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 380.07 ft

Outlet Station: 40.00 ft

Outlet Elevation: 372.00 ft

Number of Barrels: 1

Culvert Data Summary - C2

Barrel Shape: Circular

Barrel Diameter: 1.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 6 - Downstream Channel Rating Curve (Crossing: C2)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
3.08	372.84	0.84	2.20	0.52	0.60
3.10	372.84	0.84	2.21	0.52	0.60
3.12	372.84	0.84	2.21	0.52	0.60
3.14	372.84	0.84	2.21	0.53	0.60
3.16	372.84	0.84	2.22	0.53	0.60
3.18	372.85	0.85	2.22	0.53	0.60
3.18	372.85	0.85	2.22	0.53	0.60
3.22	372.85	0.85	2.23	0.53	0.60
3.24	372.85	0.85	2.23	0.53	0.60
3.26	372.85	0.85	2.23	0.53	0.60
3.28	372.86	0.86	2.24	0.53	0.60

Tailwater Channel Data - C2

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 372.00 ft

Roadway Data for Crossing: C2

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 383.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 7 - Summary of Culvert Flows at Crossing: C3

Headwater Elevation (ft)	Total Discharge (cfs)	C3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
382.57	1.16	1.16	0.00	1
382.58	1.18	1.18	0.00	1
382.59	1.20	1.20	0.00	1
382.59	1.22	1.22	0.00	1
382.60	1.24	1.24	0.00	1
382.60	1.26	1.26	0.00	1
382.61	1.28	1.28	0.00	1
382.62	1.30	1.30	0.00	1
382.62	1.32	1.32	0.00	1
382.63	1.34	1.34	0.00	1
382.63	1.36	1.36	0.00	1
384.00	4.94	4.94	0.00	Overtopping

Rating Curve Plot for Crossing: C3

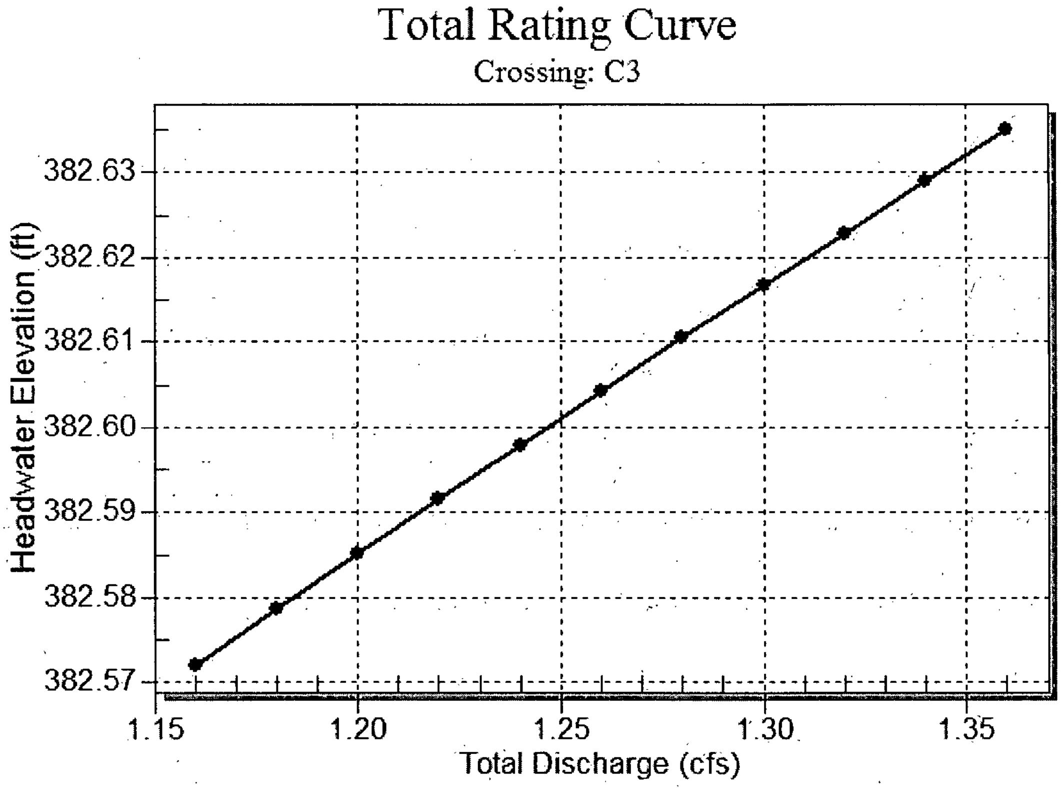


Table 8 - Culvert Summary Table: C3

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
1.16	1.16	382.57	0.572	0.0*	1-S2n	0.262	0.451	0.264	0.580	6.932	1.726
1.18	1.18	382.58	0.579	0.0*	1-S2n	0.265	0.455	0.265	0.583	7.014	1.734
1.20	1.20	382.59	0.585	0.0*	1-S2n	0.267	0.460	0.269	0.587	7.017	1.741
1.22	1.22	382.59	0.592	0.0*	1-S2n	0.270	0.464	0.273	0.591	6.989	1.748
1.24	1.24	382.60	0.598	0.0*	1-S2n	0.272	0.468	0.277	0.594	6.962	1.755
1.26	1.26	382.60	0.604	0.0*	1-S2n	0.275	0.472	0.276	0.598	7.104	1.762
1.28	1.28	382.61	0.610	0.0*	1-S2n	0.277	0.476	0.279	0.601	7.109	1.769
1.30	1.30	382.62	0.617	0.0*	1-S2n	0.279	0.480	0.280	0.605	7.185	1.776
1.32	1.32	382.62	0.623	0.0*	1-S2n	0.282	0.484	0.283	0.608	7.185	1.783
1.34	1.34	382.63	0.629	0.0*	1-S2n	0.284	0.488	0.287	0.612	7.155	1.790
1.36	1.36	382.63	0.635	0.0*	1-S2n	0.287	0.492	0.287	0.615	7.258	1.796

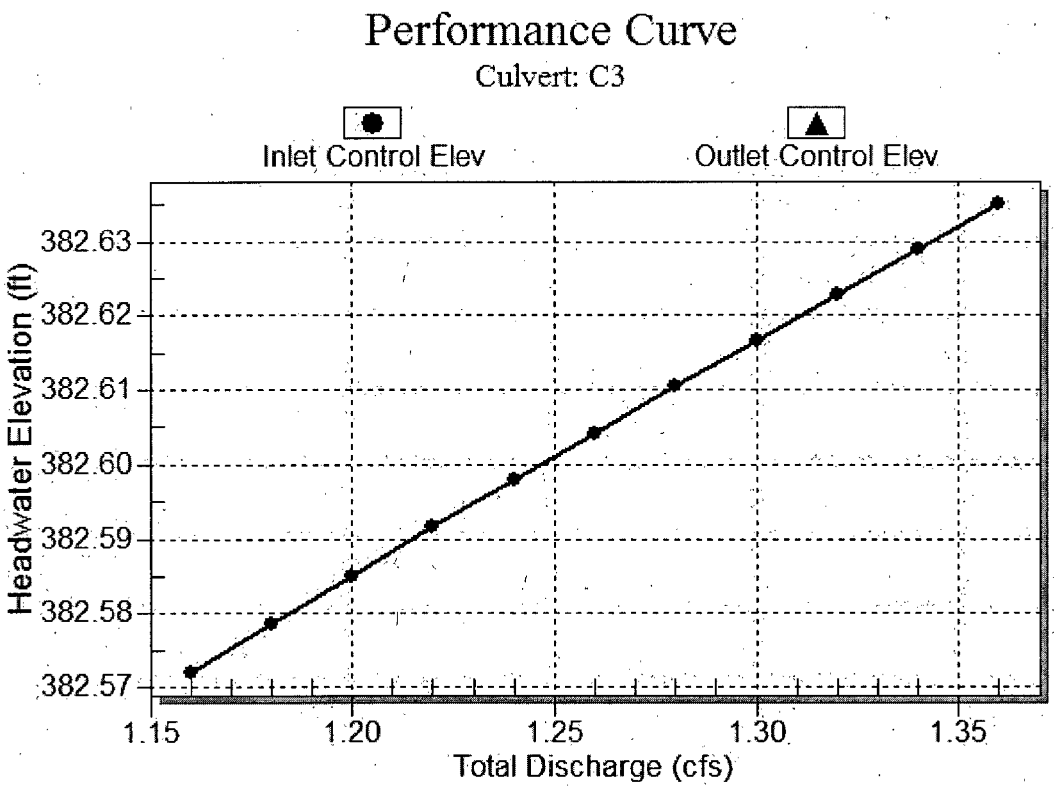
****

Inlet Elevation (invert): 382.00 ft, Outlet Elevation (invert): 376.00 ft

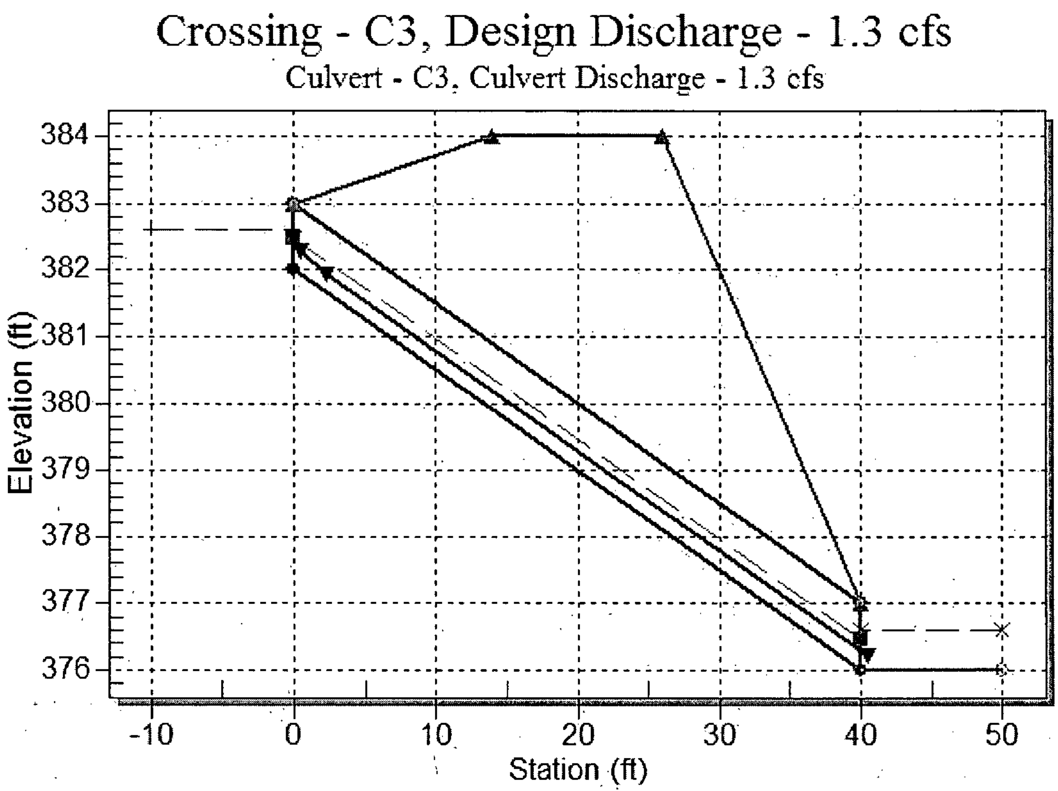
Culvert Length: 40.45 ft, Culvert Slope: 0.1500

****

Culvert Performance Curve Plot: C3



Water Surface Profile Plot for Culvert: C3



Site Data - C3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 382.00 ft

Outlet Station: 40.00 ft

Outlet Elevation: 376.00 ft

Number of Barrels: 1

Culvert Data Summary - C3

Barrel Shape: Circular

Barrel Diameter: 1.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 9 - Downstream Channel Rating Curve (Crossing: C3)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
1.16	376.58	0.58	1.73	0.36	0.57
1.18	376.58	0.58	1.73	0.36	0.57
1.20	376.59	0.59	1.74	0.37	0.57
1.22	376.59	0.59	1.75	0.37	0.57
1.24	376.59	0.59	1.76	0.37	0.57
1.26	376.60	0.60	1.76	0.37	0.57
1.28	376.60	0.60	1.77	0.38	0.57
1.30	376.60	0.60	1.78	0.38	0.57
1.32	376.61	0.61	1.78	0.38	0.57
1.34	376.61	0.61	1.79	0.38	0.57
1.36	376.62	0.62	1.80	0.38	0.57

Tailwater Channel Data - C3

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 376.00 ft

Roadway Data for Crossing: C3

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 384.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 10 - Summary of Culvert Flows at Crossing: C4

Headwater Elevation (ft)	Total Discharge (cfs)	C4 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
377.46	4.34	4.34	0.00	1
377.47	4.36	4.36	0.00	1
377.47	4.38	4.38	0.00	1
377.47	4.40	4.40	0.00	1
377.48	4.42	4.42	0.00	1
377.48	4.44	4.44	0.00	1
377.48	4.44	4.44	0.00	1
377.49	4.48	4.48	0.00	1
377.49	4.50	4.50	0.00	1
377.49	4.52	4.52	0.00	1
377.50	4.54	4.54	0.00	1
380.00	15.43	15.43	0.00	Overtopping

Rating Curve Plot for Crossing: C4

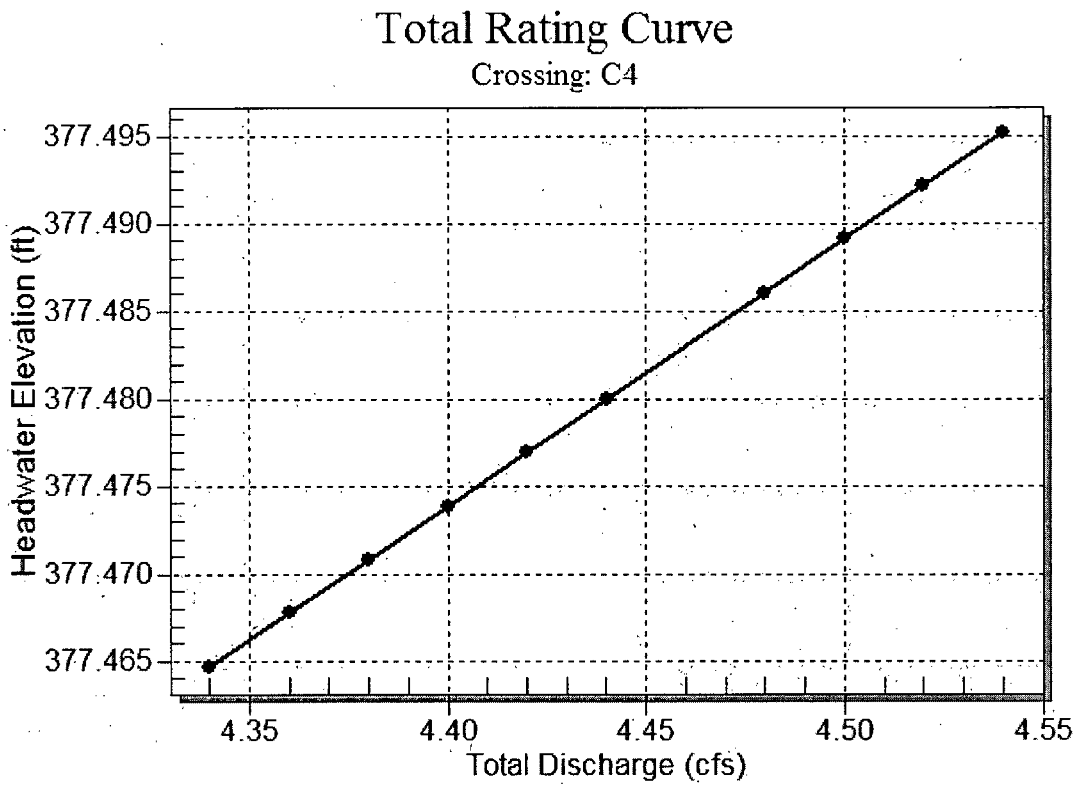


Table 11 - Culvert Summary Table: C4

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
4.34	4.34	377.46	1.115	0.0*	1-S2n	0.576	0.796	0.576	0.951	6.937	2.401
4.36	4.36	377.47	1.118	0.0*	1-S2n	0.577	0.798	0.578	0.952	6.939	2.403
4.38	4.38	377.47	1.121	0.0*	1-S2n	0.579	0.800	0.579	0.954	6.955	2.406
4.40	4.40	377.47	1.124	0.0*	1-S2n	0.580	0.802	0.581	0.956	6.958	2.409
4.42	4.42	377.48	1.127	0.0*	1-S2n	0.582	0.803	0.582	0.957	6.960	2.412
4.44	4.44	377.48	1.130	0.0*	1-S2n	0.583	0.805	0.584	0.959	6.962	2.414
4.44	4.44	377.48	1.130	0.0*	1-S2n	0.583	0.805	0.584	0.959	6.962	2.414
4.48	4.48	377.49	1.136	0.0*	1-S2n	0.586	0.809	0.588	0.962	6.967	2.420
4.50	4.50	377.49	1.139	0.0*	1-S2n	0.588	0.811	0.590	0.964	6.969	2.423
4.52	4.52	377.49	1.142	0.0*	1-S2n	0.589	0.813	0.592	0.965	6.971	2.425
4.54	4.54	377.50	1.145	0.0*	1-S2n	0.591	0.815	0.592	0.967	7.004	2.428

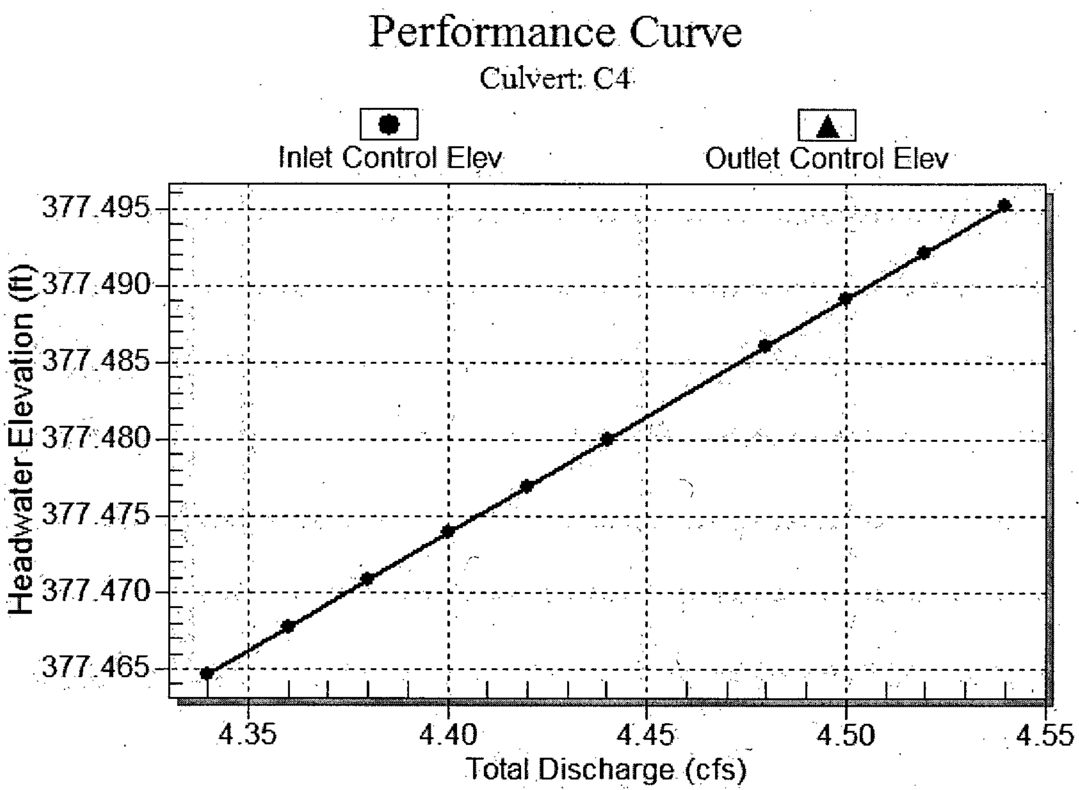
****

Inlet Elevation (invert): 376.35 ft, Outlet Elevation (invert): 374.00 ft

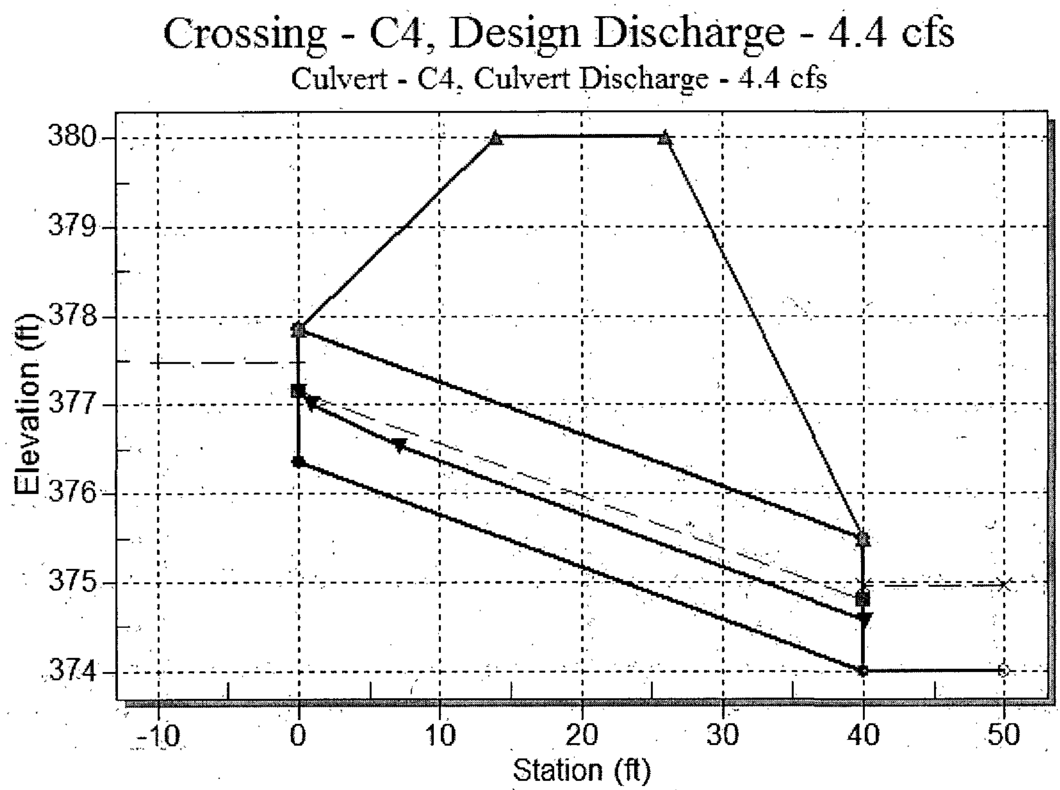
Culvert Length: 40.07 ft, Culvert Slope: 0.0588

****

Culvert Performance Curve Plot: C4



Water Surface Profile Plot for Culvert: C4



Site Data - C4

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 376.35 ft

Outlet Station: 40.00 ft

Outlet Elevation: 374.00 ft

Number of Barrels: 1

Culvert Data Summary - C4

Barrel Shape: Circular

Barrel Diameter: 1.50 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 12 - Downstream Channel Rating Curve (Crossing: C4)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
4.34	374.95	0.95	2.40	0.59	0.61
4.36	374.95	0.95	2.40	0.59	0.61
4.38	374.95	0.95	2.41	0.60	0.61
4.40	374.96	0.96	2.41	0.60	0.61
4.42	374.96	0.96	2.41	0.60	0.61
4.44	374.96	0.96	2.41	0.60	0.61
4.44	374.96	0.96	2.41	0.60	0.61
4.48	374.96	0.96	2.42	0.60	0.61
4.50	374.96	0.96	2.42	0.60	0.61
4.52	374.97	0.97	2.43	0.60	0.62
4.54	374.97	0.97	2.43	0.60	0.62

Tailwater Channel Data - C4

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 374.00 ft

Roadway Data for Crossing: C4

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 380.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 13 - Summary of Culvert Flows at Crossing: C5

Headwater Elevation (ft)	Total Discharge (cfs)	C5 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
379.26	8.51	8.51	0.00	1
379.26	8.53	8.53	0.00	1
379.26	8.55	8.55	0.00	1
379.26	8.57	8.57	0.00	1
379.26	8.59	8.59	0.00	1
379.27	8.61	8.61	0.00	1
379.27	8.63	8.63	0.00	1
379.27	8.65	8.65	0.00	1
379.27	8.67	8.67	0.00	1
379.28	8.69	8.69	0.00	1
379.28	8.71	8.71	0.00	1
384.00	32.14	32.14	0.00	Overtopping

Rating Curve Plot for Crossing: C5

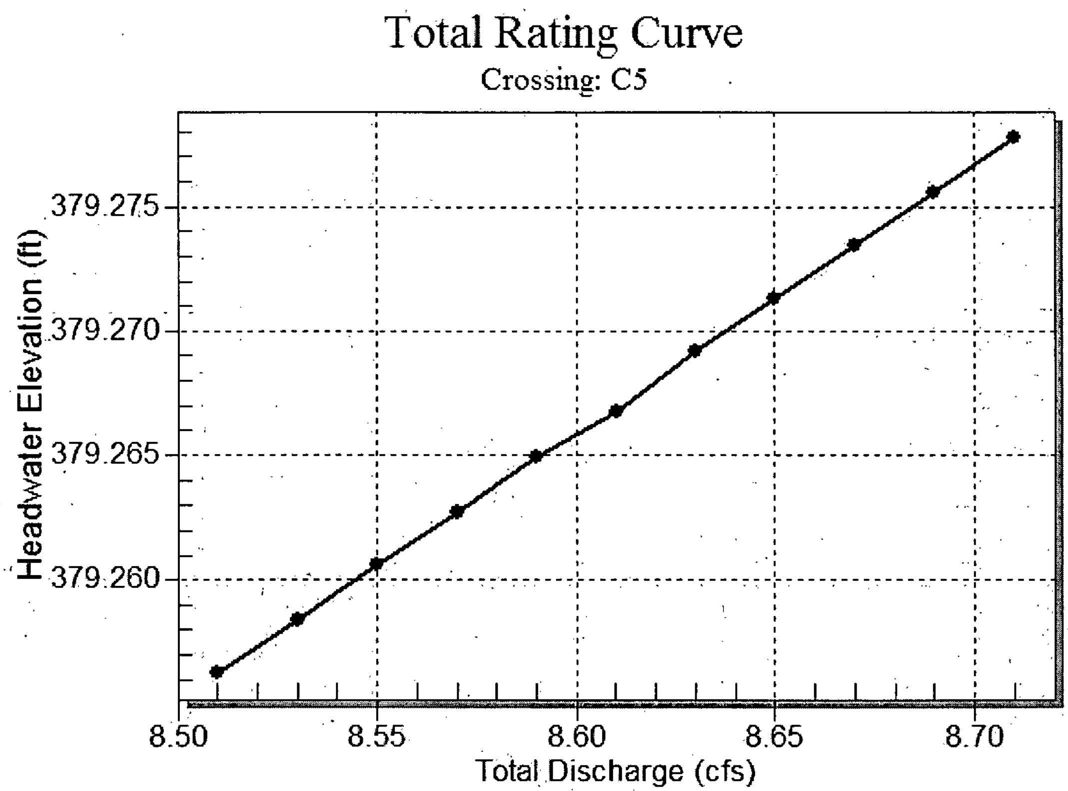


Table 14 - Culvert Summary Table: C5

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
8.51	8.51	379.26	1.495	1.556	3-M2t	1.226	1.037	1.224	1.224	4.224	2.841
8.53	8.53	379.26	1.497	1.558	3-M2t	1.228	1.038	1.225	1.225	4.229	2.842
8.55	8.55	379.26	1.499	1.561	3-M2t	1.230	1.040	1.226	1.226	4.235	2.844
8.57	8.57	379.26	1.501	1.563	3-M2t	1.232	1.041	1.227	1.227	4.240	2.846
8.59	8.59	379.26	1.503	1.565	3-M2t	1.234	1.042	1.228	1.228	4.246	2.847
8.61	8.61	379.27	1.505	1.567	3-M2t	1.236	1.043	1.229	1.229	4.251	2.849
8.63	8.63	379.27	1.507	1.569	3-M2t	1.238	1.044	1.230	1.230	4.257	2.851
8.65	8.65	379.27	1.509	1.571	3-M2t	1.239	1.046	1.231	1.231	4.262	2.852
8.67	8.67	379.27	1.511	1.573	3-M2t	1.241	1.047	1.232	1.232	4.268	2.854
8.69	8.69	379.28	1.513	1.576	3-M2t	1.243	1.048	1.233	1.233	4.273	2.856
8.71	8.71	379.28	1.515	1.578	3-M2t	1.245	1.049	1.235	1.235	4.279	2.857

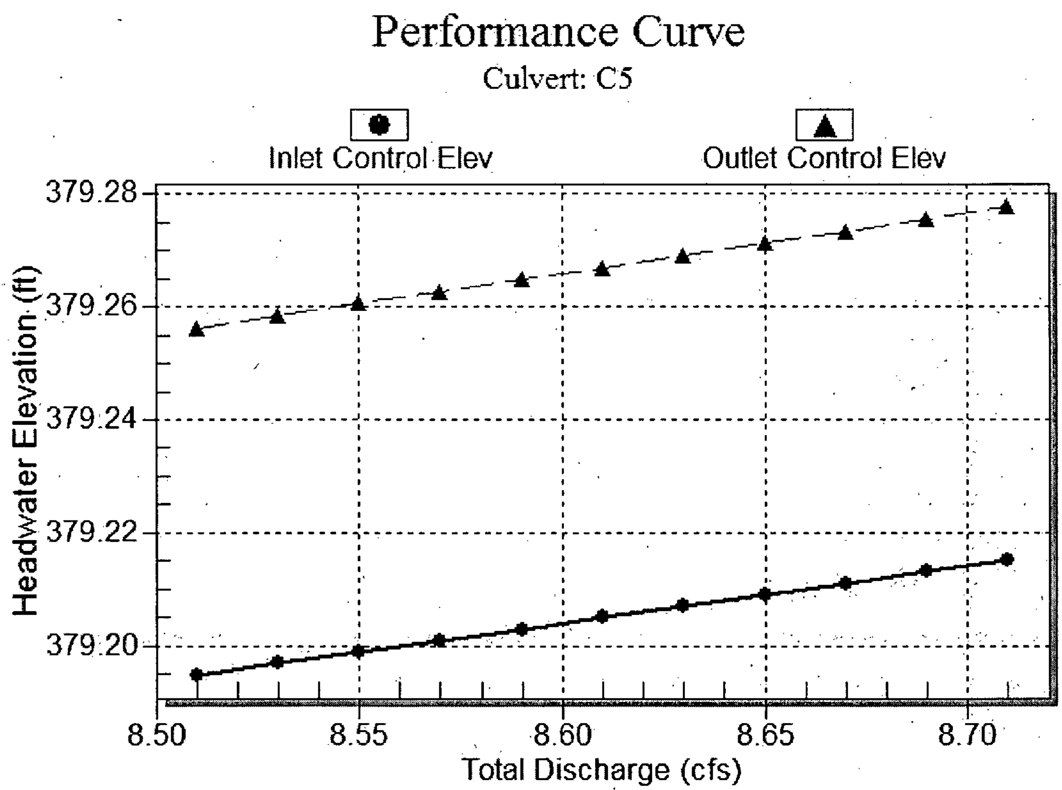
****

Inlet Elevation (invert): 377.70 ft, Outlet Elevation (invert): 377.30 ft

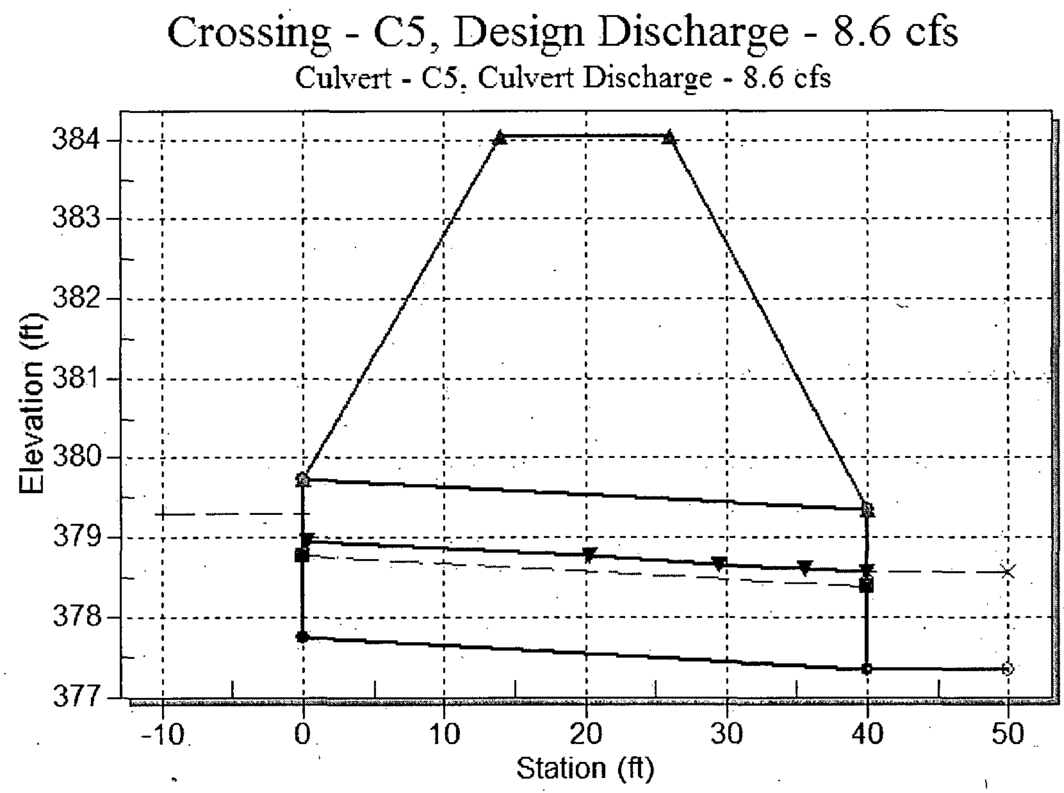
Culvert Length: 40.00 ft, Culvert Slope: 0.0100

****

Culvert Performance Curve Plot: C5



Water Surface Profile Plot for Culvert: C5



Site Data - C5

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 377.70 ft

Outlet Station: 40.00 ft

Outlet Elevation: 377.30 ft

Number of Barrels: 1

Culvert Data Summary - C5

Barrel Shape: Circular

Barrel Diameter: 2.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 15 - Downstream Channel Rating Curve (Crossing: C5)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
8.51	378.52	1.22	2.84	0.76	0.64
8.53	378.52	1.22	2.84	0.76	0.64
8.55	378.53	1.23	2.84	0.77	0.64
8.57	378.53	1.23	2.85	0.77	0.64
8.59	378.53	1.23	2.85	0.77	0.64
8.61	378.53	1.23	2.85	0.77	0.64
8.63	378.53	1.23	2.85	0.77	0.64
8.65	378.53	1.23	2.85	0.77	0.64
8.67	378.53	1.23	2.85	0.77	0.64
8.69	378.53	1.23	2.86	0.77	0.64
8.71	378.53	1.23	2.86	0.77	0.64

Tailwater Channel Data - C5

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 377.30 ft

Roadway Data for Crossing: C5

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 384.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 16 - Summary of Culvert Flows at Crossing: C6

Headwater Elevation (ft)	Total Discharge (cfs)	C6 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
371.26	20.77	20.77	0.00	1
371.26	20.79	20.79	0.00	1
371.26	20.81	20.81	0.00	1
371.27	20.83	20.83	0.00	1
371.27	20.85	20.85	0.00	1
371.27	20.87	20.87	0.00	1
371.27	20.87	20.87	0.00	1
371.27	20.91	20.91	0.00	1
371.27	20.93	20.93	0.00	1
371.27	20.95	20.95	0.00	1
371.28	20.97	20.97	0.00	1
372.00	30.30	30.30	0.00	Overtopping

Rating Curve Plot for Crossing: C6

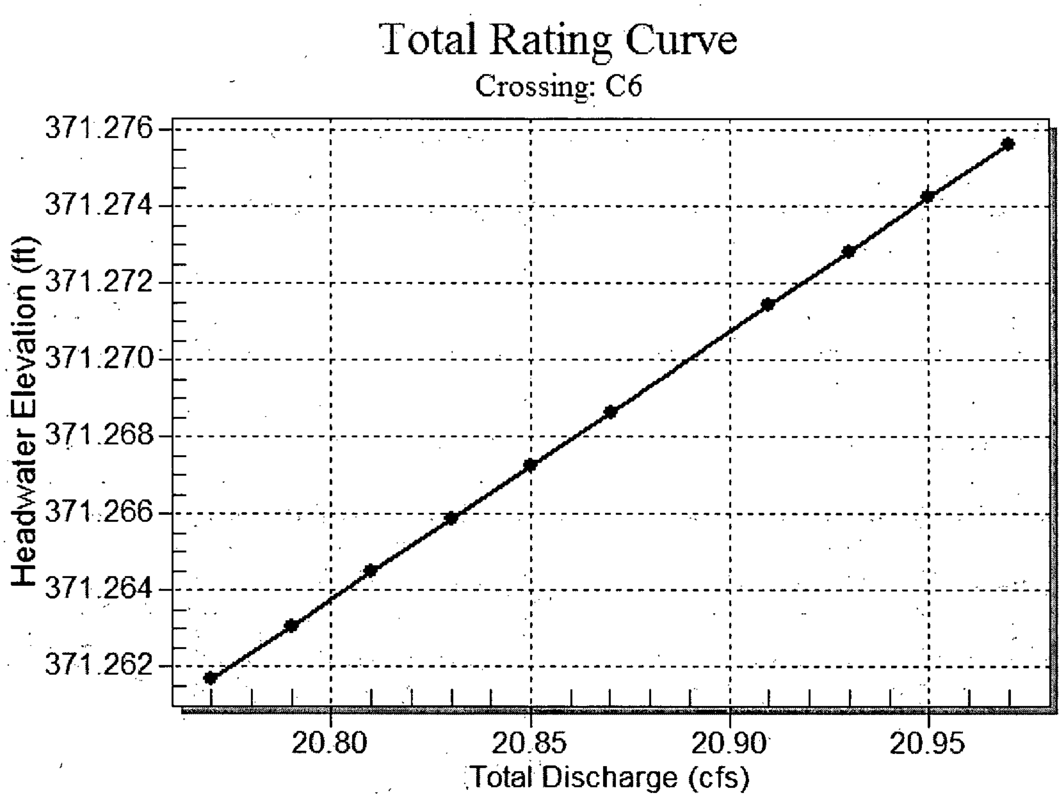


Table 17 - Culvert Summary Table: C6

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
20.77	20.77	371.26	2.262	0.0*	1-S2n	1.381	1.545	1.384	1.710	7.454	3.551
20.79	20.79	371.26	2.263	0.0*	1-S2n	1.382	1.545	1.384	1.711	7.456	3.552
20.81	20.81	371.26	2.264	0.0*	1-S2n	1.383	1.546	1.385	1.711	7.459	3.552
20.83	20.83	371.27	2.266	0.0*	1-S2n	1.383	1.547	1.386	1.712	7.461	3.553
20.85	20.85	371.27	2.267	0.0*	1-S2n	1.384	1.548	1.387	1.713	7.463	3.554
20.87	20.87	371.27	2.269	0.0*	1-S2n	1.385	1.548	1.387	1.713	7.465	3.555
20.87	20.87	371.27	2.269	0.0*	1-S2n	1.385	1.548	1.387	1.713	7.465	3.555
20.91	20.91	371.27	2.271	0.0*	1-S2n	1.387	1.550	1.389	1.714	7.470	3.557
20.93	20.93	371.27	2.273	0.0*	1-S2n	1.388	1.551	1.390	1.715	7.472	3.558
20.95	20.95	371.27	2.274	0.0*	1-S2n	1.388	1.551	1.390	1.716	7.474	3.558
20.97	20.97	371.28	2.276	0.0*	1-S2n	1.389	1.552	1.391	1.716	7.477	3.559

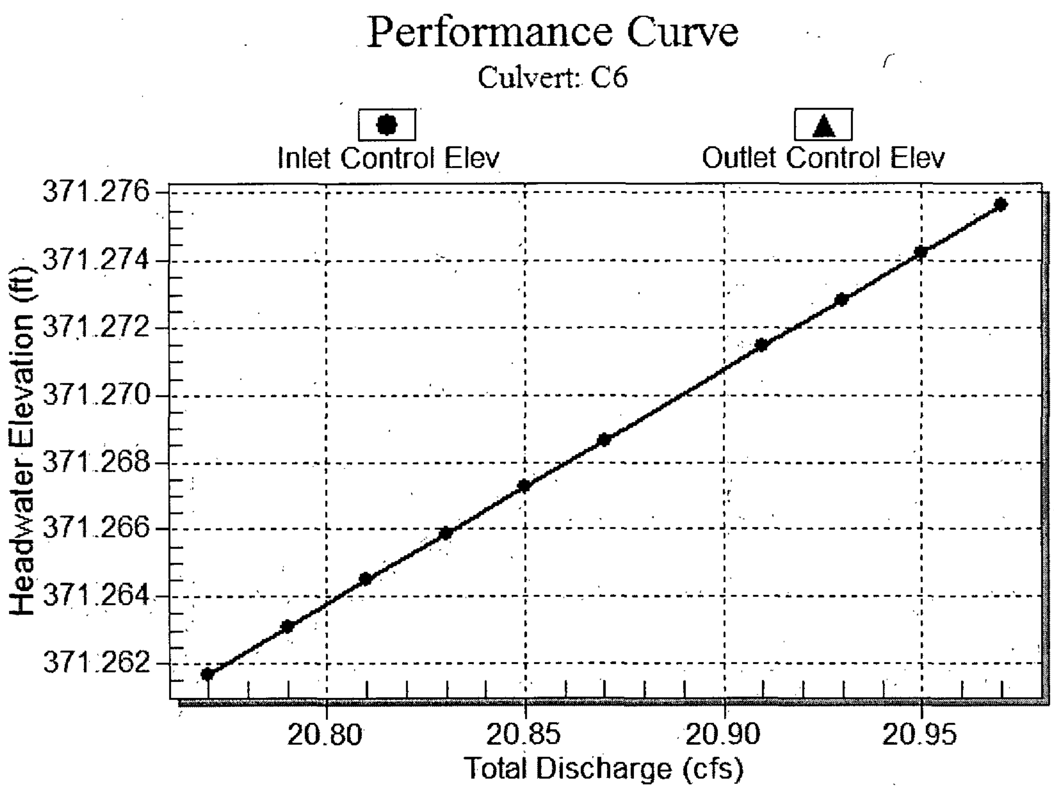
****

Inlet Elevation (invert): 369.00 ft, Outlet Elevation (invert): 368.00 ft

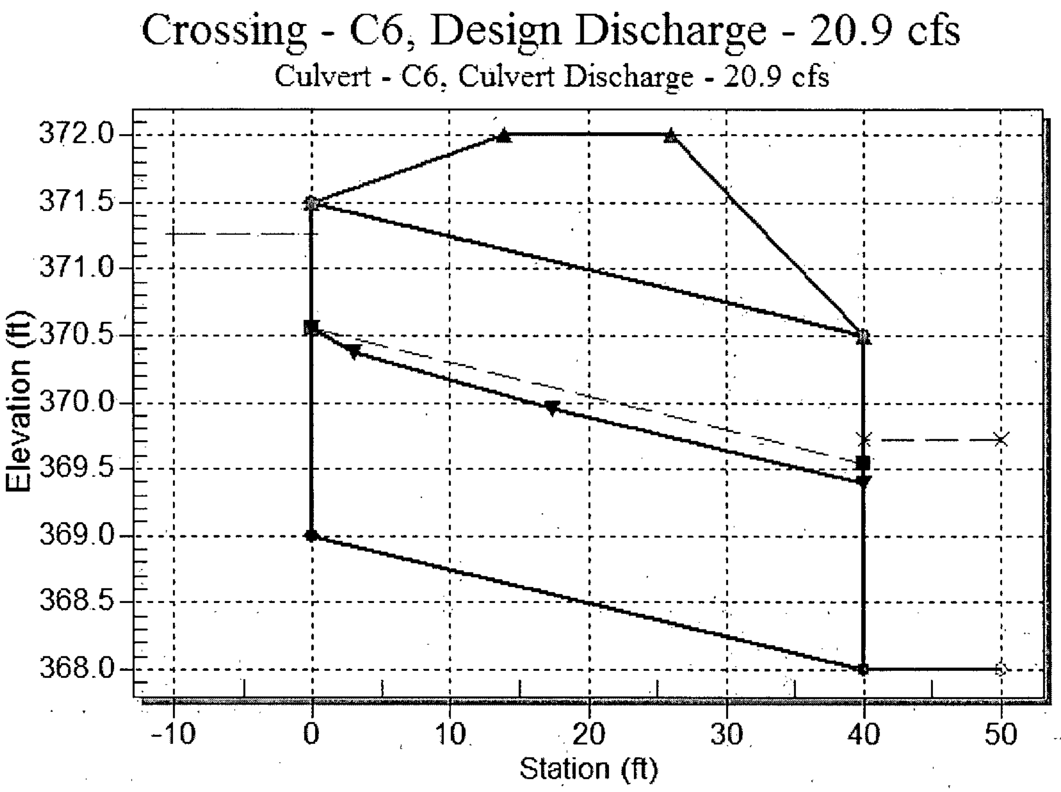
Culvert Length: 40.01 ft, Culvert Slope: 0.0250

****

Culvert Performance Curve Plot: C6



Water Surface Profile Plot for Culvert: C6



Site Data - C6

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 369.00 ft

Outlet Station: 40.00 ft

Outlet Elevation: 368.00 ft

Number of Barrels: 1

Culvert Data Summary - C6

Barrel Shape: Circular

Barrel Diameter: 2.50 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 18 - Downstream Channel Rating Curve (Crossing: C6)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
20.77	369.71	1.71	3.55	1.07	0.68
20.79	369.71	1.71	3.55	1.07	0.68
20.81	369.71	1.71	3.55	1.07	0.68
20.83	369.71	1.71	3.55	1.07	0.68
20.85	369.71	1.71	3.55	1.07	0.68
20.87	369.71	1.71	3.56	1.07	0.68
20.87	369.71	1.71	3.56	1.07	0.68
20.91	369.71	1.71	3.56	1.07	0.68
20.93	369.72	1.72	3.56	1.07	0.68
20.95	369.72	1.72	3.56	1.07	0.68
20.97	369.72	1.72	3.56	1.07	0.68

Tailwater Channel Data - C6

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 368.00 ft

Roadway Data for Crossing: C6

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 372.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 19 - Summary of Culvert Flows at Crossing: C7

Headwater Elevation (ft)	Total Discharge (cfs)	C7 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
369.76	20.77	20.77	0.00	1
369.76	20.79	20.79	0.00	1
369.76	20.81	20.81	0.00	1
369.77	20.83	20.83	0.00	1
369.77	20.85	20.85	0.00	1
369.77	20.87	20.87	0.00	1
369.77	20.87	20.87	0.00	1
369.77	20.91	20.91	0.00	1
369.77	20.93	20.93	0.00	1
369.77	20.95	20.95	0.00	1
369.78	20.97	20.97	0.00	1
372.00	44.02	44.02	0.00	Overtopping

Rating Curve Plot for Crossing: C7

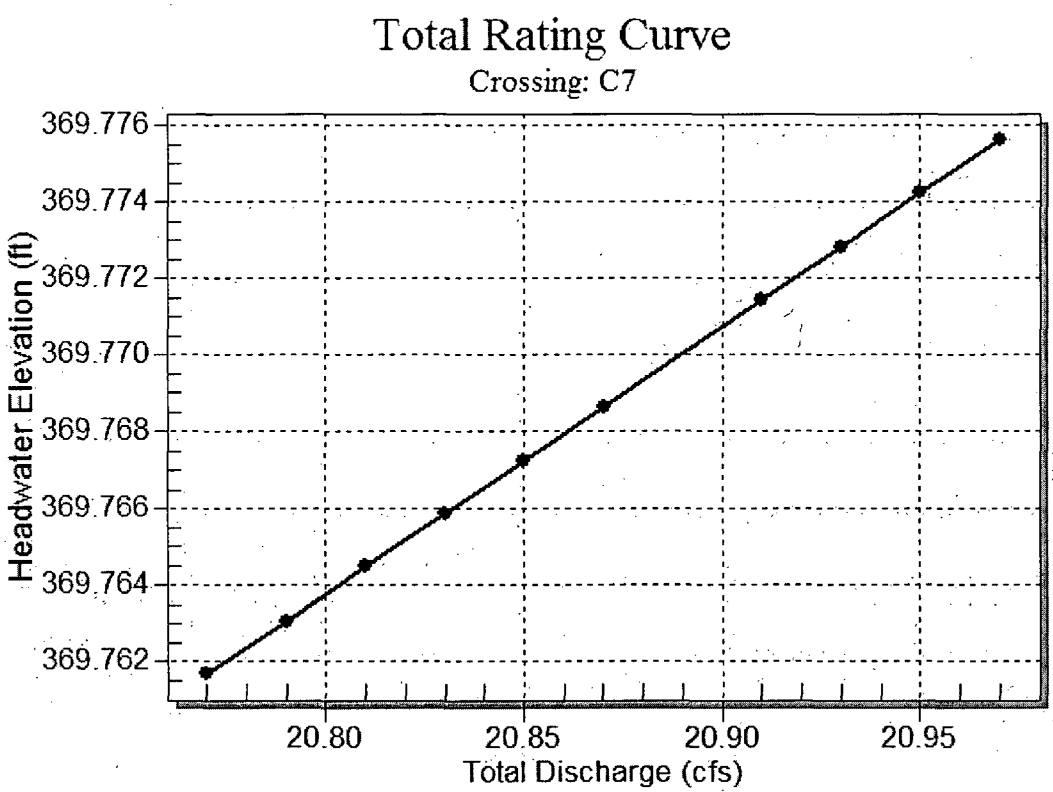


Table 20 - Culvert Summary Table: C7

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
20.77	20.77	369.76	2.262	0.0*	1-S2n	1.381	1.545	1.384	1.710	7.454	3.551
20.79	20.79	369.76	2.263	0.0*	1-S2n	1.382	1.545	1.384	1.711	7.456	3.552
20.81	20.81	369.76	2.264	0.0*	1-S2n	1.383	1.546	1.385	1.711	7.459	3.552
20.83	20.83	369.77	2.266	0.0*	1-S2n	1.383	1.547	1.386	1.712	7.461	3.553
20.85	20.85	369.77	2.267	0.0*	1-S2n	1.384	1.548	1.387	1.713	7.463	3.554
20.87	20.87	369.77	2.269	0.0*	1-S2n	1.385	1.548	1.387	1.713	7.465	3.555
20.87	20.87	369.77	2.269	0.0*	1-S2n	1.385	1.548	1.387	1.713	7.465	3.555
20.91	20.91	369.77	2.271	0.0*	1-S2n	1.387	1.550	1.389	1.714	7.470	3.557
20.93	20.93	369.77	2.273	0.0*	1-S2n	1.388	1.551	1.390	1.715	7.472	3.558
20.95	20.95	369.77	2.274	0.0*	1-S2n	1.388	1.551	1.390	1.716	7.474	3.558
20.97	20.97	369.78	2.276	0.0*	1-S2n	1.389	1.552	1.391	1.716	7.477	3.559

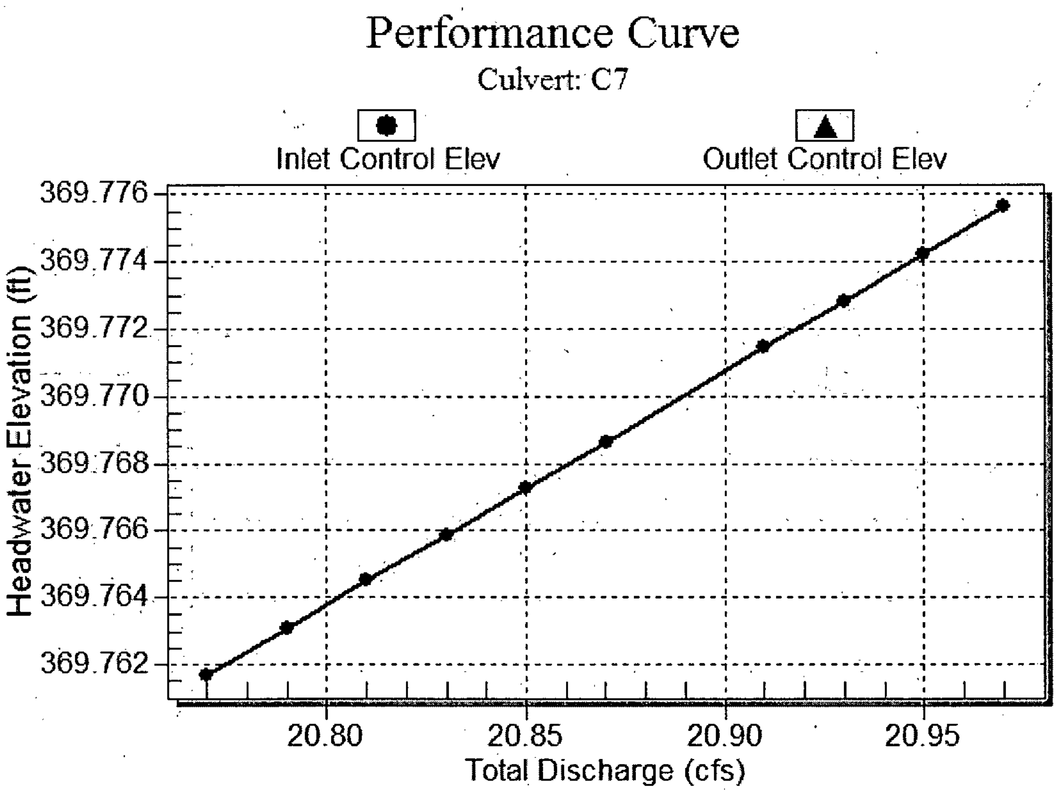
****

Inlet Elevation (invert): 367.50 ft, Outlet Elevation (invert): 366.50 ft

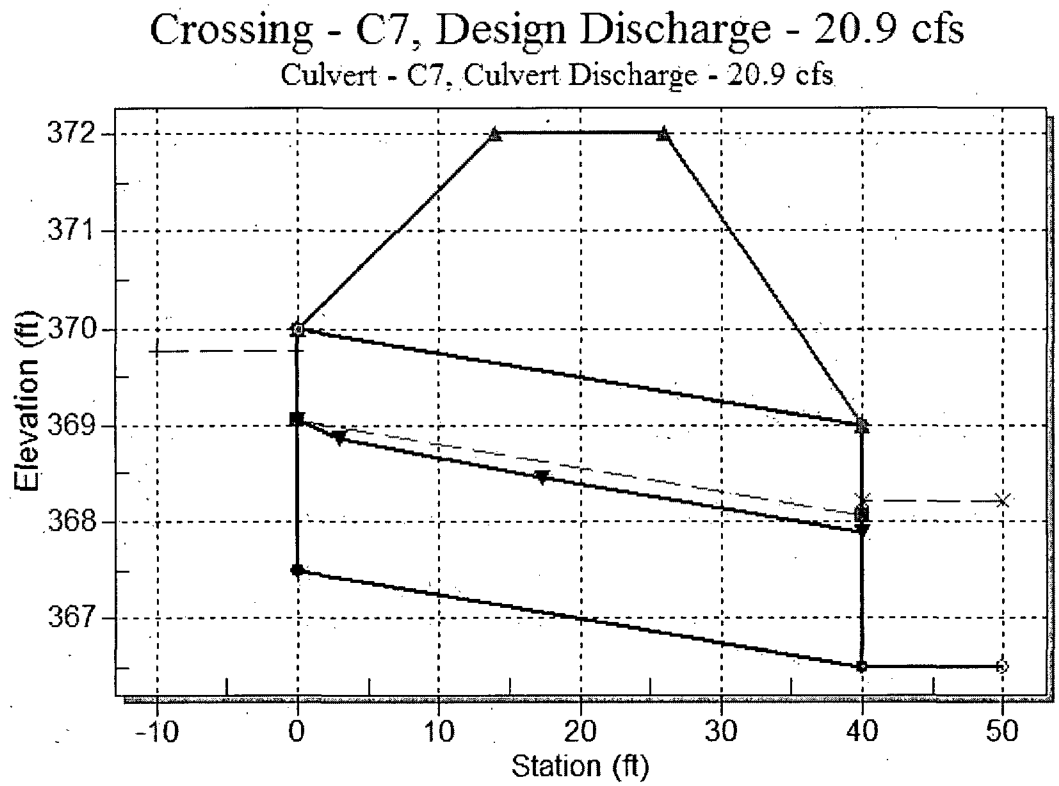
Culvert Length: 40.01 ft, Culvert Slope: 0.0250

****

Culvert Performance Curve Plot: C7



Water Surface Profile Plot for Culvert: C7



Site Data - C7

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 367.50 ft

Outlet Station: 40.00 ft

Outlet Elevation: 366.50 ft

Number of Barrels: 1

Culvert Data Summary - C7

Barrel Shape: Circular

Barrel Diameter: 2.50 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 21 - Downstream Channel Rating Curve (Crossing: C7)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
20.77	368.21	1.71	3.55	1.07	0.68
20.79	368.21	1.71	3.55	1.07	0.68
20.81	368.21	1.71	3.55	1.07	0.68
20.83	368.21	1.71	3.55	1.07	0.68
20.85	368.21	1.71	3.55	1.07	0.68
20.87	368.21	1.71	3.56	1.07	0.68
20.87	368.21	1.71	3.56	1.07	0.68
20.91	368.21	1.71	3.56	1.07	0.68
20.93	368.22	1.72	3.56	1.07	0.68
20.95	368.22	1.72	3.56	1.07	0.68
20.97	368.22	1.72	3.56	1.07	0.68

Tailwater Channel Data - C7

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 366.50 ft

Roadway Data for Crossing: C7

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 372.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 22 - Summary of Culvert Flows at Crossing: C8

Headwater Elevation (ft)	Total Discharge (cfs)	C8 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
360.85	12.26	12.26	0.00	1
360.85	12.28	12.28	0.00	1
360.85	12.30	12.30	0.00	1
360.85	12.32	12.32	0.00	1
360.85	12.34	12.34	0.00	1
360.86	12.36	12.36	0.00	1
360.86	12.38	12.38	0.00	1
360.86	12.40	12.40	0.00	1
360.86	12.42	12.42	0.00	1
360.86	12.44	12.44	0.00	1
360.87	12.46	12.46	0.00	1
362.00	21.64	21.64	0.00	Overtopping

Rating Curve Plot for Crossing: C8

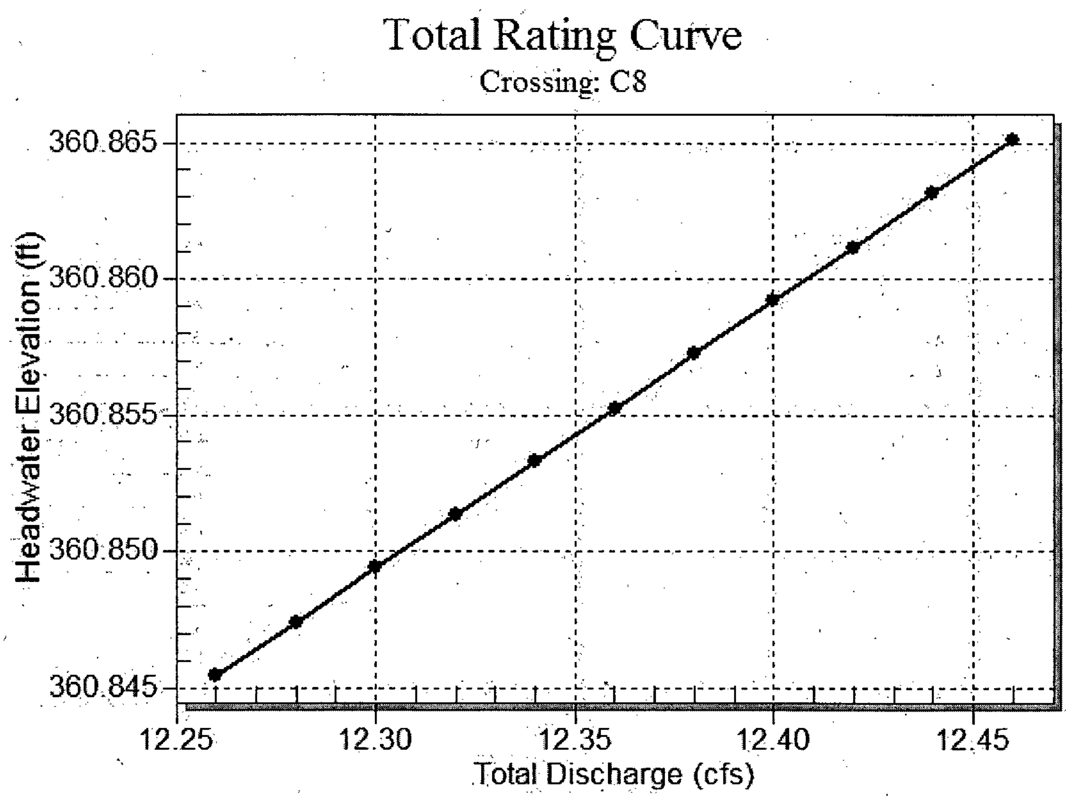


Table 23 - Culvert Summary Table: C8

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
12.26	12.26	360.85	1.845	0.0*	1-S2n	1.153	1.255	1.154	1.403	6.534	3.112
12.28	12.28	360.85	1.847	0.0*	1-S2n	1.154	1.256	1.155	1.404	6.538	3.114
12.30	12.30	360.85	1.849	0.0*	1-S2n	1.155	1.257	1.156	1.405	6.541	3.115
12.32	12.32	360.85	1.851	0.0*	1-S2n	1.157	1.258	1.157	1.406	6.545	3.116
12.34	12.34	360.85	1.853	0.0*	1-S2n	1.158	1.259	1.158	1.407	6.548	3.117
12.36	12.36	360.86	1.855	0.0*	1-S2n	1.159	1.260	1.160	1.408	6.545	3.119
12.38	12.38	360.86	1.857	0.0*	1-S2n	1.160	1.261	1.161	1.409	6.549	3.120
12.40	12.40	360.86	1.859	0.0*	1-S2n	1.161	1.262	1.162	1.409	6.552	3.121
12.42	12.42	360.86	1.861	0.0*	1-S2n	1.163	1.263	1.163	1.410	6.556	3.122
12.44	12.44	360.86	1.863	0.0*	1-S2n	1.164	1.264	1.164	1.411	6.559	3.124
12.46	12.46	360.87	1.865	0.0*	1-S2n	1.165	1.265	1.165	1.412	6.563	3.125

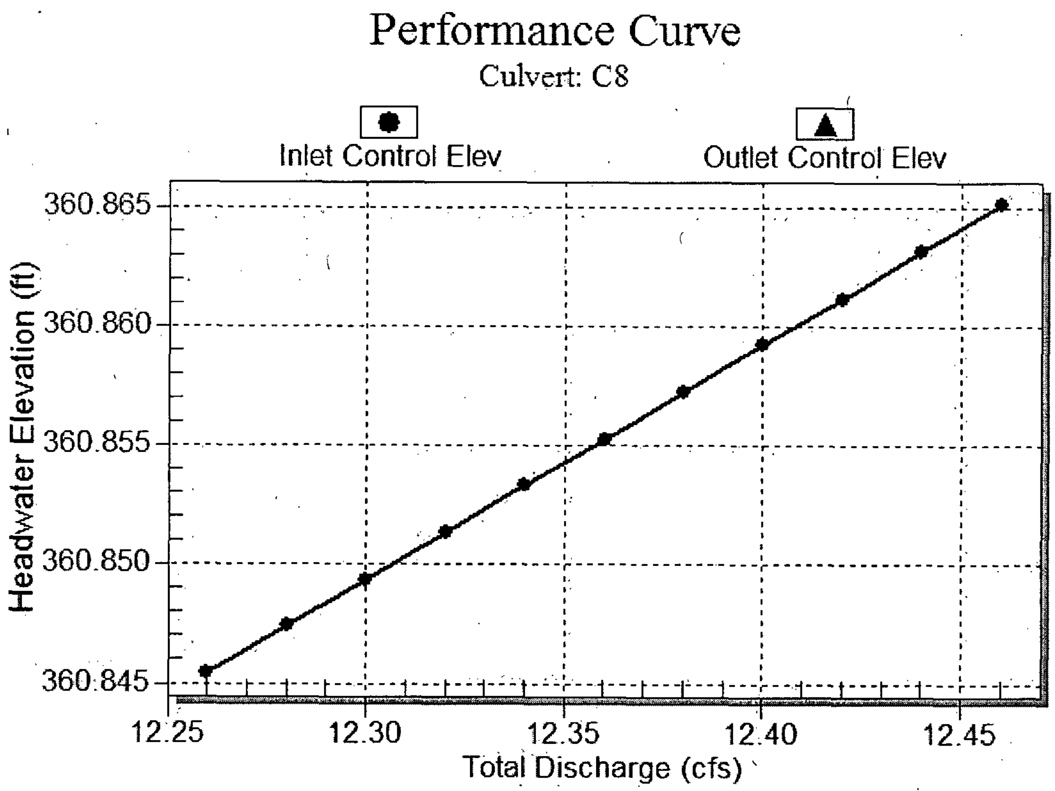
****

Inlet Elevation (invert): 359.00 ft, Outlet Elevation (invert): 358.00 ft

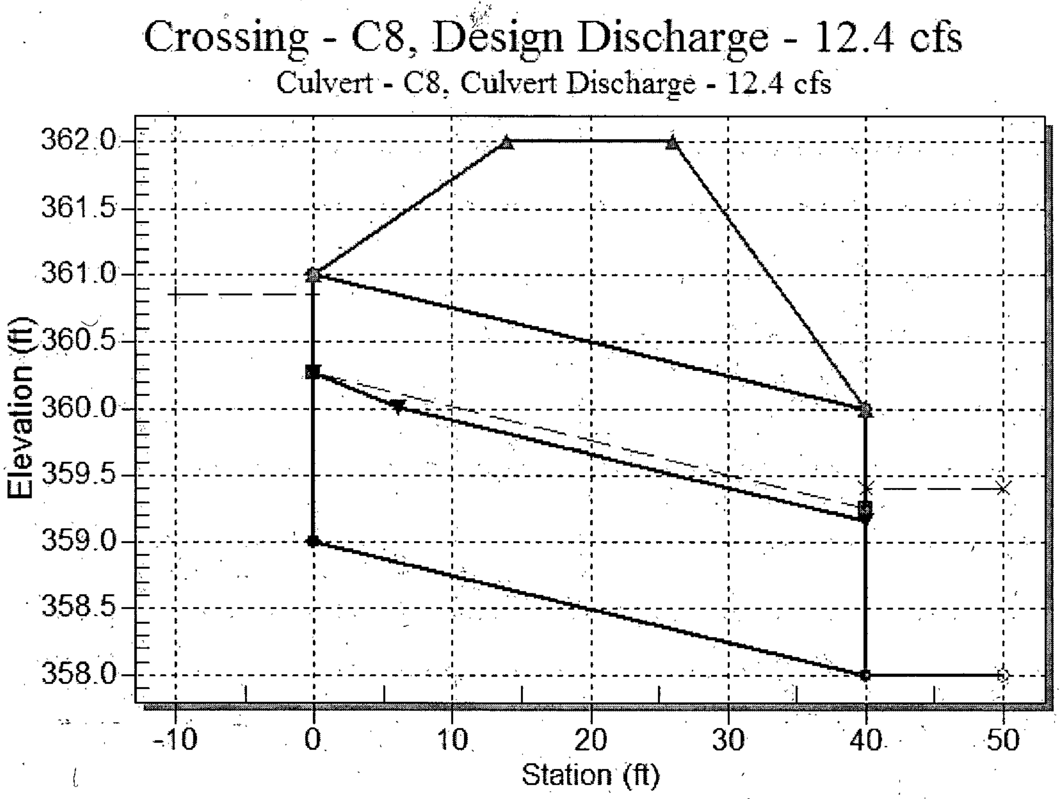
Culvert Length: 40.01 ft, Culvert Slope: 0.0250

****

Culvert Performance Curve Plot: C8



Water Surface Profile Plot for Culvert: C8



Site Data - C8

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 359.00 ft

Outlet Station: 40.00 ft

Outlet Elevation: 358.00 ft

Number of Barrels: 1

Culvert Data Summary - C8

Barrel Shape: Circular

Barrel Diameter: 2.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 24 - Downstream Channel Rating Curve (Crossing: C8)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
12.26	359.40	1.40	3.11	0.88	0.65
12.28	359.40	1.40	3.11	0.88	0.65
12.30	359.41	1.41	3.11	0.88	0.65
12.32	359.41	1.41	3.12	0.88	0.65
12.34	359.41	1.41	3.12	0.88	0.66
12.36	359.41	1.41	3.12	0.88	0.66
12.38	359.41	1.41	3.12	0.88	0.66
12.40	359.41	1.41	3.12	0.88	0.66
12.42	359.41	1.41	3.12	0.88	0.66
12.44	359.41	1.41	3.12	0.88	0.66
12.46	359.41	1.41	3.12	0.88	0.66

Tailwater Channel Data - C8

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 358.00 ft

Roadway Data for Crossing: C8

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 362.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 25 - Summary of Culvert Flows at Crossing: C9

Headwater Elevation (ft)	Total Discharge (cfs)	C9 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
361.89	41.60	41.60	0.00	1
361.89	41.62	41.62	0.00	1
361.89	41.64	41.64	0.00	1
361.90	41.66	41.66	0.00	1
361.90	41.68	41.68	0.00	1
361.90	41.70	41.70	0.00	1
361.90	41.72	41.72	0.00	1
361.90	41.74	41.74	0.00	1
361.90	41.76	41.76	0.00	1
361.90	41.78	41.78	0.00	1
361.90	41.80	41.80	0.00	1
364.00	83.86	83.86	0.00	Overtopping

Rating Curve Plot for Crossing: C9

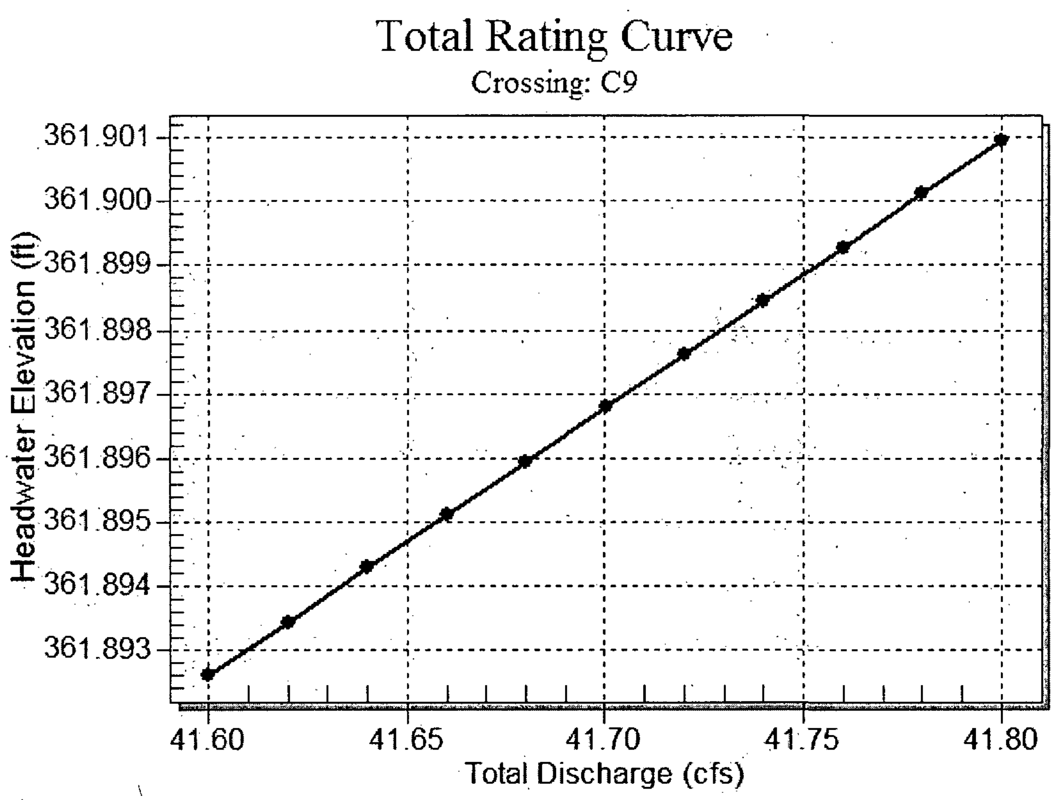


Table 26 - Culvert Summary Table: C9

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
41.60	41.60	361.89	2.893	0.0*	1-S2n	1.711	2.002	1.715	2.219	8.869	4.224
41.62	41.62	361.89	2.893	0.0*	1-S2n	1.711	2.002	1.716	2.219	8.870	4.225
41.64	41.64	361.89	2.894	0.0*	1-S2n	1.712	2.003	1.716	2.220	8.871	4.225
41.66	41.66	361.90	2.895	0.0*	1-S2n	1.712	2.003	1.717	2.220	8.873	4.226
41.68	41.68	361.90	2.896	0.0*	1-S2n	1.713	2.004	1.717	2.221	8.873	4.226
41.70	41.70	361.90	2.897	0.0*	1-S2n	1.713	2.004	1.718	2.221	8.875	4.227
41.72	41.72	361.90	2.898	0.0*	1-S2n	1.714	2.005	1.718	2.221	8.876	4.227
41.74	41.74	361.90	2.898	0.0*	1-S2n	1.714	2.005	1.719	2.222	8.877	4.228
41.76	41.76	361.90	2.899	0.0*	1-S2n	1.715	2.006	1.719	2.222	8.878	4.228
41.78	41.78	361.90	2.900	0.0*	1-S2n	1.715	2.007	1.720	2.223	8.879	4.229
41.80	41.80	361.90	2.901	0.0*	1-S2n	1.716	2.007	1.720	2.223	8.880	4.229

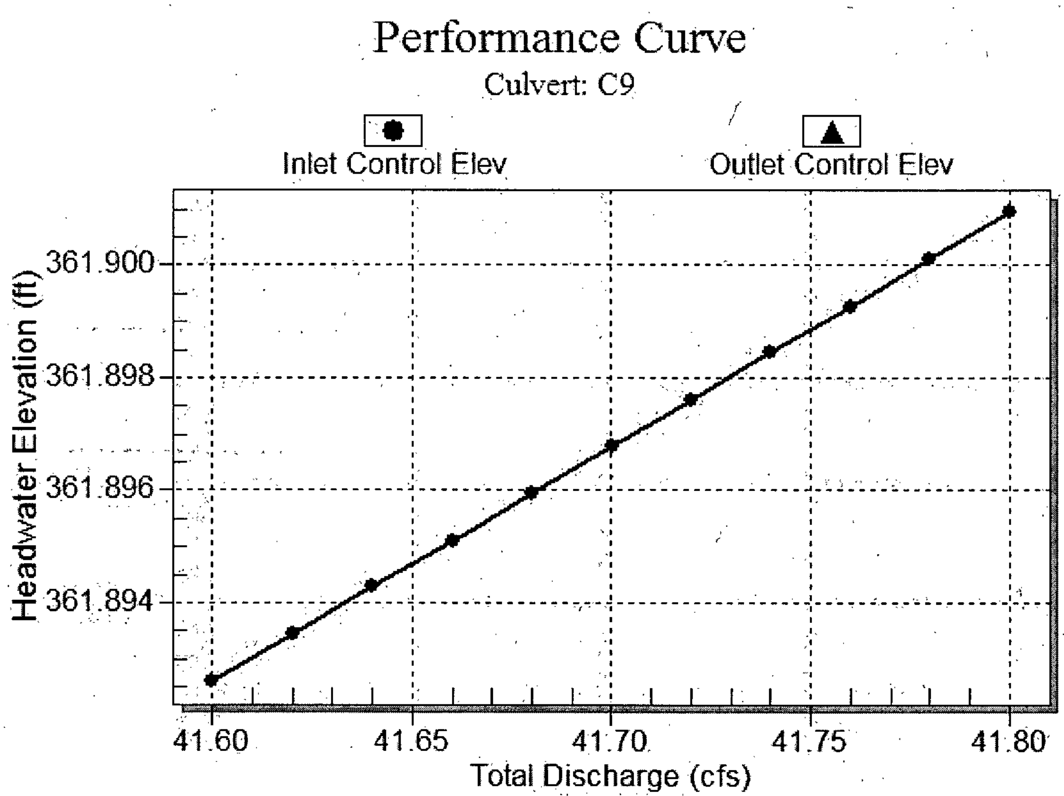
****

Inlet Elevation (invert): 359.00 ft, Outlet Elevation (invert): 358.00 ft

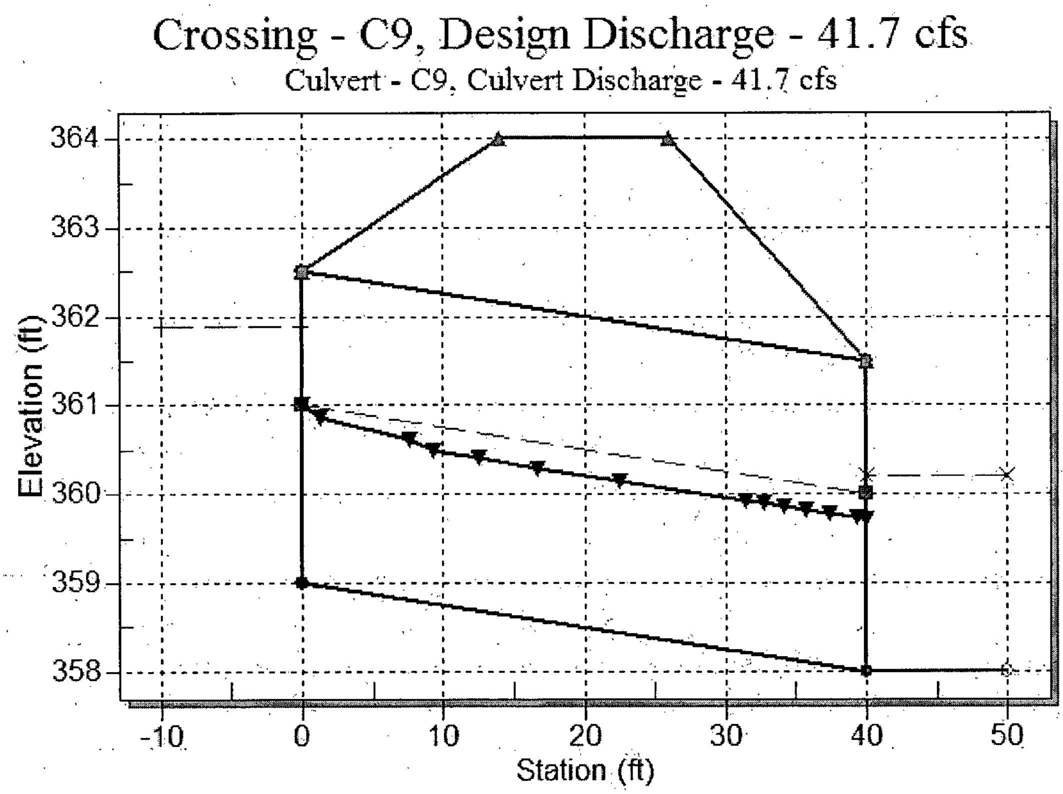
Culvert Length: 40.01 ft, Culvert Slope: 0.0250

****

Culvert Performance Curve Plot: C9



Water Surface Profile Plot for Culvert: C9



Site Data - C9

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 359.00 ft

Outlet Station: 40.00 ft

Outlet Elevation: 358.00 ft

Number of Barrels: 1

Culvert Data Summary - C9

Barrel Shape: Circular

Barrel Diameter: 3.50 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 27 - Downstream Channel Rating Curve (Crossing: C9)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
41.60	360.22	2.22	4.22	1.38	0.71
41.62	360.22	2.22	4.22	1.38	0.71
41.64	360.22	2.22	4.23	1.39	0.71
41.66	360.22	2.22	4.23	1.39	0.71
41.68	360.22	2.22	4.23	1.39	0.71
41.70	360.22	2.22	4.23	1.39	0.71
41.72	360.22	2.22	4.23	1.39	0.71
41.74	360.22	2.22	4.23	1.39	0.71
41.76	360.22	2.22	4.23	1.39	0.71
41.78	360.22	2.22	4.23	1.39	0.71
41.80	360.22	2.22	4.23	1.39	0.71

Tailwater Channel Data - C9

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 358.00 ft

Roadway Data for Crossing: C9

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 364.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Table 28 - Summary of Culvert Flows at Crossing: C10

Headwater Elevation (ft)	Total Discharge (cfs)	C10 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
385.77	2.13	2.13	0.00	1
385.78	2.15	2.15	0.00	1
385.78	2.17	2.17	0.00	1
385.79	2.19	2.19	0.00	1
385.79	2.21	2.21	0.00	1
385.80	2.23	2.23	0.00	1
385.80	2.25	2.25	0.00	1
385.81	2.27	2.27	0.00	1
385.82	2.29	2.29	0.00	1
385.82	2.31	2.31	0.00	1
385.83	2.33	2.33	0.00	1
386.00	2.89	2.89	0.00	Overtopping

Rating Curve Plot for Crossing: C10

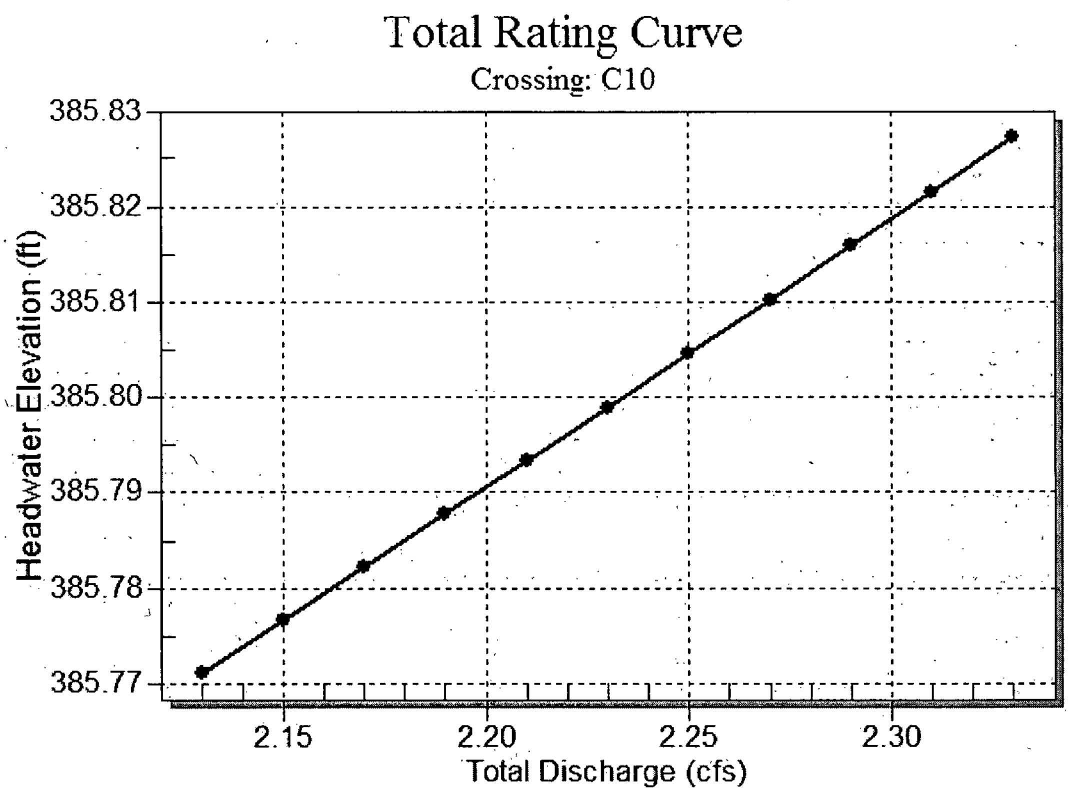


Table 29 - Culvert Summary Table: C10

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
2.13	2.13	385.77	0.901	0.0*	1-S2n	0.503	0.622	0.504	0.728	5.371	2.009
2.15	2.15	385.78	0.907	0.0*	1-S2n	0.506	0.625	0.506	0.731	5.390	2.014
2.17	2.17	385.78	0.912	0.0*	1-S2n	0.509	0.628	0.509	0.733	5.407	2.019
2.19	2.19	385.79	0.918	0.0*	1-S2n	0.511	0.631	0.512	0.736	5.418	2.023
2.21	2.21	385.79	0.923	0.0*	1-S2n	0.514	0.634	0.514	0.738	5.433	2.028
2.23	2.23	385.80	0.929	0.0*	1-S2n	0.517	0.637	0.517	0.741	5.445	2.033
2.25	2.25	385.80	0.935	0.0*	1-S2n	0.520	0.639	0.520	0.743	5.457	2.037
2.27	2.27	385.81	0.940	0.0*	1-S2n	0.522	0.642	0.522	0.746	5.470	2.042
2.29	2.29	385.82	0.946	0.0*	1-S2n	0.525	0.645	0.525	0.748	5.482	2.046
2.31	2.31	385.82	0.951	0.0*	1-S2n	0.528	0.648	0.528	0.751	5.493	2.051
2.33	2.33	385.83	0.957	0.0*	1-S2n	0.531	0.651	0.531	0.753	5.505	2.055

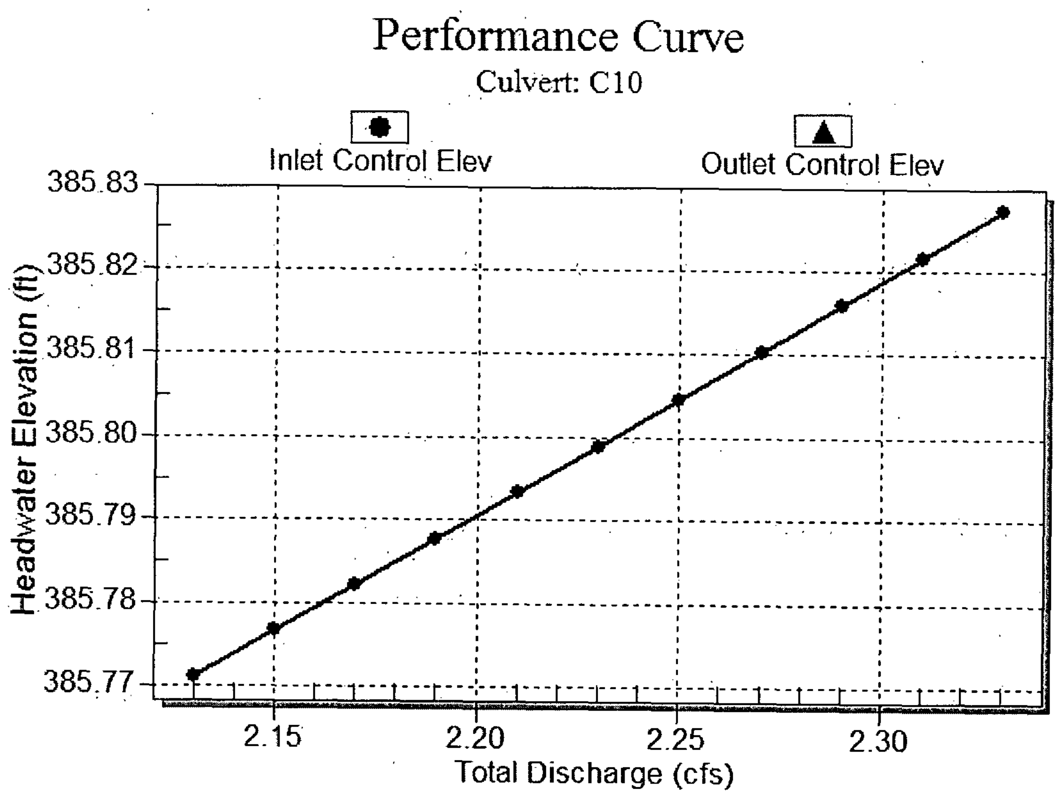
****

Inlet Elevation (invert): 384.87 ft, Outlet Elevation (invert): 382.97 ft

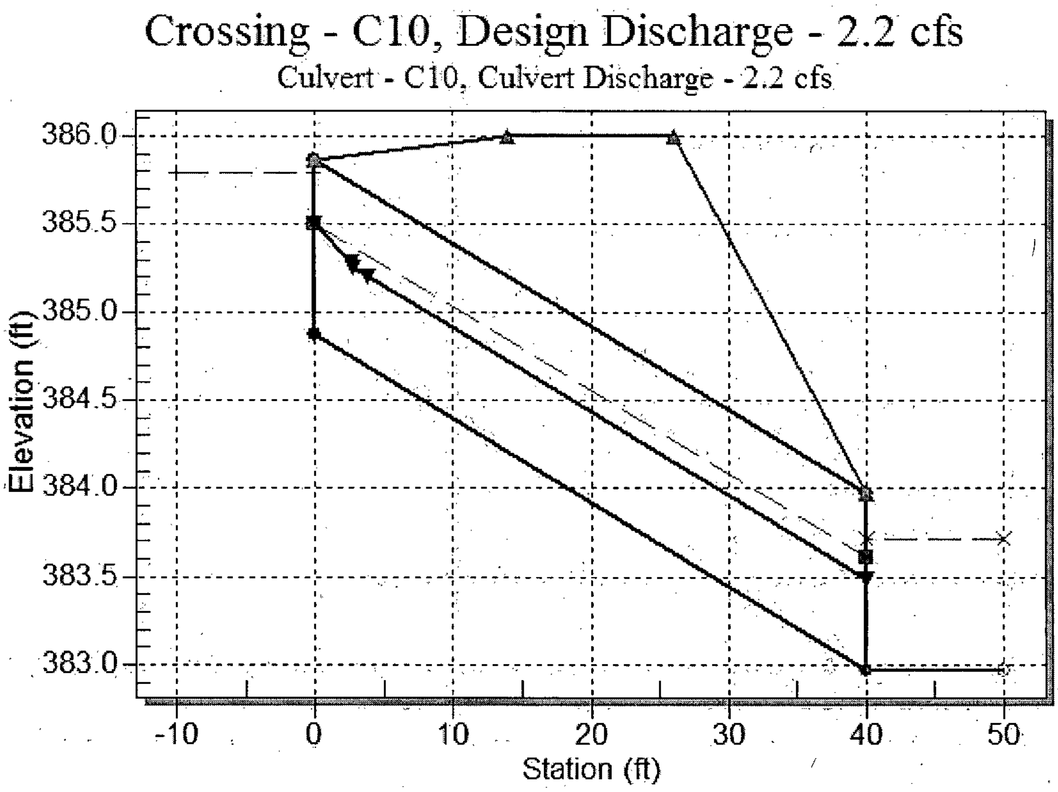
Culvert Length: 40.05 ft, Culvert Slope: 0.0475

****

Culvert Performance Curve Plot: C10



Water Surface Profile Plot for Culvert: C10



Site Data - C10

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 384.87 ft

Outlet Station: 40.00 ft

Outlet Elevation: 382.97 ft

Number of Barrels: 1

Culvert Data Summary - C10

Barrel Shape: Circular

Barrel Diameter: 1.00 ft

Barrel Material: Corrugated PE

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 30 - Downstream Channel Rating Curve (Crossing: C10)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
2.13	383.70	0.73	2.01	0.45	0.59
2.15	383.70	0.73	2.01	0.46	0.59
2.17	383.70	0.73	2.02	0.46	0.59
2.19	383.71	0.74	2.02	0.46	0.59
2.21	383.71	0.74	2.03	0.46	0.59
2.23	383.71	0.74	2.03	0.46	0.59
2.25	383.71	0.74	2.04	0.46	0.59
2.27	383.72	0.75	2.04	0.47	0.59
2.29	383.72	0.75	2.05	0.47	0.59
2.31	383.72	0.75	2.05	0.47	0.59
2.33	383.72	0.75	2.05	0.47	0.59

Tailwater Channel Data - C10

Tailwater Channel Option: Triangular Channel

Side Slope (H:V): 2.00 (_:1)

Channel Slope: 0.0100

Channel Manning's n: 0.0350

Channel Invert Elevation: 382.97 ft

Roadway Data for Crossing: C10

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 ft

Crest Elevation: 386.00 ft

Roadway Surface: Gravel

Roadway Top Width: 12.00 ft

Stormwater Drainage Calculations

Filter Layer Hydraulic Conductivity

CH2MHILL SUBJECT GRANULAR FILTER LAYER PERMEABILITY CALC BY T. PYLE
SHEET NO. ___ of ___ DATE 10-11-10
PROJECT NO. ___

Checked By: R. WARD 10-11-10

HAZEN EQ.

$$K = C \times (D_{10})^2$$

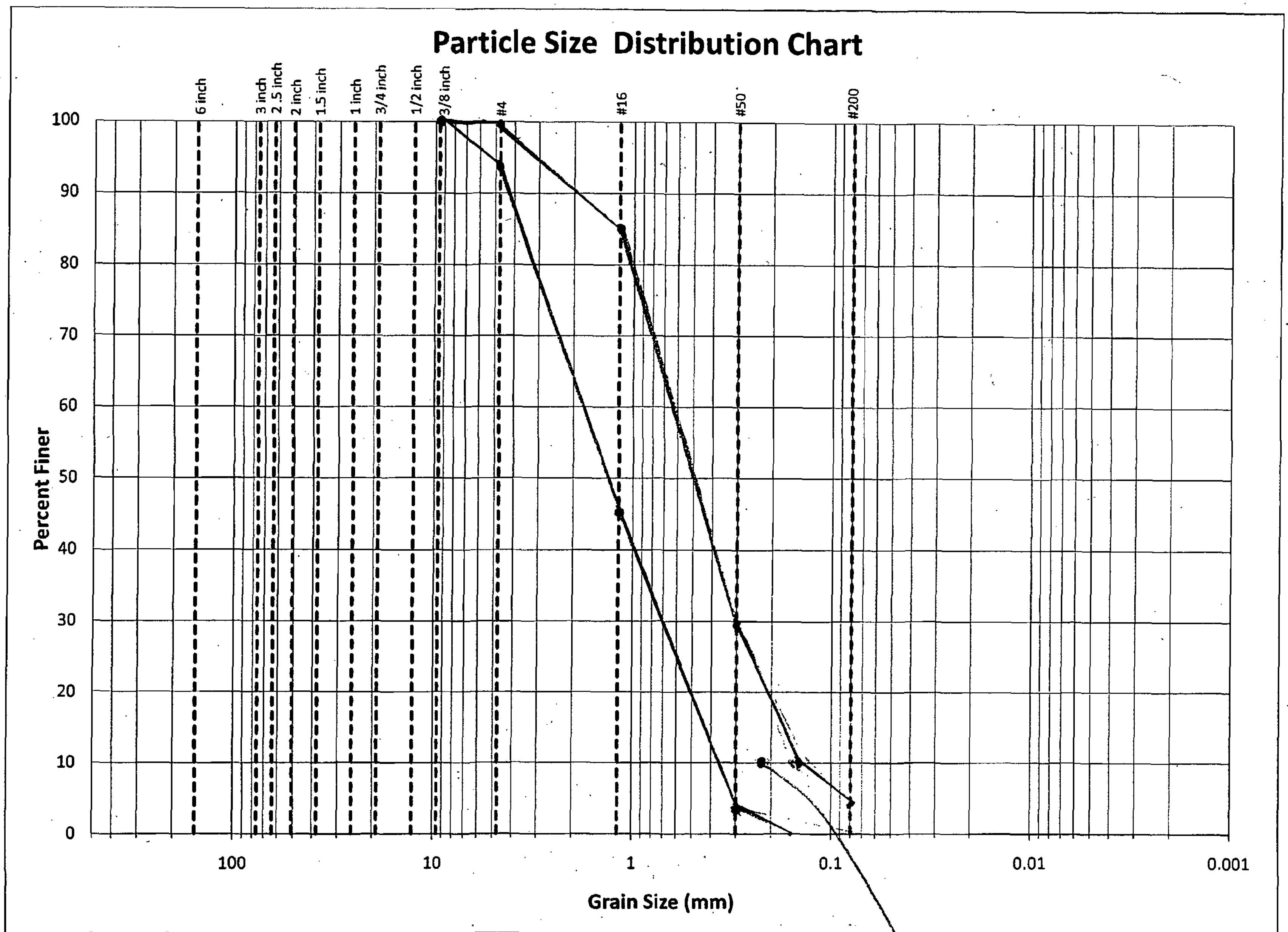
K = hydraulic conductivity (cm/sec)

C = Coefficient 0.8 to 1.2 (1.0 commonly used)

D_{10} = Grain Size diam w/ 10% particles finer.
= 0.2 (see attached IDOT FA1 mat'l gradation)

$$K = 1.0 (0.2)^2 = 0.04 \text{ cm/sec}$$

∴ use 0.02 cm/sec as a conservative value ✓


Particle Size Distribution Chart
6 inch
3 inch
2.5 inch
2 inch
1.5 inch
1 inch
3/4 inch
1/2 inch
3/8 inch
#4
#16
#50
#200
Percent Finer
100
90
80
70
60
50
40
30
20
10
0
100
10
1
0.1
0.01
0.001
Grain Size (mm)

0.21 use 0.2

Stormwater Drainage Calculations

HELP Model Calculations

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:      C:\HELP3\honey\p2.D4
TEMPERATURE DATA FILE:        C:\HELP3\honey\t1.D7
SOLAR RADIATION DATA FILE:    C:\HELP3\honey\s1.D13
EVAPOTRANSPIRATION DATA:      C:\HELP3\honey\e1.D11
SOIL AND DESIGN DATA FILE:    C:\HELP3\honey\no cdn 2.D10
OUTPUT DATA FILE:             C:\HELP3\honey\no cdn 2.OUT


TIME:  11:39     DATE:  10/ 7/2010


******************************************************************************

     TITLE:  Honeywell Final Cover No CDN

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                     LAYER  1
                                     --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER  12
           THICKNESS                  =      24.00    INCHES
           POROSITY                   =       0.4710 VOL/VOL
           FIELD CAPACITY             =       0.3420 VOL/VOL
           WILTING POINT              =       0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.3621 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.419999997000E-04 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                     LAYER  2
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TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	12.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0450 VOL/VOL
WILTING POINT	=	0.0180 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2342 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.199999996000E-01 CM/SEC
SLOPE	=	4.00 PERCENT
DRAINAGE LENGTH	=	125.0 FEET

LAYER 3

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

THICKNESS	=	0.06 INCHES
POROSITY	=	0.0000 VOL/VOL
FIELD CAPACITY	=	0.0000 VOL/VOL
WILTING POINT	=	0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY	=	1.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	2.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 4

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 17

THICKNESS	=	0.25 INCHES
POROSITY	=	0.7500 VOL/VOL
FIELD CAPACITY	=	0.7470 VOL/VOL
WILTING POINT	=	0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.300000003000E-08 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #12 WITH A FAIR STAND OF GRASS, A SURFACE SLOPE OF 4.% AND A SLOPE LENGTH OF 125. FEET.

SCS RUNOFF CURVE NUMBER	=	88.50
FRACTION OF AREA ALLOWING RUNOFF	=	100.0 PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000 ACRES
EVAPORATIVE ZONE DEPTH	=	12.0 INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.963 INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	5.652 INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.520 INCHES

INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	11.690	INCHES
TOTAL INITIAL WATER	=	11.690	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
EAST ST. LOUIS ILLINOIS

STATION LATITUDE	=	38.80 DEGREES
MAXIMUM LEAF AREA INDEX	=	3.00
START OF GROWING SEASON (JULIAN DATE)	=	97
END OF GROWING SEASON (JULIAN DATE)	=	300
EVAPORATIVE ZONE DEPTH	=	12.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	10.40 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	73.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	71.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	74.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ST. LOUIS MISSOURI

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.47	3.93	4.27	4.95	4.75	4.51
4.45	2.99	3.56	3.45	4.53	4.38

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR EAST ST. LOUIS ILLINOIS

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
32.90	38.10	47.60	57.00	65.90	74.50
78.20	76.20	69.10	58.00	46.80	36.90

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR EAST ST. LOUIS ILLINOIS
AND STATION LATITUDE = 38.80 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.00	3.76	3.82	4.79	4.30	5.62
	3.99	2.94	3.77	3.27	3.87	4.58
STD. DEVIATIONS	1.59	1.92	1.16	1.98	2.33	3.16
	2.53	1.49	1.89	1.90	2.82	2.13
RUNOFF						
TOTALS	1.091	1.217	0.454	0.294	0.341	0.779
	0.418	0.077	0.285	0.263	0.675	0.603
STD. DEVIATIONS	1.153	1.172	0.766	0.321	0.518	1.430
	0.645	0.114	0.299	0.320	0.721	0.691
EVAPOTRANSPIRATION						
TOTALS	0.727	1.142	2.859	3.759	3.448	4.495
	3.415	2.736	2.479	1.544	1.259	0.890
STD. DEVIATIONS	0.317	0.528	0.321	0.931	1.331	1.277
	1.491	1.179	1.084	0.384	0.398	0.227
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	1.7780	1.4102	1.5018	1.0971	0.8092	0.6502
	0.4340	0.1782	0.2583	0.6816	1.5604	2.1644
STD. DEVIATIONS	1.0659	1.3336	0.7849	0.8202	0.8868	0.8082
	0.3627	0.2741	0.4736	0.7325	1.1939	1.3344
PERCOLATION/LEAKAGE THROUGH LAYER 4						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
DAILY AVERAGE HEAD ON TOP OF LAYER 3						
AVERAGES	1.5833	1.3803	1.3373	1.0095	0.7206	0.5983
	0.3864	0.1587	0.2377	0.6070	1.4359	1.9274
STD. DEVIATIONS	0.9492	1.3129	0.6989	0.7548	0.7897	0.7437
	0.3230	0.2441	0.4358	0.6523	1.0986	1.1882

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 20

	INCHES		CU. FEET	PERCENT
PRECIPITATION	47.71	(6.613)	173189.1	100.00
RUNOFF	6.497	(2.6309)	23584.16	13.618
EVAPOTRANSPIRATION	28.755	(2.9313)	104379.65	60.269
LATERAL DRAINAGE COLLECTED FROM LAYER 2	12.52343	(3.83387)	45460.031	26.24878
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00010	(0.00004)	0.381	0.00022
AVERAGE HEAD ON TOP OF LAYER 3	0.949	(0.292)		
CHANGE IN WATER STORAGE	-0.065	(1.3851)	-235.11	-0.136

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	7.42	26934.600
RUNOFF	4.977	18066.9199
DRAINAGE COLLECTED FROM LAYER 2	0.29851	1083.60291
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.000004	0.01325
AVERAGE HEAD ON TOP OF LAYER 3	8.241	
MAXIMUM HEAD ON TOP OF LAYER 3	11.936	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	34.3 FEET	
SNOW WATER	3.93	14263.6641

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4418
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 20

LAYER	(INCHES)	(VOL/VOL)
1	8.3694	0.3487
2	1.8373	0.1531
3	0.0000	0.0000
4	0.1875	0.7500
SNOW WATER	0.000	

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**                                                                        **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE             **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)              **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                 **
**                    USAE WATERWAYS EXPERIMENT STATION                   **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY            **
**                                                                        **
**                                                                        **
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PRECIPITATION DATA FILE:     C:\HELP3\honey\p2.D4
TEMPERATURE DATA FILE:       C:\HELP3\honey\t1.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\honey\si.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\honey\e1.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\honey\gd cdn 2.D10
OUTPUT DATA FILE:            C:\HELP3\honey\gd cdn 2.OUT


TIME:  11:39     DATE:  10/ 7/2010


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     TITLE:  Honeywell Final Cover with CDN

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  12
           THICKNESS                  =      24.00   INCHES
           POROSITY                   =       0.4710 VOL/VOL
           FIELD CAPACITY             =       0.3420 VOL/VOL
           WILTING POINT              =       0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.3794 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.419999997000E-04 CM/SEC
       NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY   4.20
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                  LAYER  2
                                  --------
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              TYPE 2 - LATERAL DRAINAGE LAYER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                     =       12.00    INCHES
POROSITY                      =        0.4170 VOL/VOL
FIELD CAPACITY                =        0.0450 VOL/VOL
WILTING POINT                 =        0.0180 VOL/VOL
INITIAL SOIL WATER CONTENT    =        0.1383 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =   0.199999996000E-01 CM/SEC


                          LAYER  3
                          --------

              TYPE 2 - LATERAL DRAINAGE LAYER
                MATERIAL TEXTURE NUMBER  20
THICKNESS                     =        0.25    INCHES
POROSITY                      =        0.8500 VOL/VOL
FIELD CAPACITY                =        0.0100 VOL/VOL
WILTING POINT                 =        0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT    =        0.0547 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =    10.0000000000      CM/SEC
SLOPE                         =        4.00    PERCENT
DRAINAGE LENGTH               =      125.0     FEET


                          LAYER  4
                          --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
                MATERIAL TEXTURE NUMBER  35
THICKNESS                     =        0.06    INCHES
POROSITY                      =        0.0000 VOL/VOL
FIELD CAPACITY                =        0.0000 VOL/VOL
WILTING POINT                 =        0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT    =        0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =   0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY           =        1.00    HOLES/ACRE
FML INSTALLATION DEFECTS      =        2.00    HOLES/ACRE
FML PLACEMENT QUALITY         =   3 - GOOD


                          LAYER  5
                          --------

                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER  17
THICKNESS                     =        0.25    INCHES
POROSITY                      =        0.7500 VOL/VOL
FIELD CAPACITY                =        0.7470 VOL/VOL
WILTING POINT                 =        0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT    =        0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =   0.300000003000E-08 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #12 WITH A FAIR STAND OF GRASS, A SURFACE SLOPE OF 4.% AND A SLOPE LENGTH OF 125. FEET.

SCS RUNOFF CURVE NUMBER	=	88.50	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	12.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	4.203	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	5.652	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.520	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	10.966	INCHES
TOTAL INITIAL WATER	=	10.966	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM EAST ST. LOUIS ILLINOIS

STATION LATITUDE	=	38.80	DEGREES
MAXIMUM LEAF AREA INDEX	=	3.00	
START OF GROWING SEASON (JULIAN DATE)	=	97	
END OF GROWING SEASON (JULIAN DATE)	=	300	
EVAPORATIVE ZONE DEPTH	=	12.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	10.40	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	73.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	74.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR ST. LOUIS MISSOURI

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.47	3.93	4.27	4.95	4.75	4.51
4.45	2.99	3.56	3.45	4.53	4.38

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR EAST ST. LOUIS ILLINOIS

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
32.90	38.10	47.60	57.00	65.90	74.50
78.20	76.20	69.10	58.00	46.80	36.90

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR EAST ST. LOUIS ILLINOIS
AND STATION LATITUDE = 38.80 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.00	3.76	3.82	4.79	4.30	5.62
	3.99	2.94	3.77	3.27	3.87	4.58
STD. DEVIATIONS	1.59	1.92	1.16	1.98	2.33	3.16
	2.53	1.49	1.89	1.90	2.82	2.13
RUNOFF						
TOTALS	1.165	1.322	0.500	0.381	0.400	0.846
	0.477	0.084	0.352	0.336	0.785	0.758
STD. DEVIATIONS	1.172	1.204	0.791	0.457	0.581	1.521
	0.697	0.125	0.353	0.448	0.809	0.848
EVAPOTRANSPIRATION						
TOTALS	0.725	1.139	2.879	3.874	3.547	4.559
	3.519	2.760	2.474	1.515	1.244	0.883
STD. DEVIATIONS	0.314	0.525	0.304	0.861	1.302	1.333
	1.538	1.214	1.102	0.371	0.380	0.224
LATERAL DRAINAGE COLLECTED FROM LAYER 3						
TOTALS	1.4506	1.3163	1.3236	0.9570	0.7870	0.4773
	0.2725	0.1649	0.2087	0.5660	1.5789	2.1268
STD. DEVIATIONS	0.9927	1.3360	0.7997	0.8074	0.8752	0.6173
	0.2479	0.2053	0.3933	0.7730	1.0774	1.3509
PERCOLATION/LEAKAGE THROUGH LAYER 5						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 4

AVERAGES	0.0026	0.0026	0.0024	0.0018	0.0014	0.0009
	0.0005	0.0003	0.0004	0.0010	0.0029	0.0038
STD. DEVIATIONS	0.0018	0.0026	0.0014	0.0015	0.0016	0.0011
	0.0004	0.0004	0.0007	0.0014	0.0020	0.0024

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 20

	INCHES		CU. FEET	PERCENT
PRECIPITATION	47.71	(6.613)	173189.1	100.00
RUNOFF	7.405	(2.8192)	26880.81	15.521
EVAPOTRANSPIRATION	29.118	(2.9776)	105698.99	61.031
LATERAL DRAINAGE COLLECTED FROM LAYER 3	11.22973	(3.40143)	40763.918	23.53723
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.00000	(0.00000)	0.009	0.00001
AVERAGE HEAD ON TOP OF LAYER 4	0.002	(0.001)		
CHANGE IN WATER STORAGE	-0.043	(1.1284)	-154.62	-0.089

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	7.42	26934.600
RUNOFF	5.239	19018.6914
DRAINAGE COLLECTED FROM LAYER 3	0.70920	2574.40039
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.000000	0.00004
AVERAGE HEAD ON TOP OF LAYER 4	0.039	
MAXIMUM HEAD ON TOP OF LAYER 4	0.078	
LOCATION OF MAXIMUM HEAD IN LAYER 3 (DISTANCE FROM DRAIN)	0.6 FEET	
SNOW WATER	3.93	14263.6641

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4595
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 20

LAYER	(INCHES)	(VOL/VOL)
1	8.4724	0.3530
2	1.4475	0.1206
3	0.0063	0.0251
4	0.0000	0.0000
5	0.1875	0.7500
SNOW WATER	0.000	

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Reference Materials

Reference Materials

NOAA Precipitation Data

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

PADUCAH WSO, KENTUCKY (15-6110) 37.0564 N 88.7739 W 400 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 3
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2004
Extracted: Wed Sep 8 2010

Confidence Limits | Seasonality | Related Info | GIS data | Maps | Docs | Return to State Map

Precipitation Frequency Estimates (inches)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.42	0.65	0.81	1.08	1.32	1.58	1.72	2.13	2.57	3.11	3.69	4.12	4.79	5.35	7.26	8.86	11.11	13.14
2	0.49	0.77	0.95	1.29	1.59	1.91	2.07	2.56	3.09	3.74	4.44	4.95	5.75	6.39	8.63	10.49	13.15	15.53
5	0.57	0.89	1.11	1.53	1.94	2.33	2.54	3.13	3.79	4.58	5.44	6.03	7.02	7.75	10.28	12.36	15.37	18.04
10	0.63	0.98	1.22	1.72	2.20	2.67	2.91	3.59	4.35	5.23	6.18	6.84	8.00	8.78	11.49	13.73	16.97	19.84
25	0.70	1.09	1.36	1.95	2.55	3.12	3.42	4.23	5.12	6.08	7.17	7.89	9.28	10.13	13.06	15.50	18.99	22.11
50	0.76	1.17	1.46	2.13	2.83	3.48	3.82	4.74	5.75	6.75	7.92	8.71	10.29	11.17	14.25	16.83	20.49	23.77
100	0.81	1.25	1.56	2.30	3.10	3.84	4.25	5.28	6.40	7.42	8.69	9.51	11.30	12.21	15.41	18.12	21.95	25.35
200	0.87	1.32	1.65	2.46	3.38	4.22	4.69	5.84	7.08	8.10	9.45	10.32	12.32	13.25	16.55	19.39	23.35	26.87
500	0.94	1.42	1.77	2.69	3.76	4.74	5.30	6.63	8.04	9.02	10.48	11.39	13.69	14.64	18.02	21.02	25.15	28.83
1000	0.99	1.49	1.86	2.85	4.06	5.15	5.79	7.27	8.81	9.74	11.27	12.21	14.74	15.70	19.14	22.24	26.49	30.28

* These precipitation frequency estimates are based on a partial duration series. **ARI** is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: *Formatting forces estimates near zero to appear as zero.*

*** Upper bound of the 90% confidence interval Precipitation Frequency Estimates (inches)**

ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.45	0.71	0.88	1.17	1.44	1.73	1.89	2.35	2.82	3.34	3.97	4.44	5.17	5.75	7.75	9.42	11.80	13.90
2	0.53	0.84	1.04	1.40	1.73	2.08	2.27	2.81	3.39	4.02	4.77	5.33	6.21	6.89	9.22	11.18	13.97	16.41
5	0.62	0.97	1.20	1.67	2.11	2.54	2.78	3.44	4.16	4.92	5.83	6.49	7.58	8.35	10.98	13.17	16.32	19.05
10	0.68	1.07	1.33	1.87	2.39	2.90	3.18	3.94	4.78	5.61	6.63	7.35	8.62	9.45	12.28	14.63	18.01	20.95
25	0.77	1.19	1.48	2.12	2.77	3.39	3.73	4.63	5.61	6.52	7.68	8.49	10.02	10.91	13.95	16.51	20.16	23.33
50	0.83	1.27	1.58	2.30	3.06	3.78	4.17	5.18	6.29	7.24	8.49	9.36	11.10	12.04	15.21	17.93	21.77	25.09
100	0.88	1.35	1.69	2.49	3.35	4.18	4.63	5.77	6.99	7.96	9.31	10.23	12.19	13.16	16.45	19.31	23.34	26.78
200	0.94	1.44	1.79	2.67	3.66	4.59	5.11	6.38	7.74	8.69	10.14	11.10	13.30	14.30	17.67	20.67	24.85	28.43
500	1.02	1.54	1.92	2.91	4.07	5.17	5.78	7.25	8.81	9.69	11.25	12.26	14.79	15.80	19.26	22.44	26.78	30.56
1000	1.08	1.61	2.02	3.09	4.40	5.62	6.31	7.94	9.67	10.46	12.12	13.16	15.96	16.97	20.48	23.75	28.21	32.12

* The upper bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are **greater** than.
** These precipitation frequency estimates are based on a partial duration series. **ARI** is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

*** Lower bound of the 90% confidence interval Precipitation Frequency Estimates (inches)**

ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.38	0.60	0.74	0.99	1.22	1.45	1.58	1.95	2.35	2.90	3.44	3.83	4.45	4.97	6.80	8.34	10.42	12.41
2	0.45	0.71	0.88	1.19	1.47	1.75	1.89	2.34	2.83	3.48	4.13	4.60	5.33	5.95	8.09	9.90	12.35	14.67
5	0.52	0.82	1.02	1.41	1.78	2.13	2.32	2.86	3.47	4.27	5.05	5.61	6.51	7.21	9.61	11.65	14.42	17.04
10	0.58	0.90	1.12	1.58	2.03	2.44	2.66	3.27	3.97	4.86	5.74	6.35	7.40	8.15	10.74	12.93	15.90	18.73
25	0.65	1.00	1.25	1.79	2.34	2.83	3.11	3.83	4.64	5.63	6.63	7.31	8.57	9.39	12.19	14.57	17.76	20.85
50	0.70	1.07	1.33	1.94	2.58	3.15	3.46	4.28	5.19	6.23	7.32	8.05	9.47	10.33	13.28	15.80	19.14	22.40

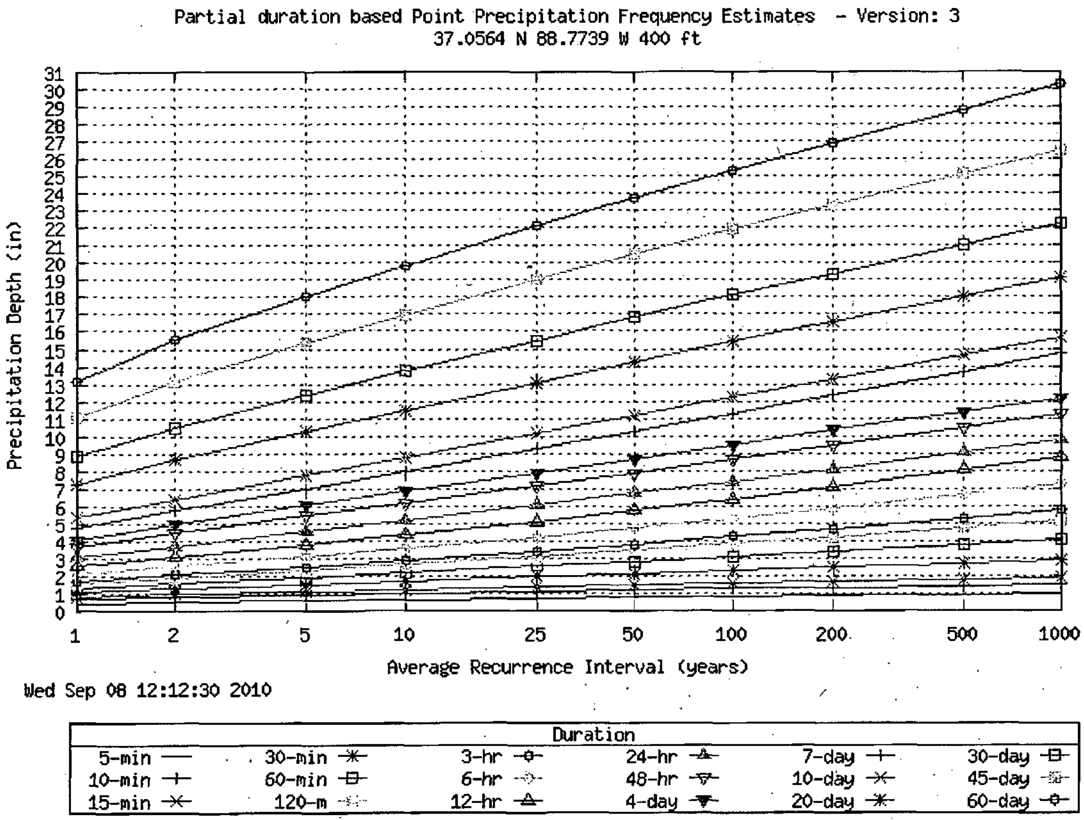
100	0.74	1.14	1.42	2.09	2.82	3.47	3.83	4.74	5.74	6.84	8.01	8.77	10.37	11.26	14.33	16.98	20.45	23.86
200	0.79	1.20	1.50	2.23	3.06	3.79	4.20	5.21	6.31	7.44	8.69	9.49	11.27	12.19	15.36	18.11	21.71	25.25
500	0.85	1.28	1.59	2.42	3.38	4.23	4.70	5.86	7.09	8.25	9.60	10.44	12.47	13.42	16.67	19.59	23.32	27.01
1000	0.89	1.33	1.66	2.55	3.63	4.56	5.10	6.37	7.71	8.87	10.28	11.15	13.38	14.34	17.66	20.68	24.51	28.31

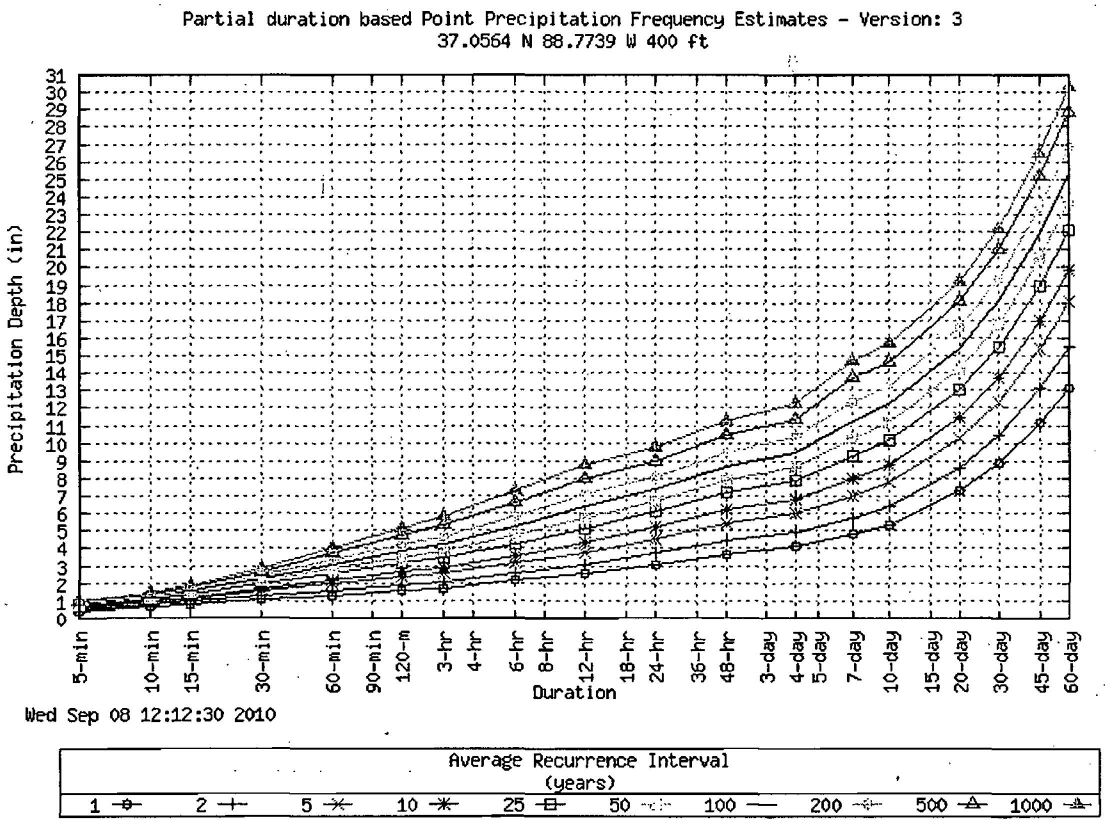
* The lower bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are less than.

** These precipitation frequency estimates are based on a partial duration maxima series. ARI is the Average Recurrence Interval.

Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

Text version of tables





Related Information

Maps & Aerials

Click here to see topographic maps and aerial photographs available for this location from Microsoft Research Maps

Watershed/Streamflow Information

Click here to see watershed and streamflow information available for this location from the U.S. Environmental Protection Agency's site

Climate Data Sources

National Climatic Data Center (NCDC) database

Locate NCDC climate stations within:

+/-30 minutes or +/-1 degree of this location. Digital ASCII data can be obtained directly from NCDC.

Note: Precipitation frequency results are based on analysis of precipitation data from a variety of sources, but largely NCDC. The following links provide general information about observing sites in the area, regardless of if their data was used in this study. For detailed information about the stations used in this study, please refer to the matching documentation available at the PF Document page

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US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Office of Hydrologic Development
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

Disclaimer

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

PADUCAH WSO, KENTUCKY (15-6110) 37.0564 N 88.7739 W 400 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 3
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2004

Extracted: Wed Sep 8 2010

Confidence Limits | Seasonality | Related Info | GIS data | Maps | Docs | Return to State Map

Precipitation Intensity Estimates (in/hr)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	4.99	3.92	3.22	2.15	1.32	0.79	0.57	0.36	0.21	0.13	0.08	0.04	0.03	0.02	0.02	0.01	0.01	0.01
2	5.88	4.63	3.80	2.57	1.59	0.95	0.69	0.43	0.26	0.16	0.09	0.05	0.03	0.03	0.02	0.01	0.01	0.01
5	6.84	5.36	4.43	3.07	1.94	1.17	0.85	0.52	0.31	0.19	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01
10	7.56	5.90	4.88	3.44	2.20	1.33	0.97	0.60	0.36	0.22	0.13	0.07	0.05	0.04	0.02	0.02	0.02	0.01
25	8.46	6.56	5.44	3.90	2.55	1.56	1.14	0.71	0.43	0.25	0.15	0.08	0.06	0.04	0.03	0.02	0.02	0.02
50	9.17	7.04	5.85	4.25	2.83	1.74	1.27	0.79	0.48	0.28	0.17	0.09	0.06	0.05	0.03	0.02	0.02	0.02
100	9.78	7.49	6.24	4.59	3.10	1.92	1.41	0.88	0.53	0.31	0.18	0.10	0.07	0.05	0.03	0.03	0.02	0.02
200	10.46	7.95	6.61	4.93	3.38	2.11	1.56	0.98	0.59	0.34	0.20	0.11	0.07	0.06	0.03	0.03	0.02	0.02
500	11.33	8.51	7.08	5.37	3.76	2.37	1.77	1.11	0.67	0.38	0.22	0.12	0.08	0.06	0.04	0.03	0.02	0.02
1000	11.93	8.91	7.43	5.70	4.06	2.58	1.93	1.21	0.73	0.41	0.23	0.13	0.09	0.07	0.04	0.03	0.02	0.02

* These precipitation frequency estimates are based on a partial duration series. ARI is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting forces estimates near zero to appear as zero.

* Upper bound of the 90% confidence interval Precipitation Intensity Estimates (in/hr)

ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	5.44	4.27	3.51	2.35	1.44	0.86	0.63	0.39	0.23	0.14	0.08	0.05	0.03	0.02	0.02	0.01	0.01	0.01
2	6.41	5.05	4.14	2.80	1.73	1.04	0.76	0.47	0.28	0.17	0.10	0.06	0.04	0.03	0.02	0.02	0.01	0.01
5	7.44	5.83	4.82	3.33	2.11	1.27	0.93	0.57	0.35	0.21	0.12	0.07	0.05	0.03	0.02	0.02	0.02	0.01
10	8.21	6.40	5.30	3.73	2.39	1.45	1.06	0.66	0.40	0.23	0.14	0.08	0.05	0.04	0.03	0.02	0.02	0.01
25	9.18	7.12	5.91	4.23	2.77	1.69	1.24	0.77	0.47	0.27	0.16	0.09	0.06	0.05	0.03	0.02	0.02	0.02
50	9.92	7.63	6.34	4.61	3.06	1.89	1.39	0.87	0.52	0.30	0.18	0.10	0.07	0.05	0.03	0.02	0.02	0.02
100	10.58	8.11	6.75	4.97	3.35	2.09	1.54	0.96	0.58	0.33	0.19	0.11	0.07	0.05	0.03	0.03	0.02	0.02
200	11.34	8.62	7.16	5.34	3.66	2.30	1.70	1.07	0.64	0.36	0.21	0.12	0.08	0.06	0.04	0.03	0.02	0.02
500	12.28	9.22	7.68	5.82	4.07	2.58	1.92	1.21	0.73	0.40	0.23	0.13	0.09	0.07	0.04	0.03	0.02	0.02
1000	12.94	9.66	8.06	6.19	4.40	2.81	2.10	1.33	0.80	0.44	0.25	0.14	0.09	0.07	0.04	0.03	0.03	0.02

* The upper bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are greater than.
** These precipitation frequency estimates are based on a partial duration series. ARI is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

* Lower bound of the 90% confidence interval Precipitation Intensity Estimates (in/hr)

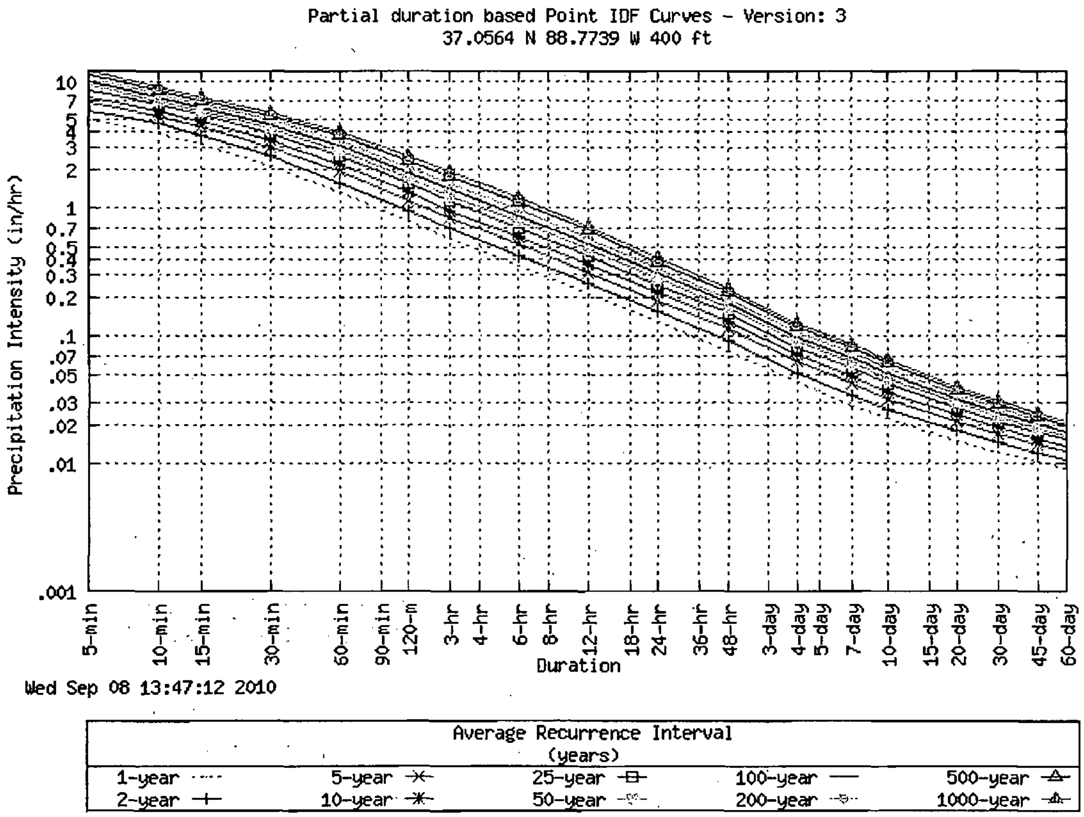
ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	4.60	3.61	2.97	1.98	1.22	0.72	0.53	0.33	0.20	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
2	5.42	4.27	3.51	2.37	1.47	0.87	0.63	0.39	0.23	0.15	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01
5	6.29	4.93	4.08	2.82	1.78	1.07	0.77	0.48	0.29	0.18	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01
10	6.96	5.42	4.49	3.16	2.03	1.22	0.88	0.55	0.33	0.20	0.12	0.07	0.04	0.03	0.02	0.02	0.01	0.01
25	7.74	6.01	4.98	3.57	2.34	1.42	1.03	0.64	0.39	0.23	0.14	0.08	0.05	0.04	0.03	0.02	0.02	0.01
50	8.36	6.43	5.34	3.88	2.58	1.57	1.15	0.71	0.43	0.26	0.15	0.08	0.06	0.04	0.03	0.02	0.02	0.02

100	8.89	6.82	5.67	4.18	2.82	1.73	1.27	0.79	0.48	0.29	0.17	0.09	0.06	0.05	0.03	0.02	0.02	0.02
200	9.48	7.20	5.99	4.46	3.06	1.90	1.40	0.87	0.52	0.31	0.18	0.10	0.07	0.05	0.03	0.03	0.02	0.02
500	10.20	7.66	6.38	4.83	3.38	2.11	1.57	0.98	0.59	0.34	0.20	0.11	0.07	0.06	0.03	0.03	0.02	0.02
1000	10.67	7.97	6.65	5.10	3.63	2.28	1.70	1.06	0.64	0.37	0.21	0.12	0.08	0.06	0.04	0.03	0.02	0.02

* The lower bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are less than.
** These precipitation frequency estimates are based on a partial duration maxima series. ARI is the Average Recurrence Interval.

Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

Text version of tables



Related Information

Maps & Aerials

Click here to see topographic maps and aerial photographs available for this location from Microsoft Research Maps

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Click here to see watershed and streamflow information available for this location from the U.S. Environmental Protection Agency's site

Climate Data Sources

National Climatic Data Center (NCDC) database

Locate NCDC climate stations within:

+/-30 minutes or +/-1 degree of this location. Digital ASCII data can be obtained directly from NCDC.

Reference Materials

HMR51 PMP Figures

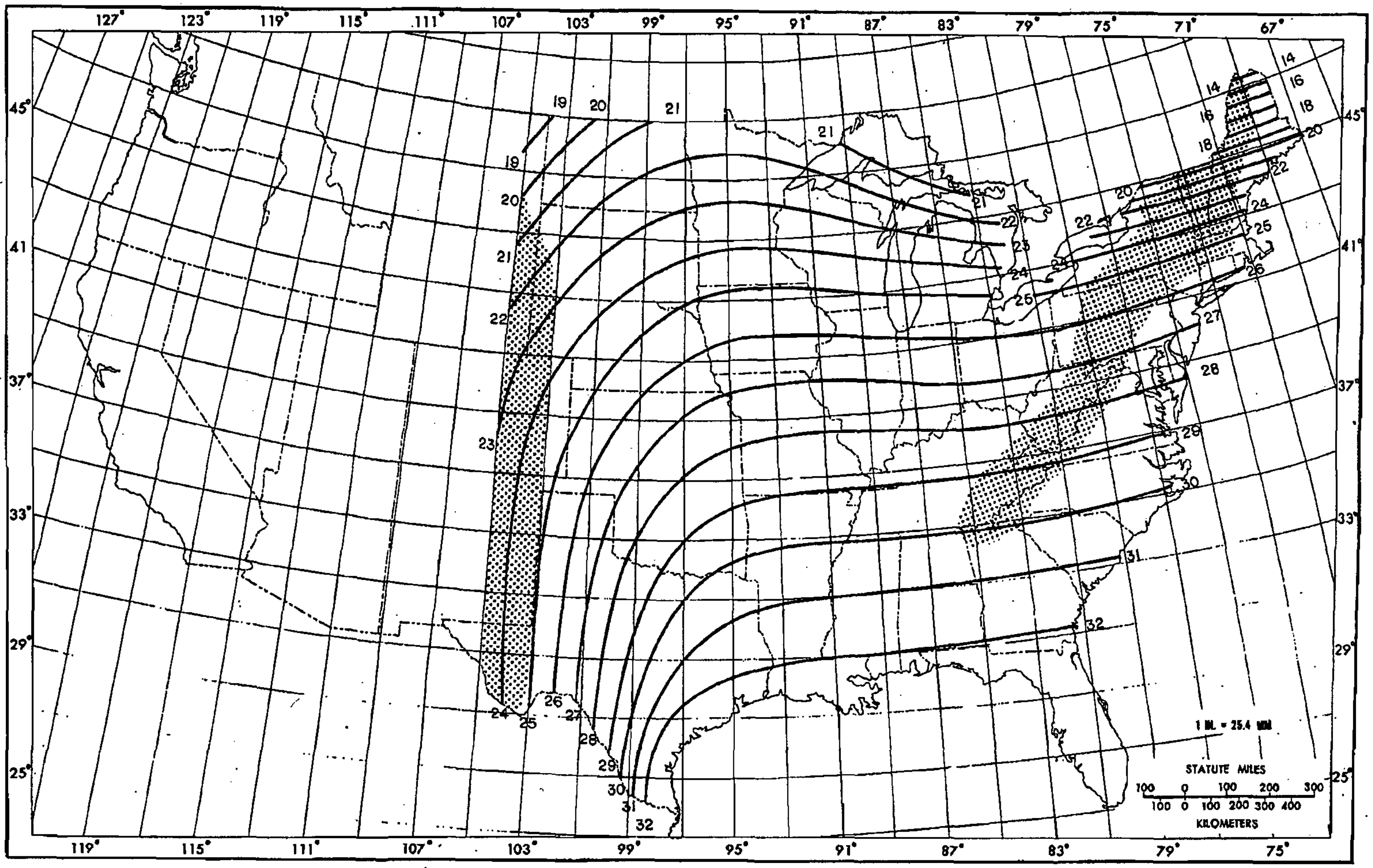

Figure 18.--All-season PMP (in.) for 6 hr 10 mi^2 (26 km^2).

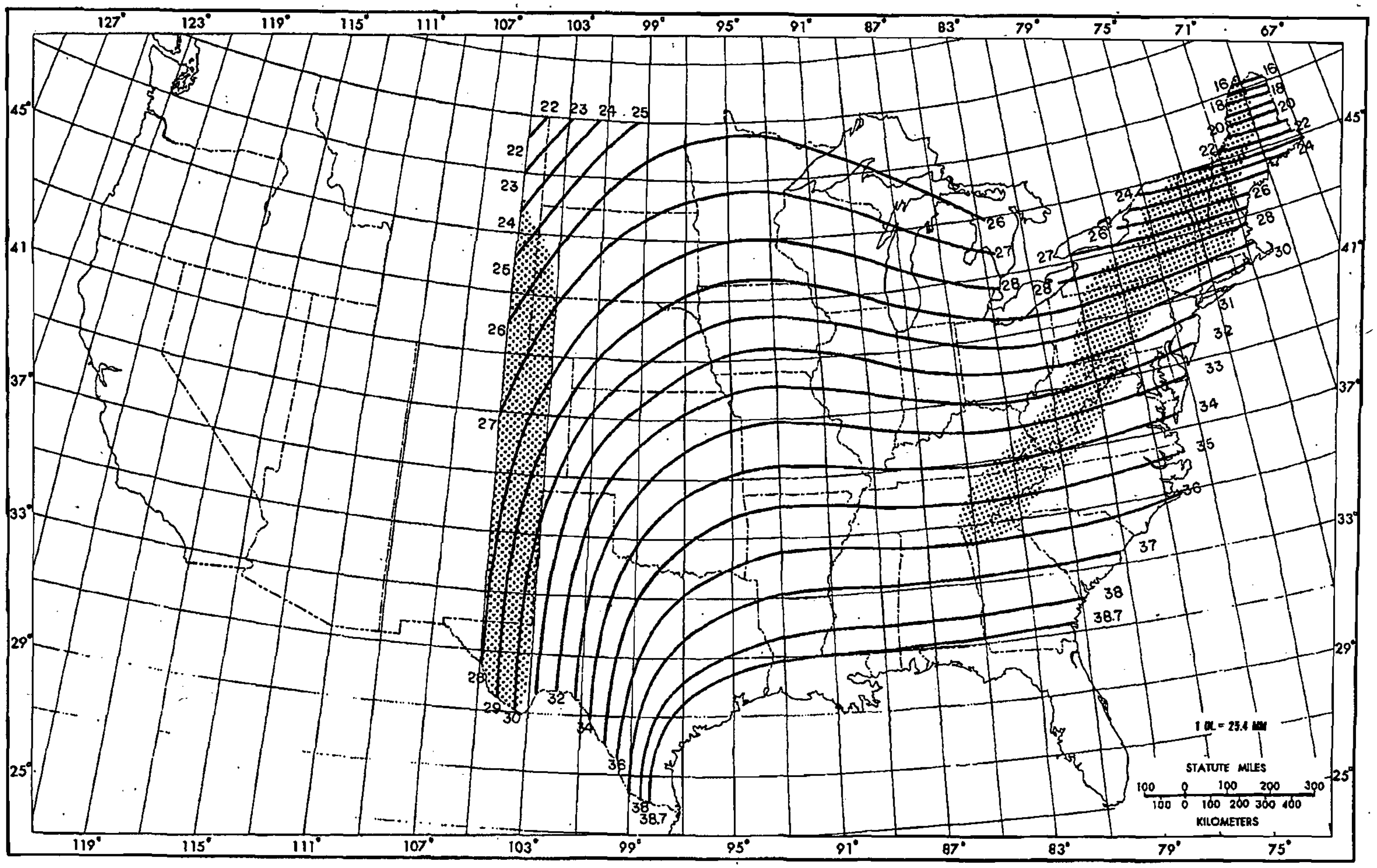

Figure 19.--All-season PMP (in.) for 12 hr 10 mi^2 (26 km^2).

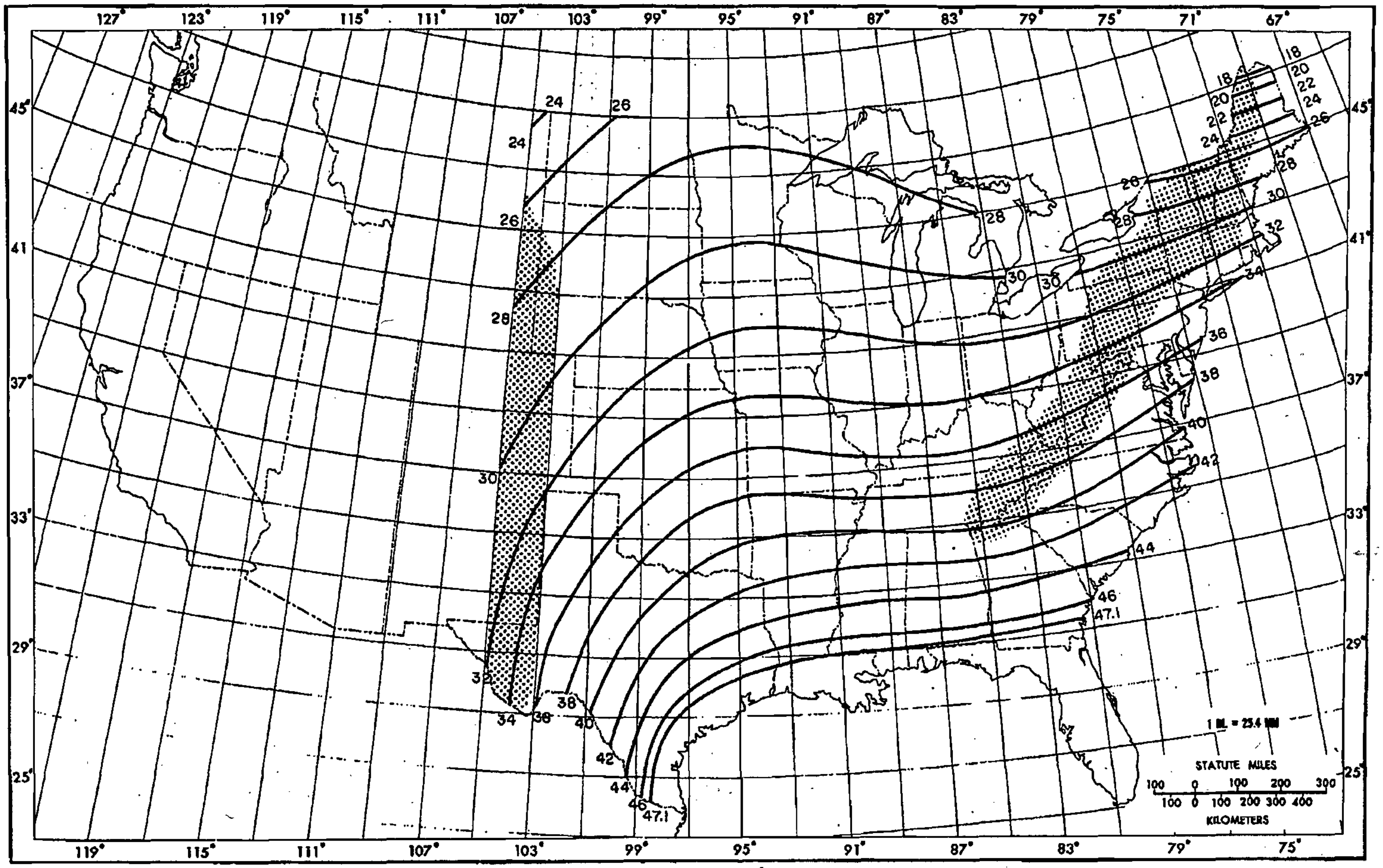

Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

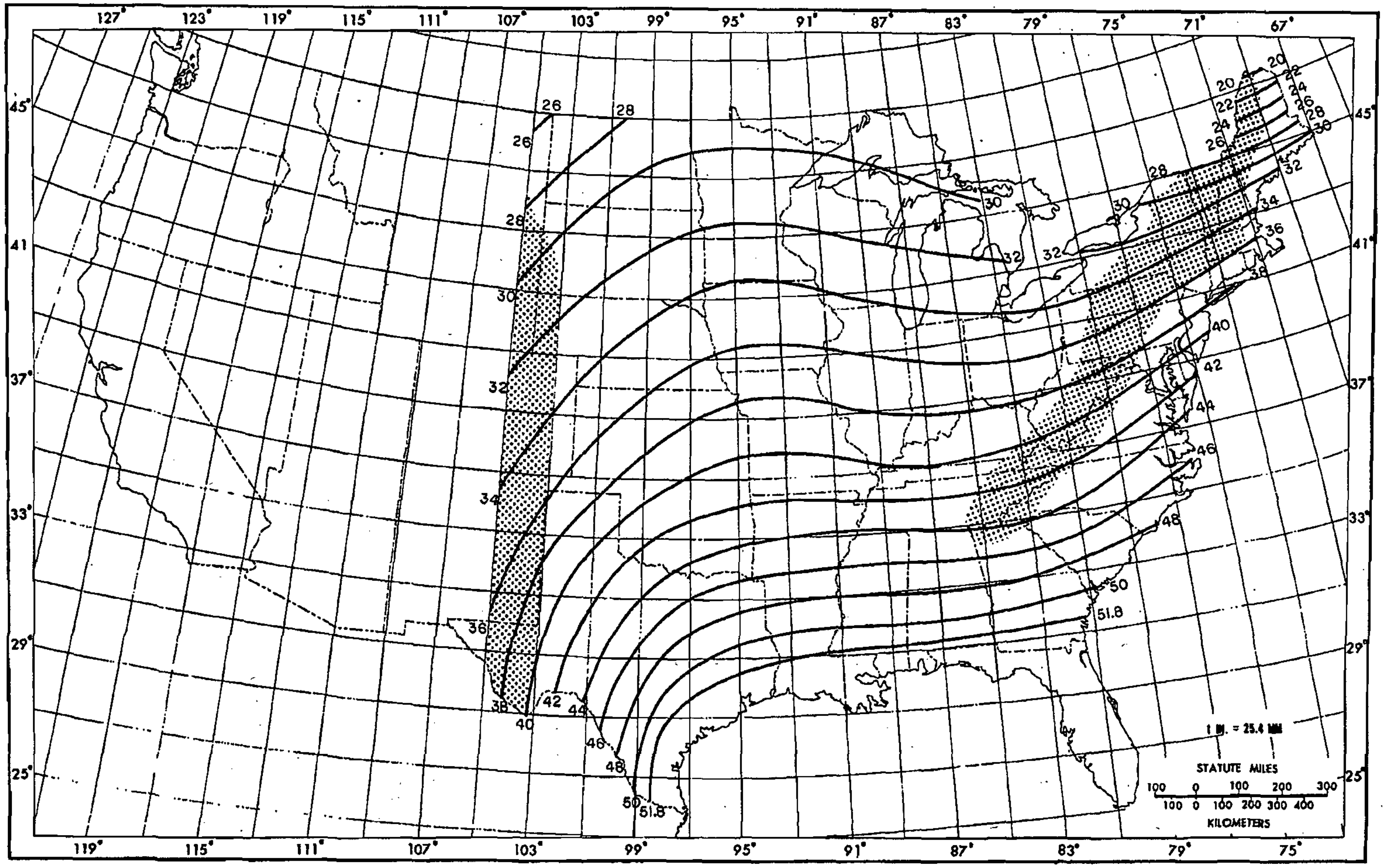

Figure 21.--All-season PMP (in.) for 48 hr 10 mi² (26 km²).

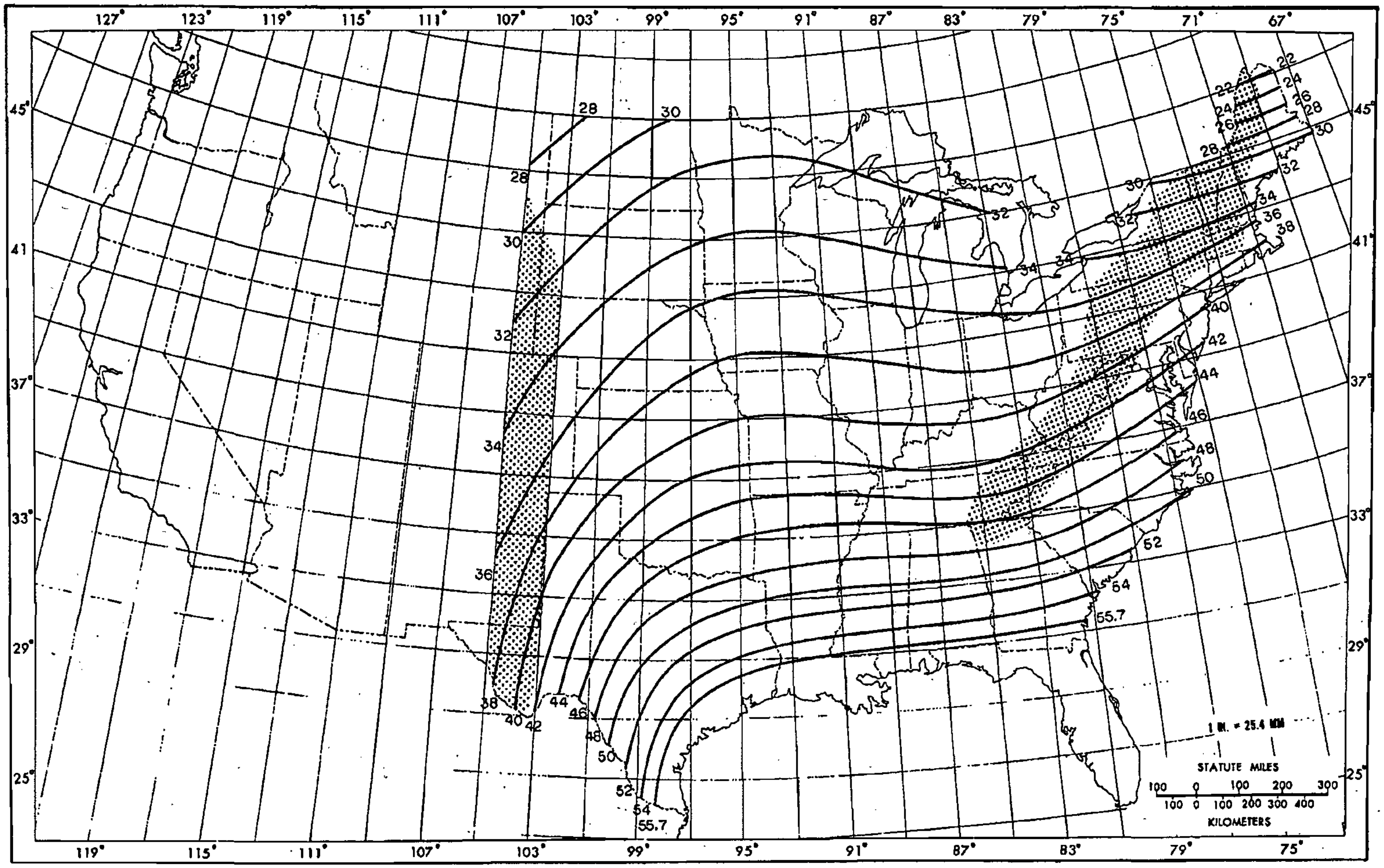

Figure 22.--All-season PMP (in.) for 72 hr 10 mi^2 (26 km^2).

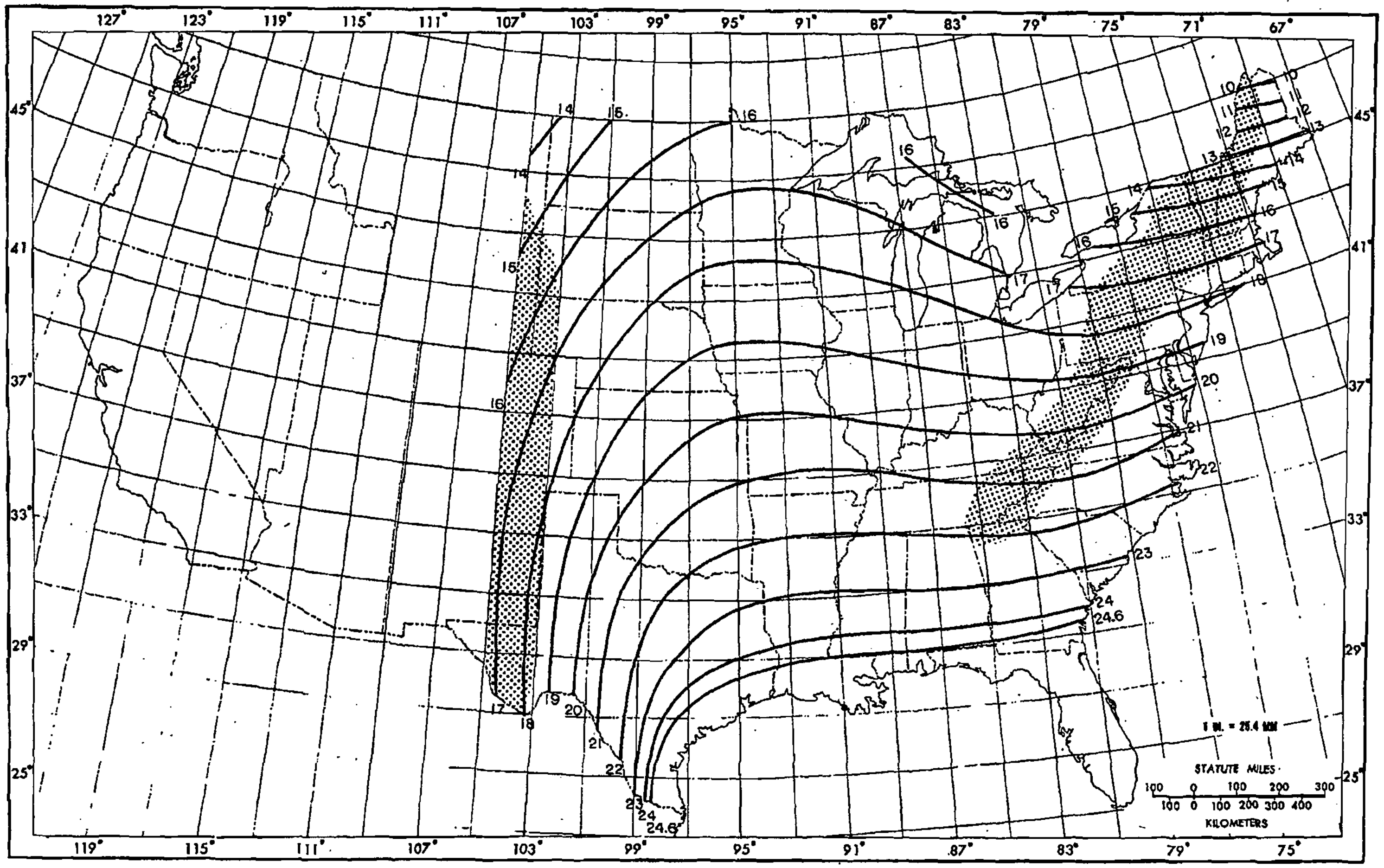

Figure 23.--All-season PMP (in.) for 6 hr 200 mi^2 (518 km^2).

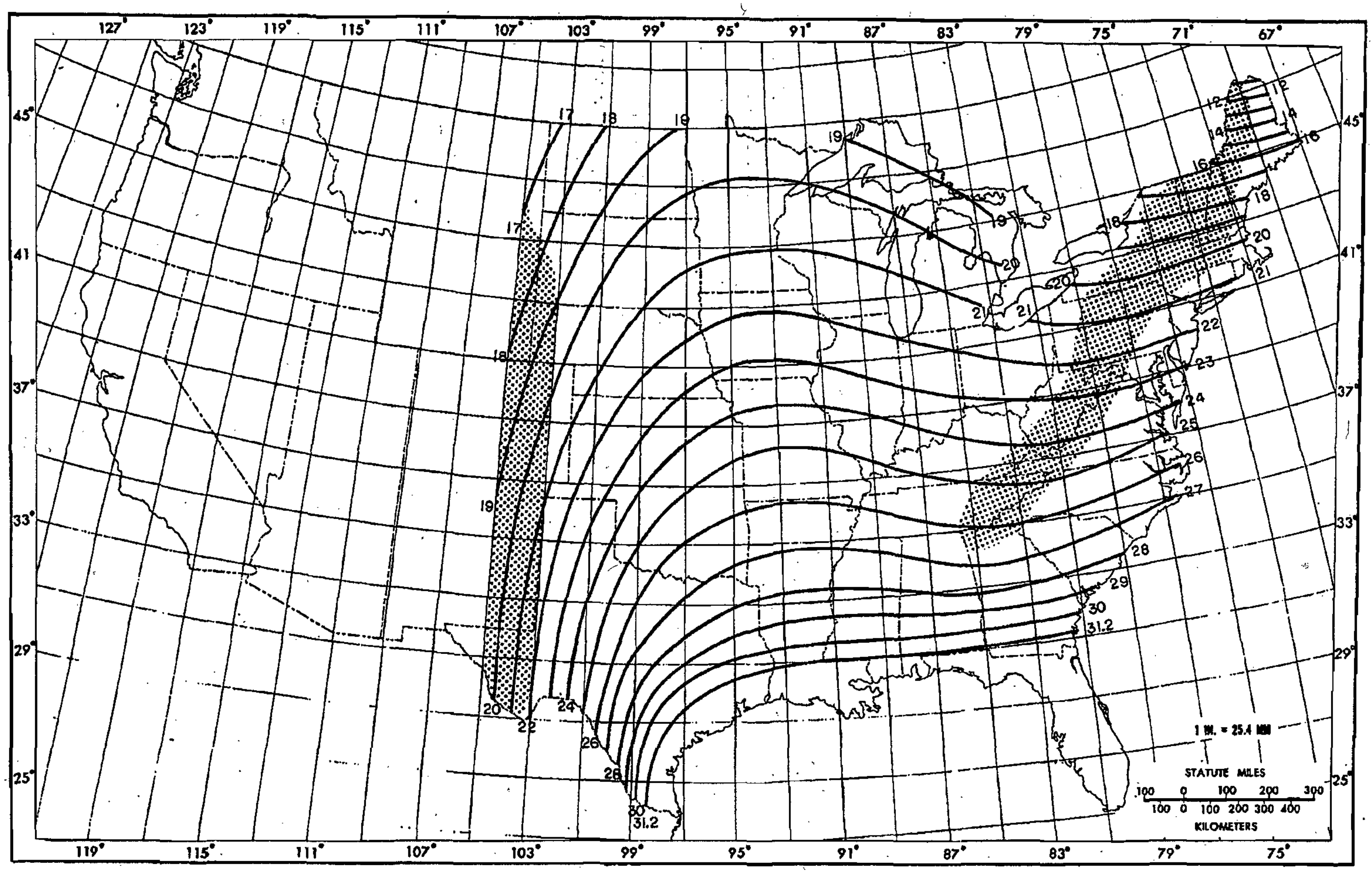

Figure 24.--All-season PMP (in.) for 12 hr 200 mi^2 (518 km^2).

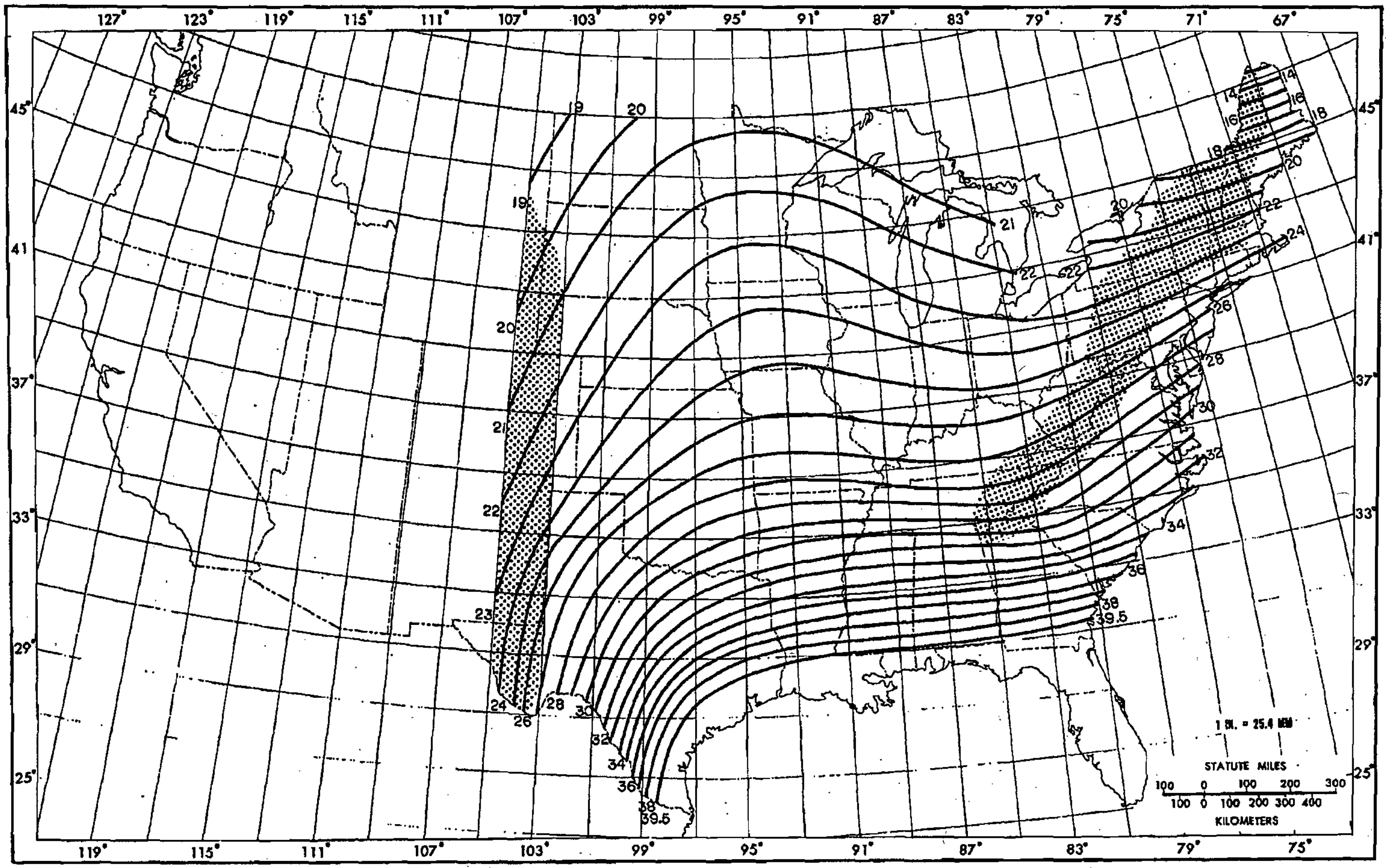

Figure 25.--All-season PMP (in.) for 24 hr 200 mi² (518 km²).

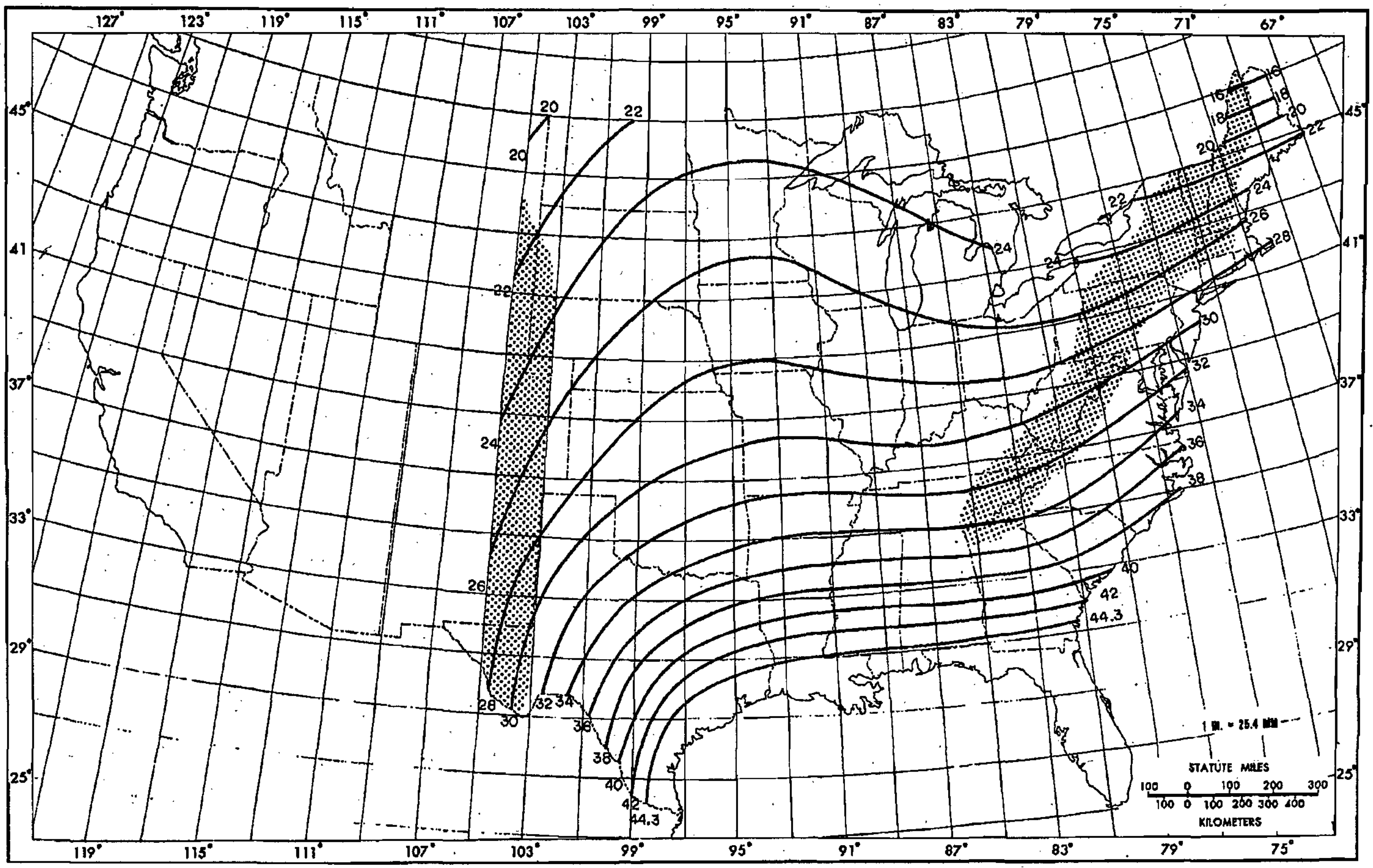

Figure 26.--All-season PMP (in.) for 48 hr 200 mi^2 (518 km^2).

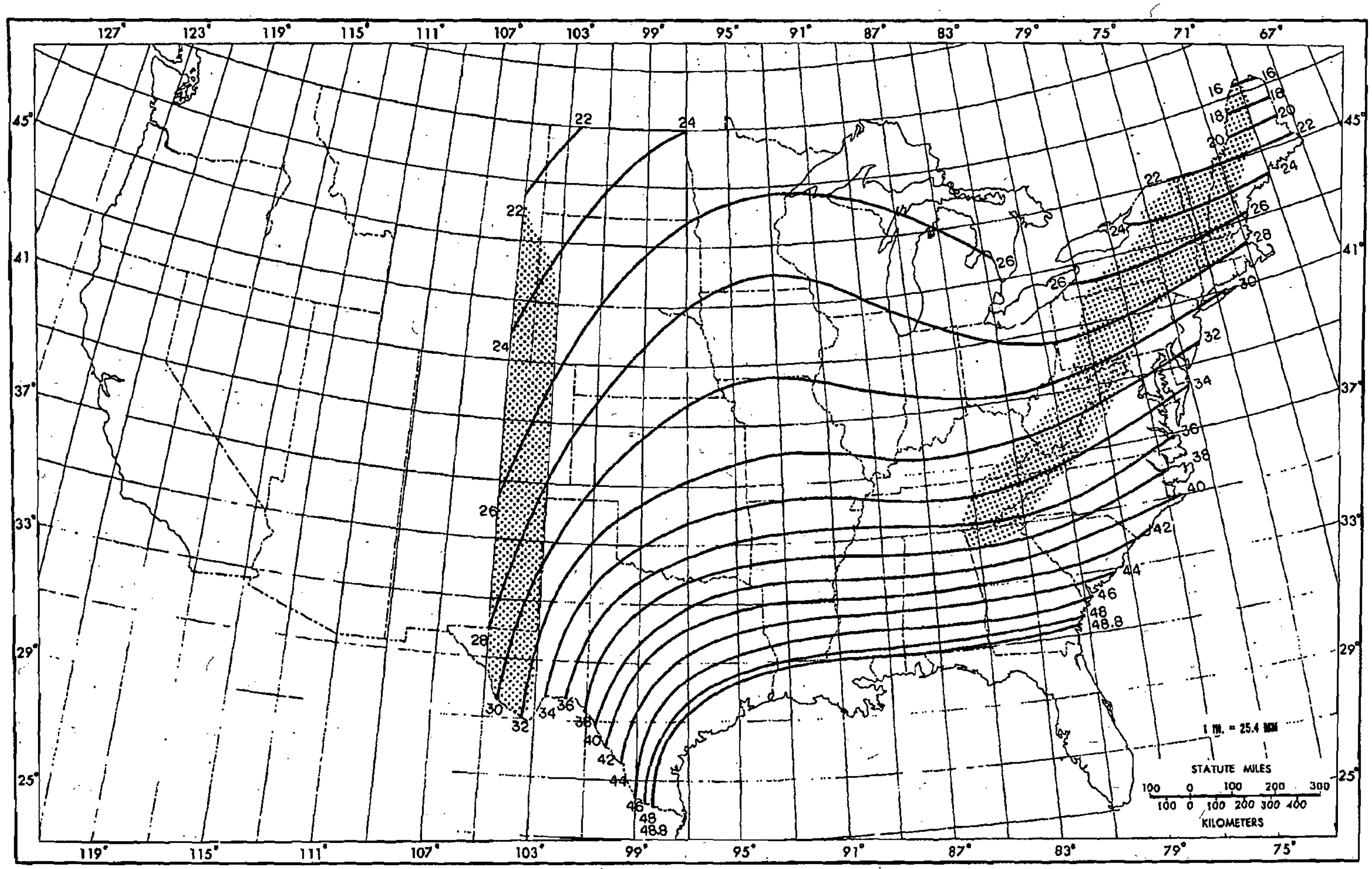

Figure 27.--All-season PMP (in.) for 72 hr 200 mi^2 (518 km^2).

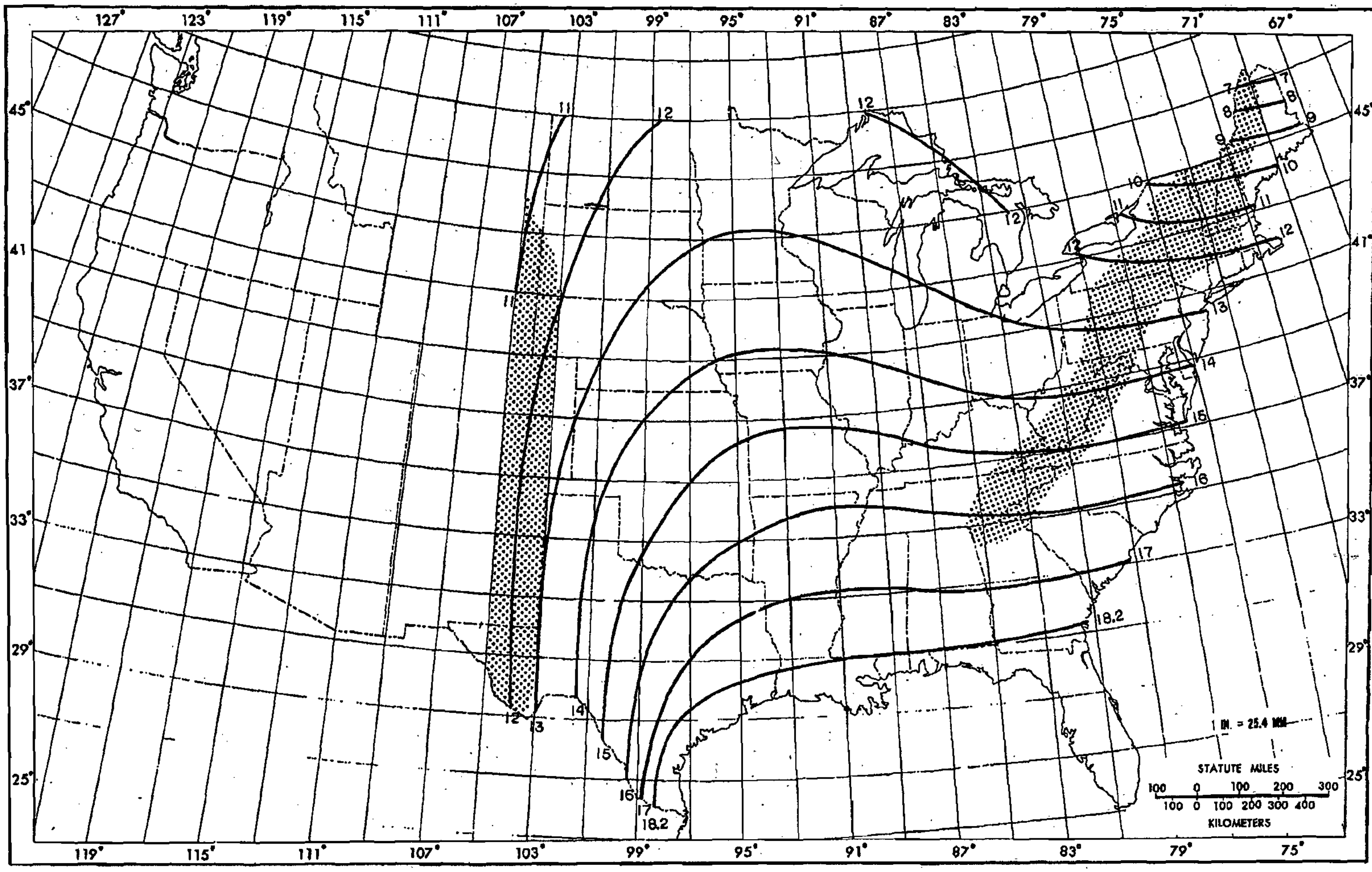

Figure 28.--All-season PMP (in.) for 6 hr 1,000 mi^2 (2,590 km^2).

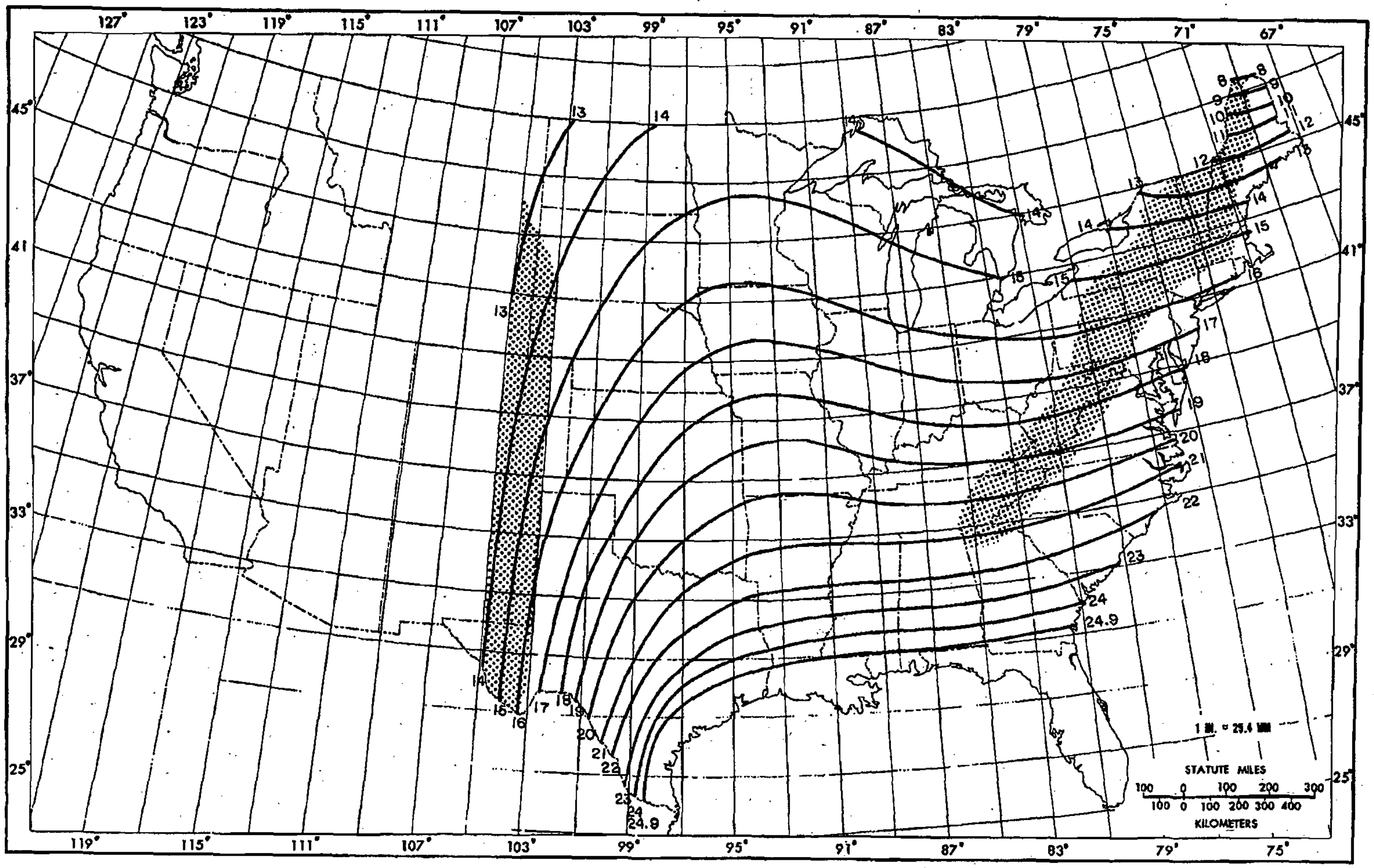

Figure 29.--All-season PMP (in.) for 12 hr 1,000 mi² (2,590 km²).

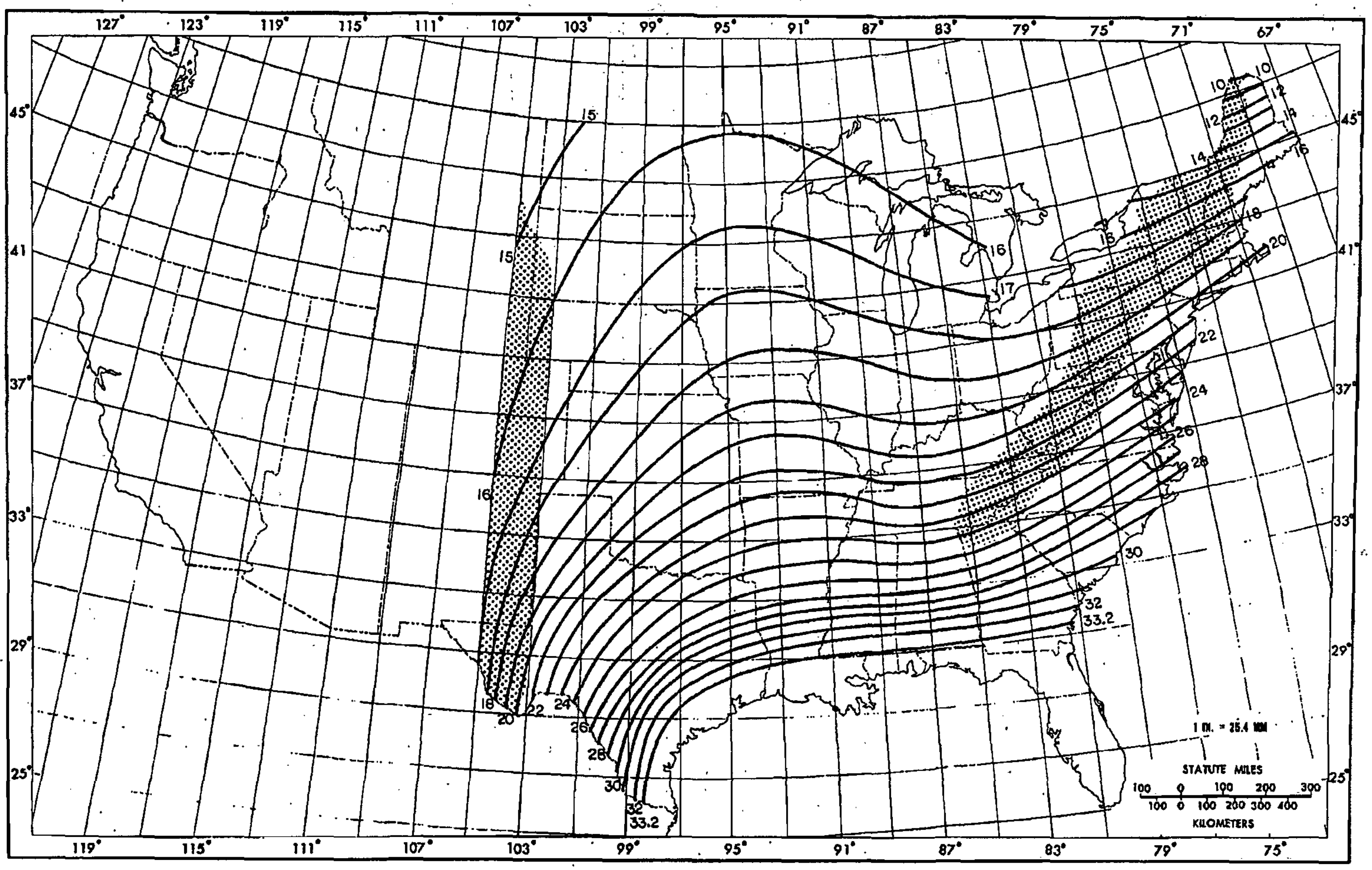

Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi² (2,590 km²).

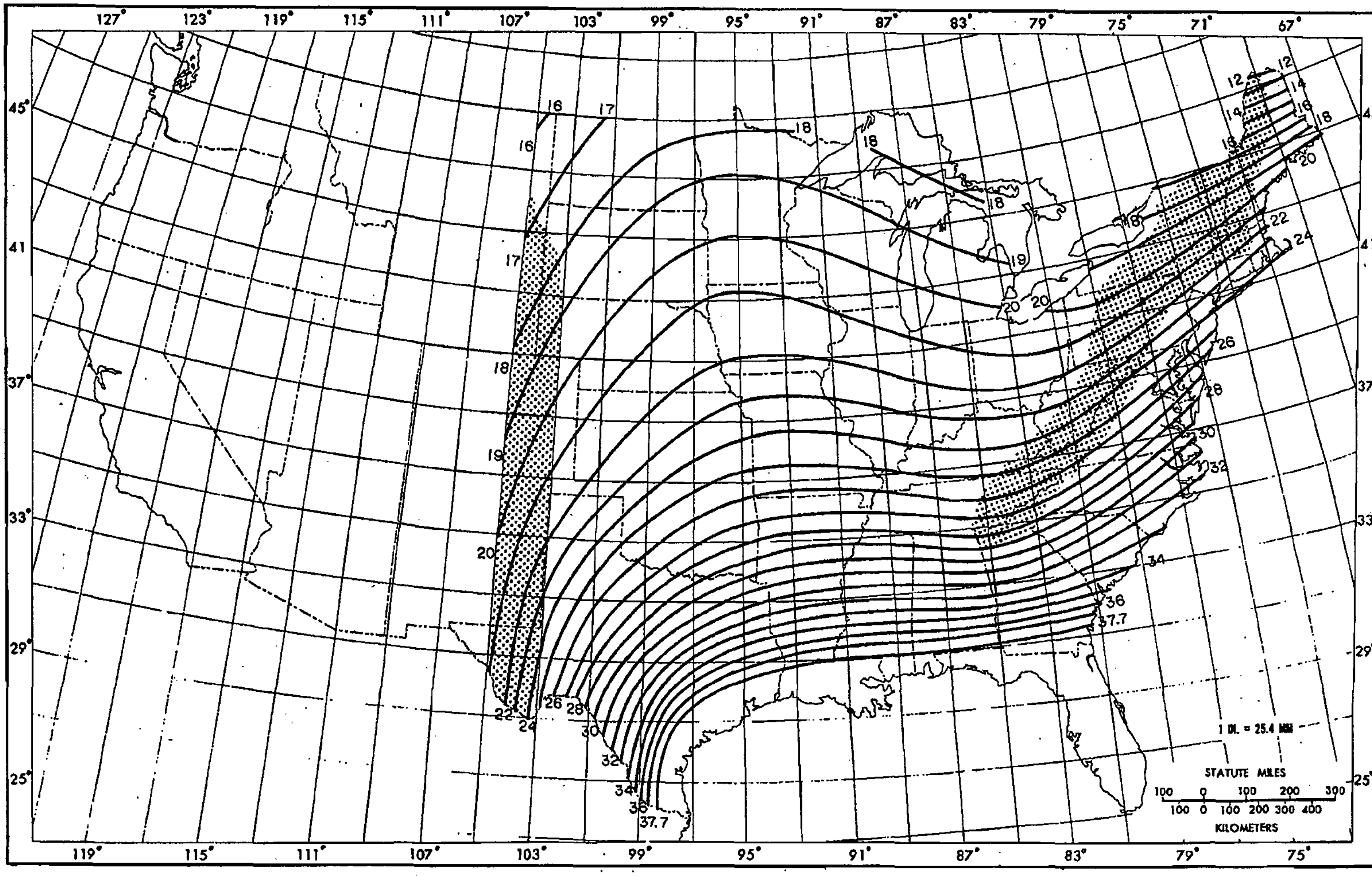

Figure 31.--All-season PMP (in.) for 48 hr 1,000 mi^2 (2,590 km^2).

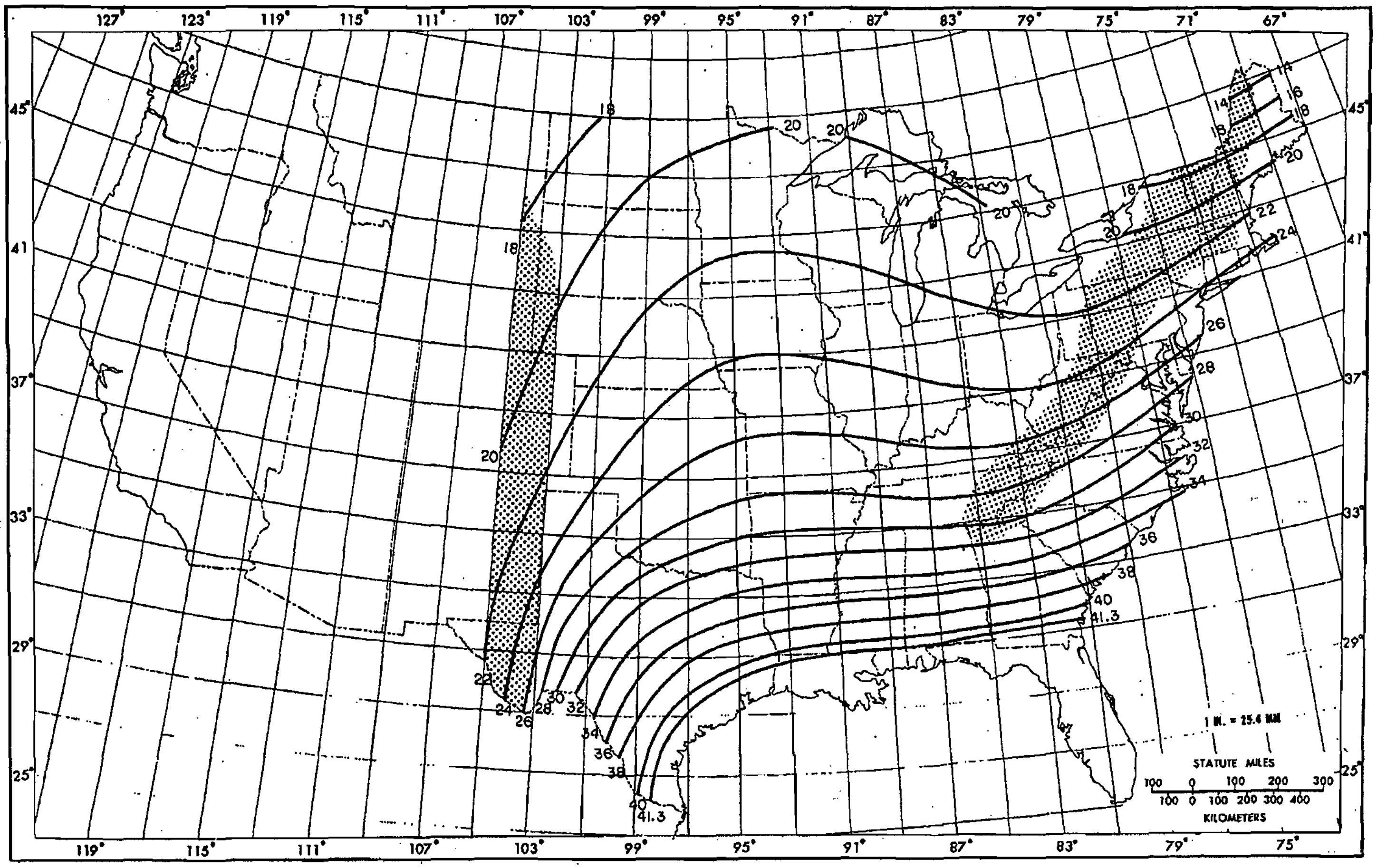

Figure 32.--All-season PMP (in.) for 72 hr 1,000 mi² (2,590 km²).

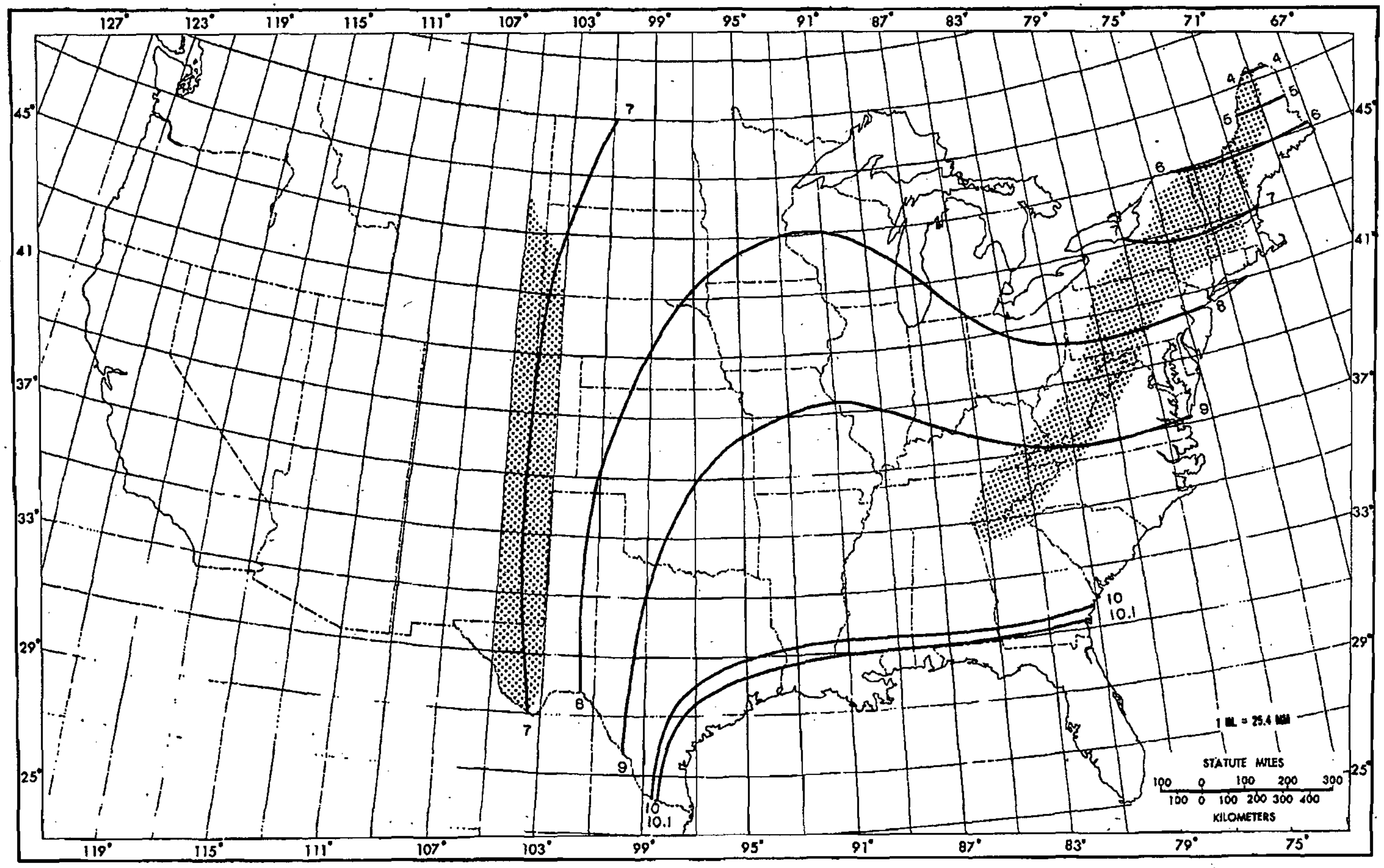

Figure 33.--All-season PMP (in.) for 6 hr 5,000 mi² (12,950 km²).

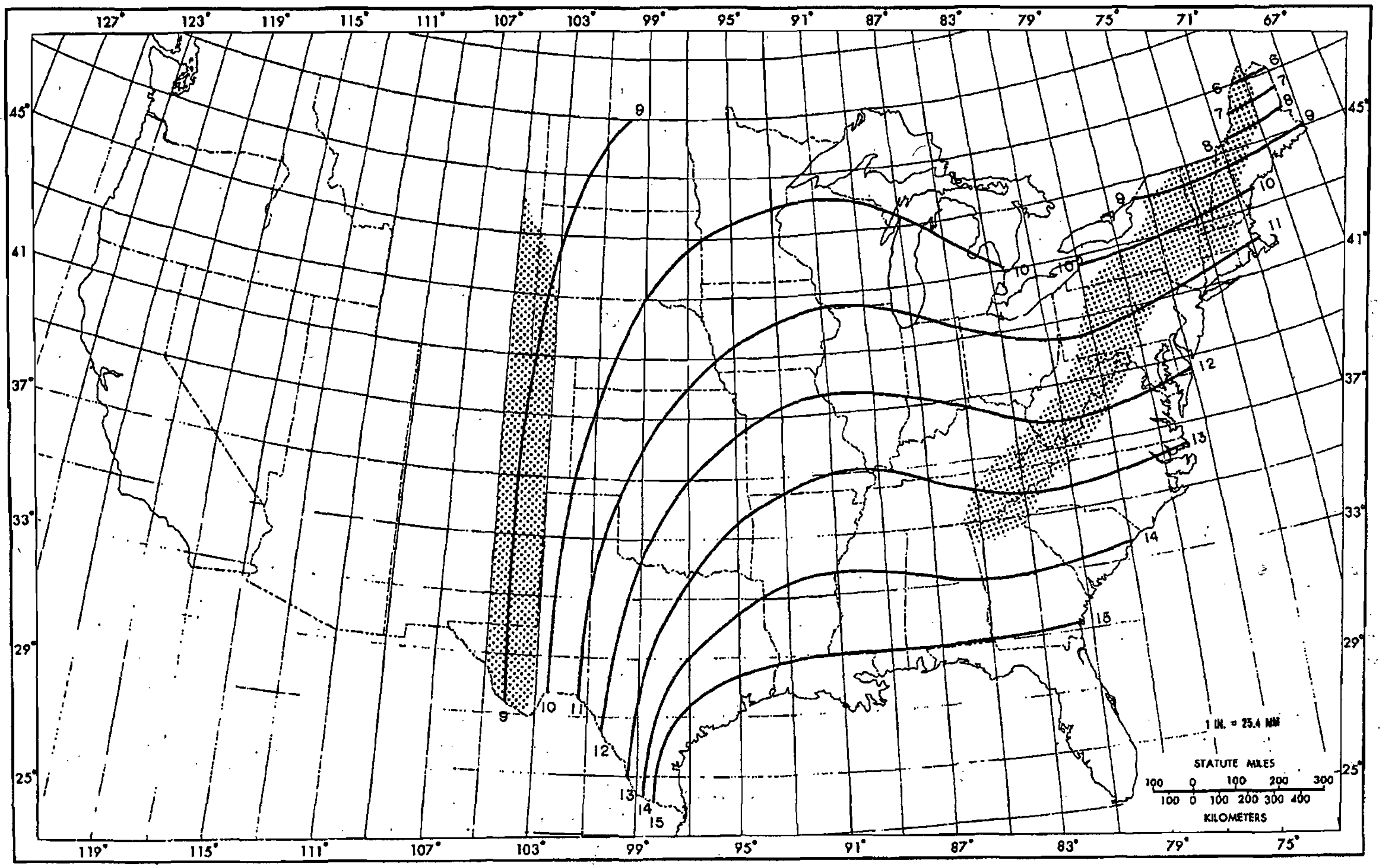

Figure 34.--All-season PMP (in.) for 12 hr 5,000 mi^2 (12,950 km^2).

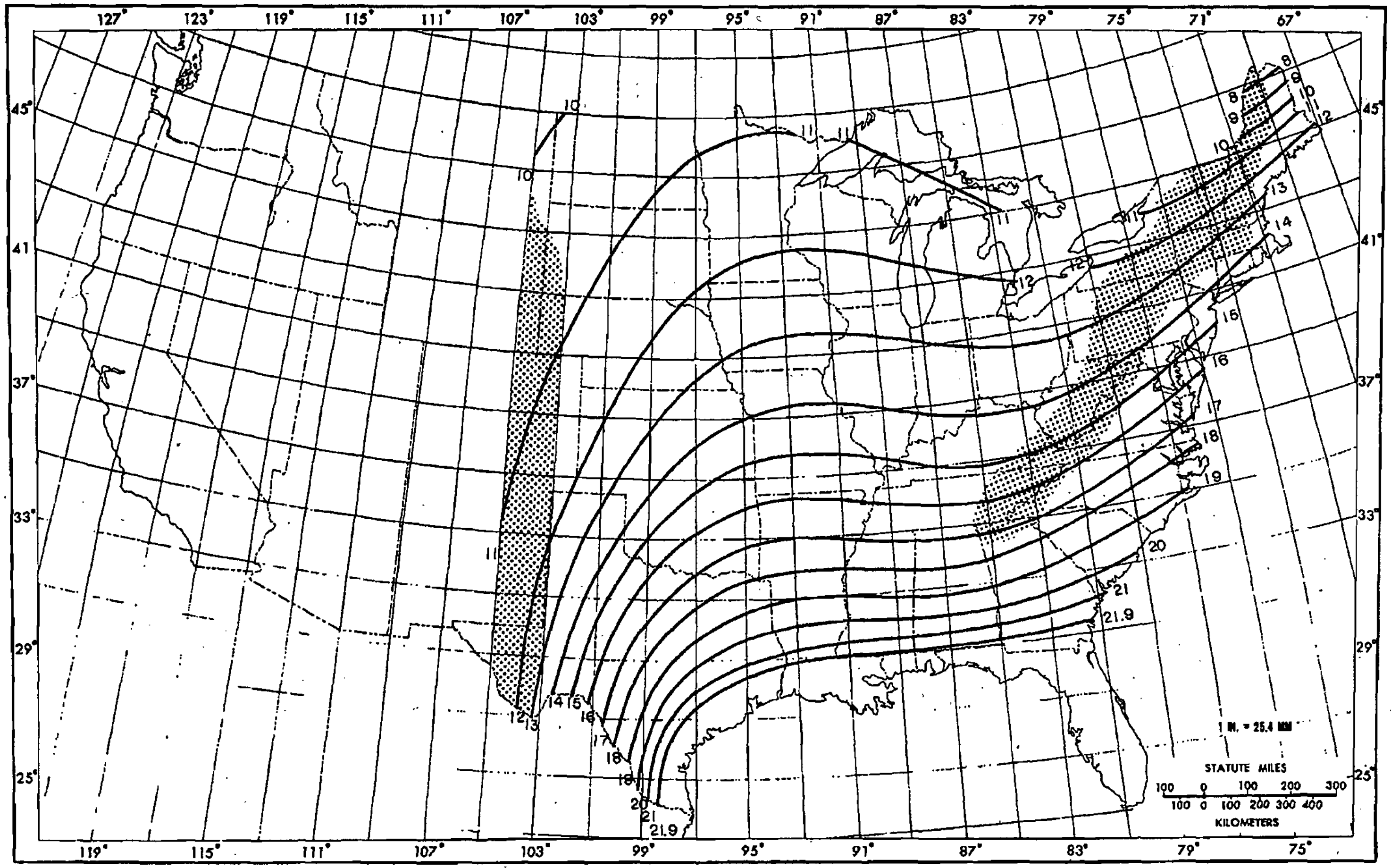

Figure 35.--All-season PMP (in.) for 24 hr 5,000 mi² (12,950 km²).

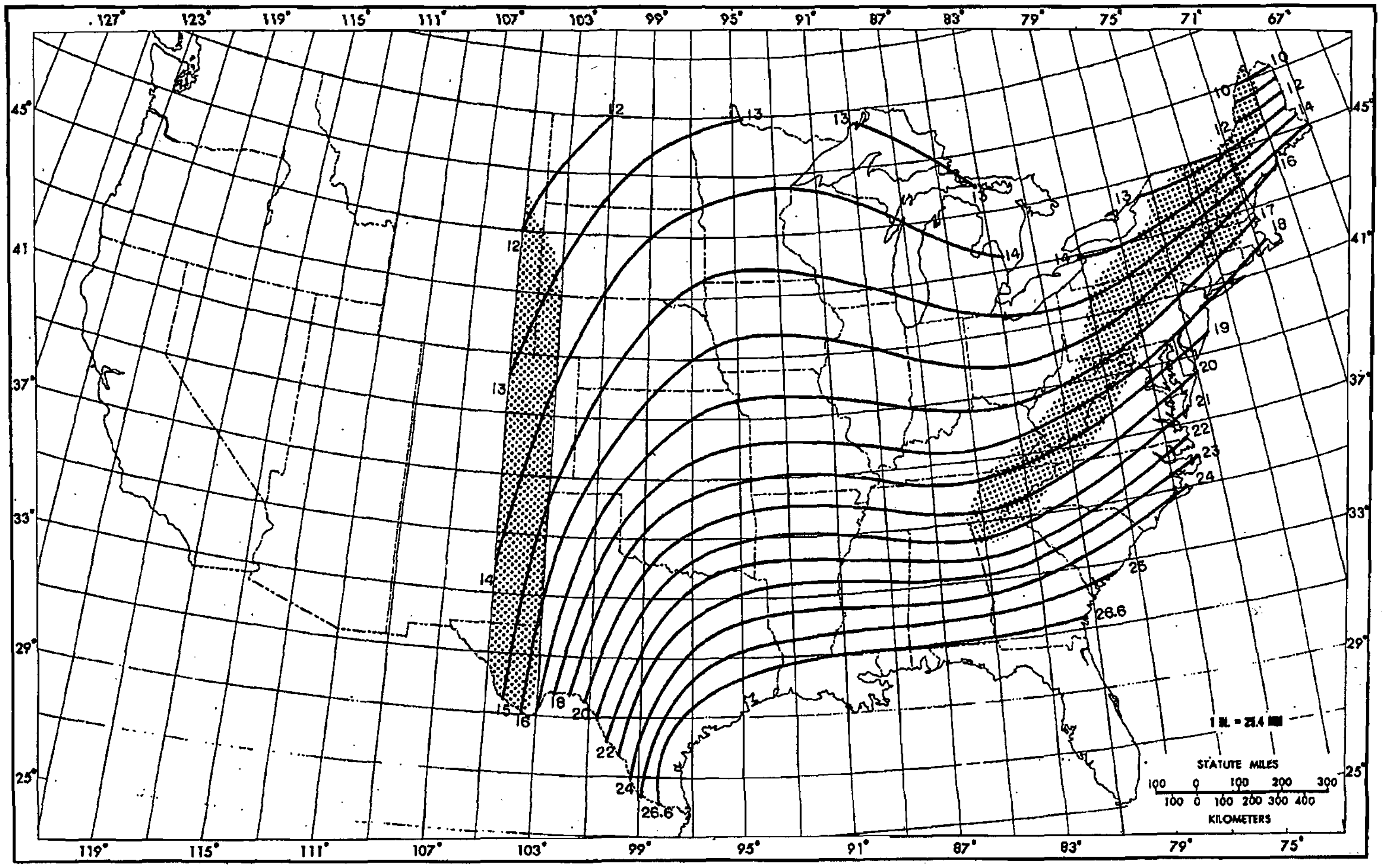

Figure 36.--All-season PMP (in.) for 48 hr 5,000 mi² (12,950 km²).

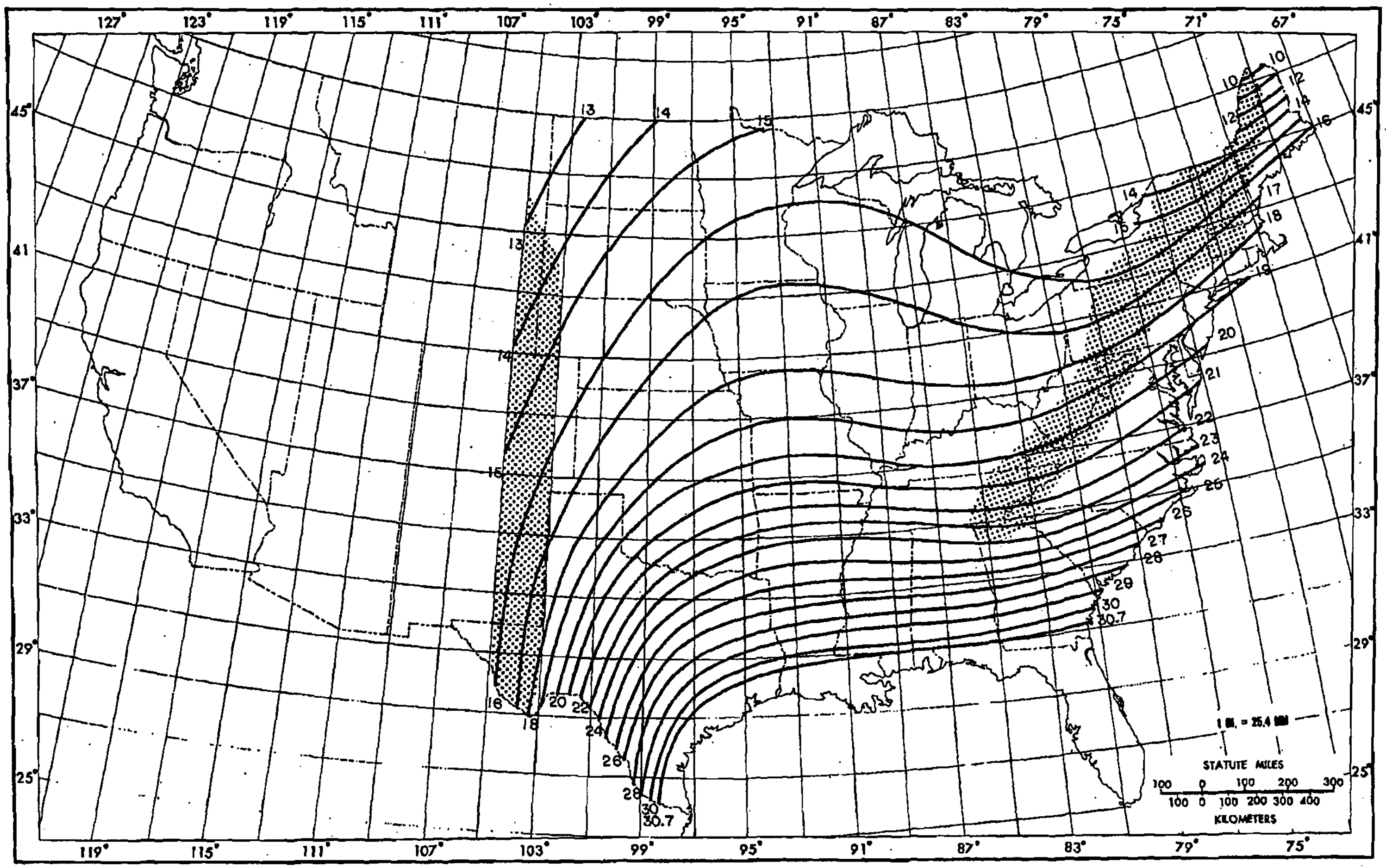

Figure 37.--All-season PMP (in.) for 72 hr 5,000 mi² (12,950 km²).

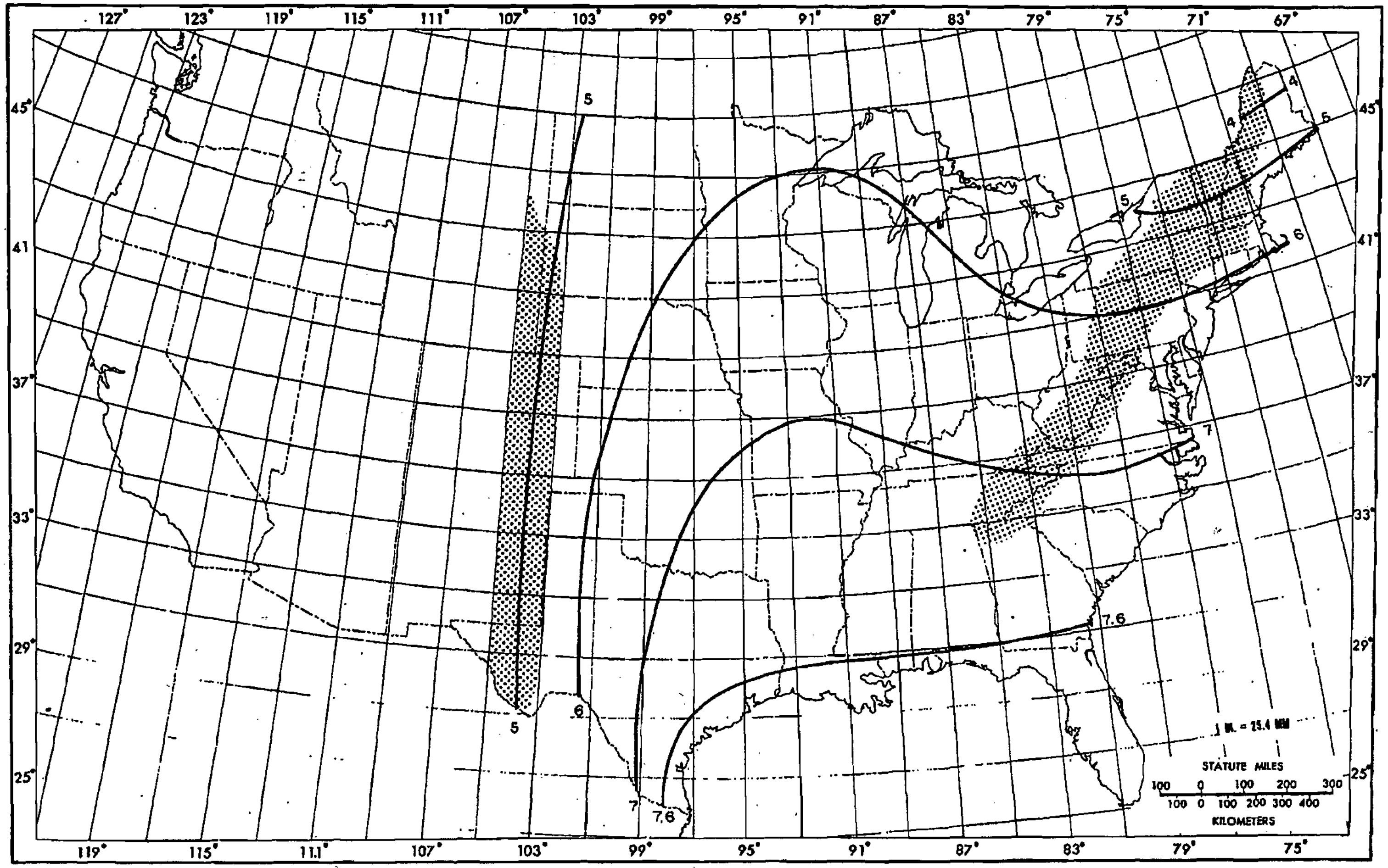

Figure 38.--All-season PMP (in.) for 6 hr 10,000 mi^2 (25,900 km^2).

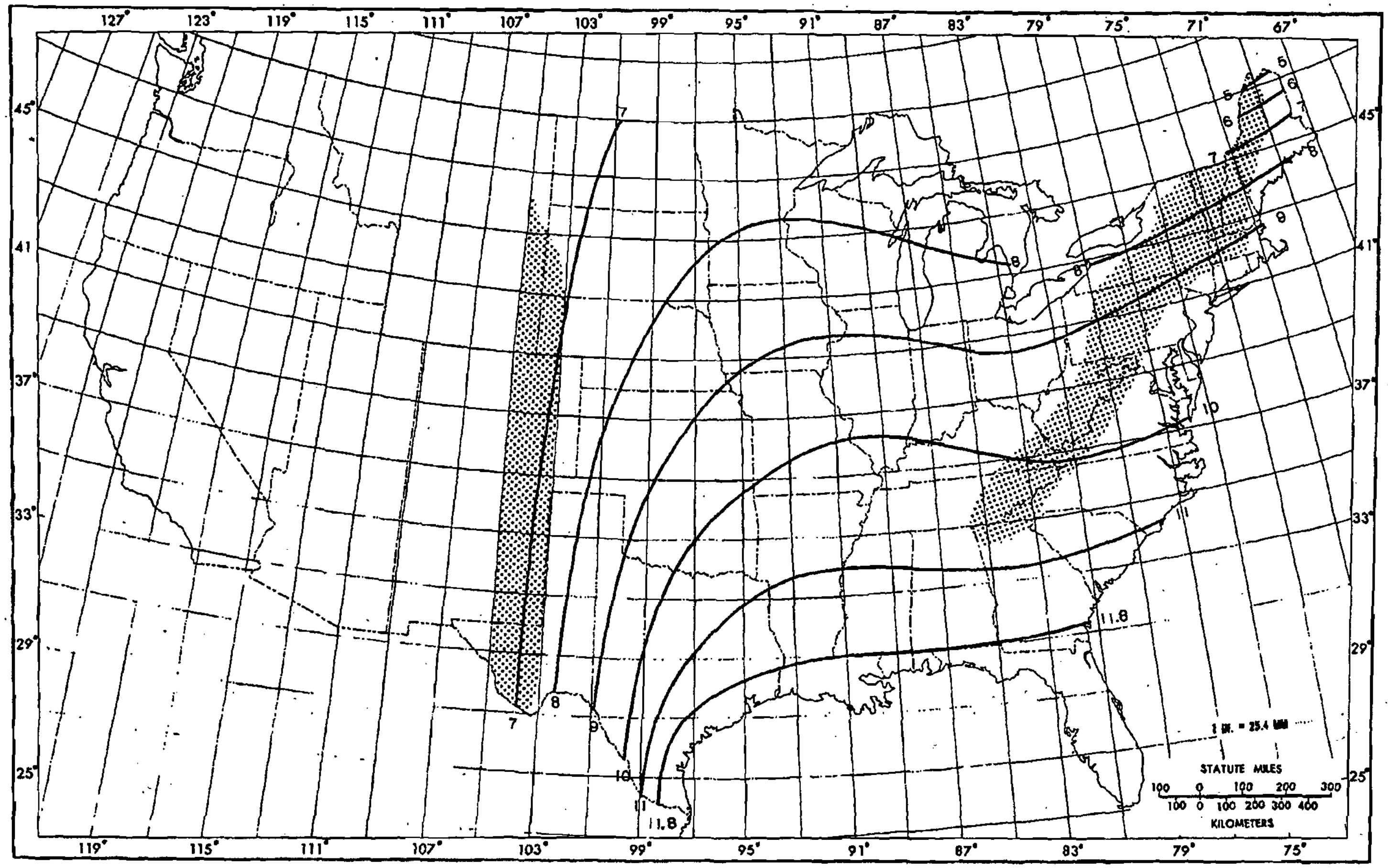

Figure 39.--All-season PMP (in.) for 12 hr 10,000 mi² (25,900 km²).

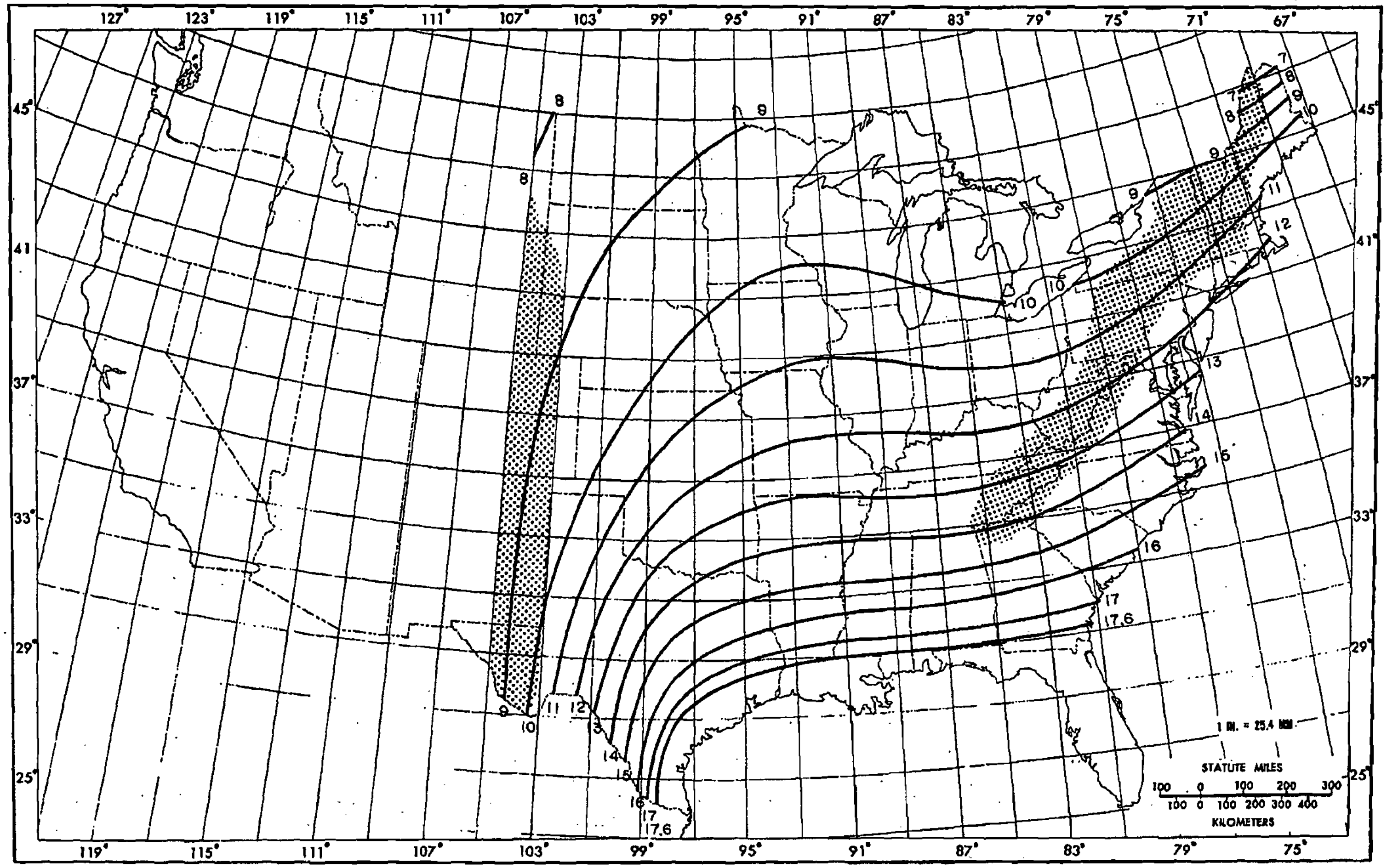

Figure 40.--All-season PMP (in.) for 24 hr 10,000 mi^2 (25,900 km^2).

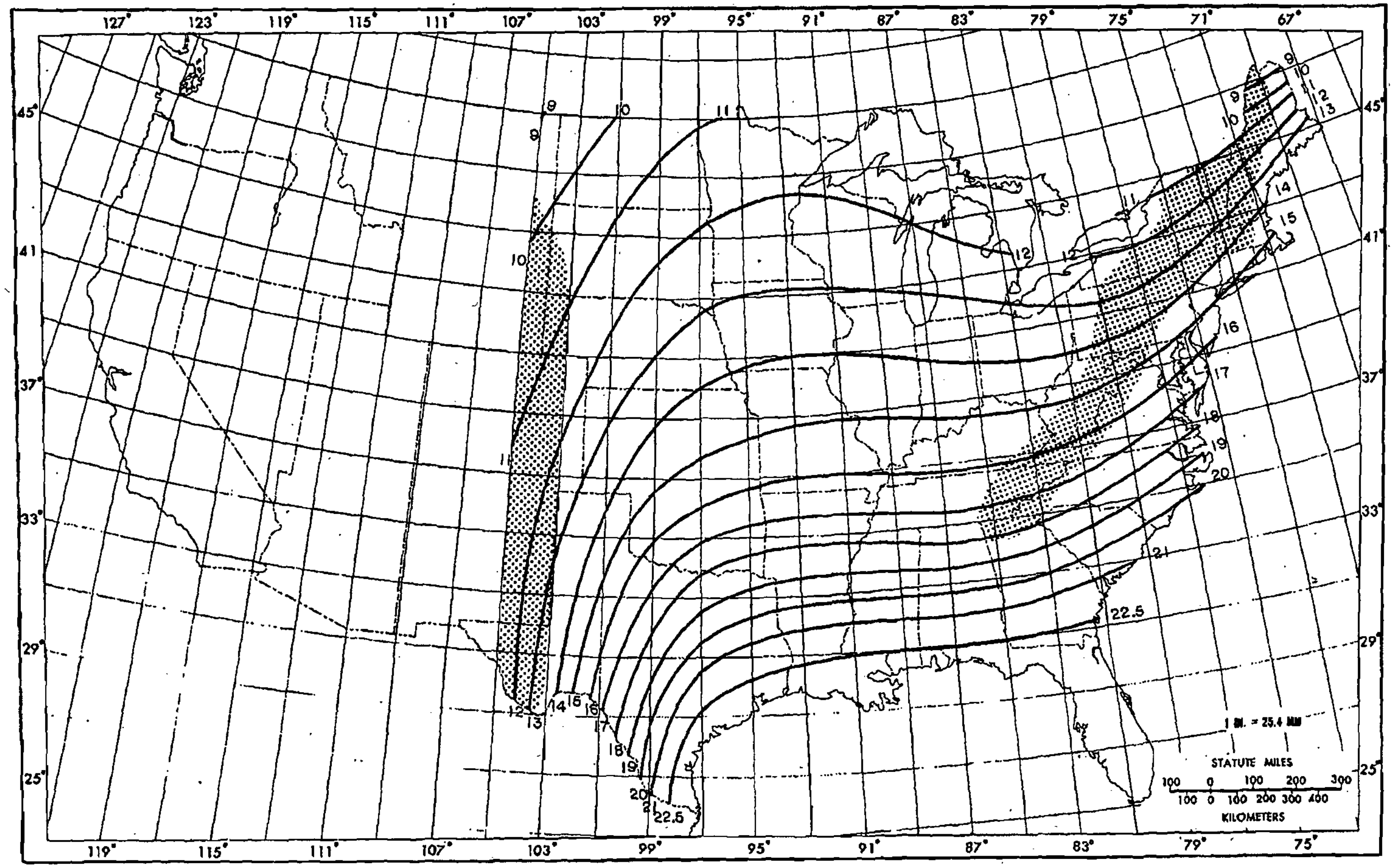

Figure 41.--All-season PMP (in.) for 48 hr 10,000 mi² (25,900 km²).

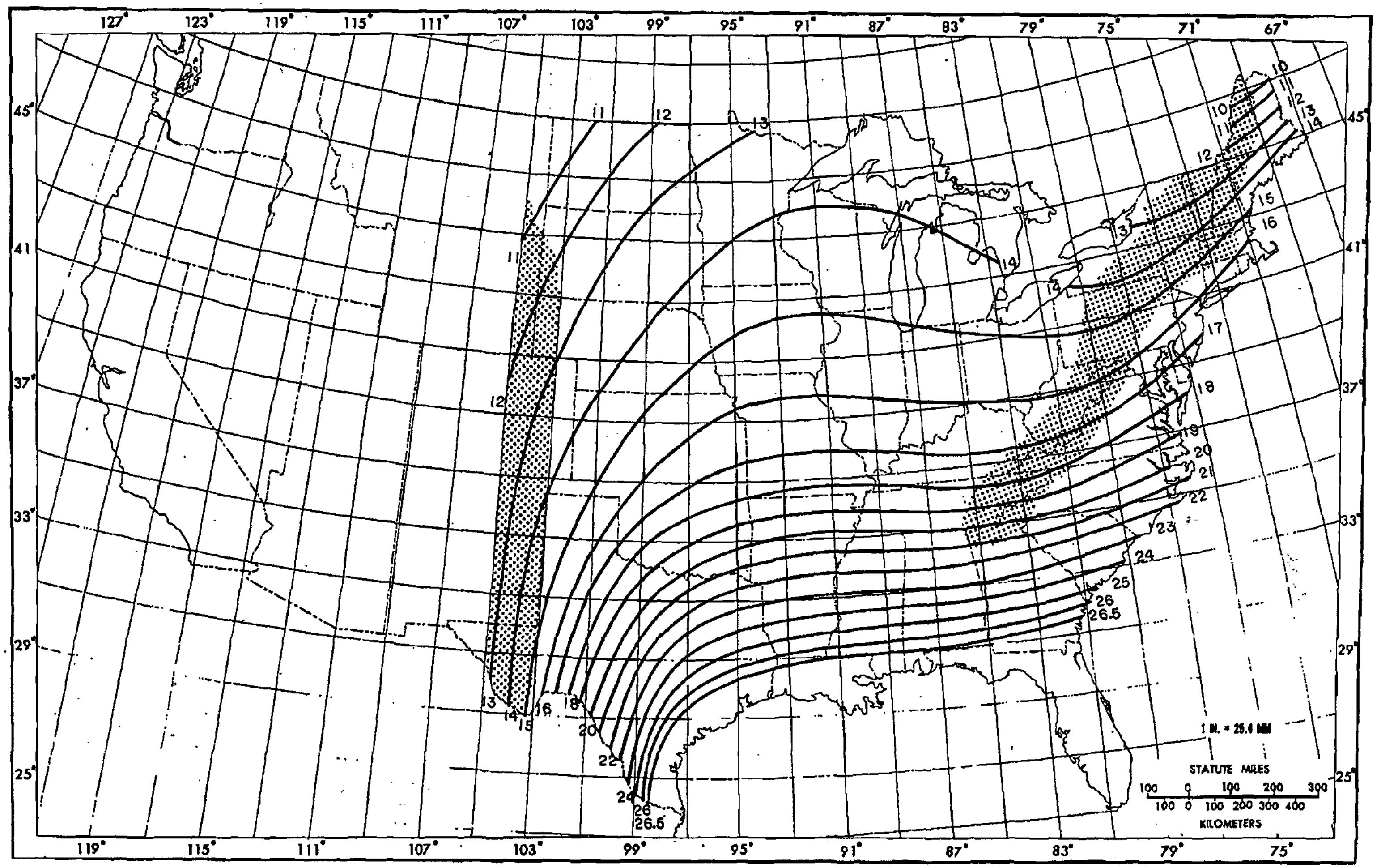

Figure 42.--All-season PMP (in.) for 72 hr 10,000 mi² (25,900 km²).

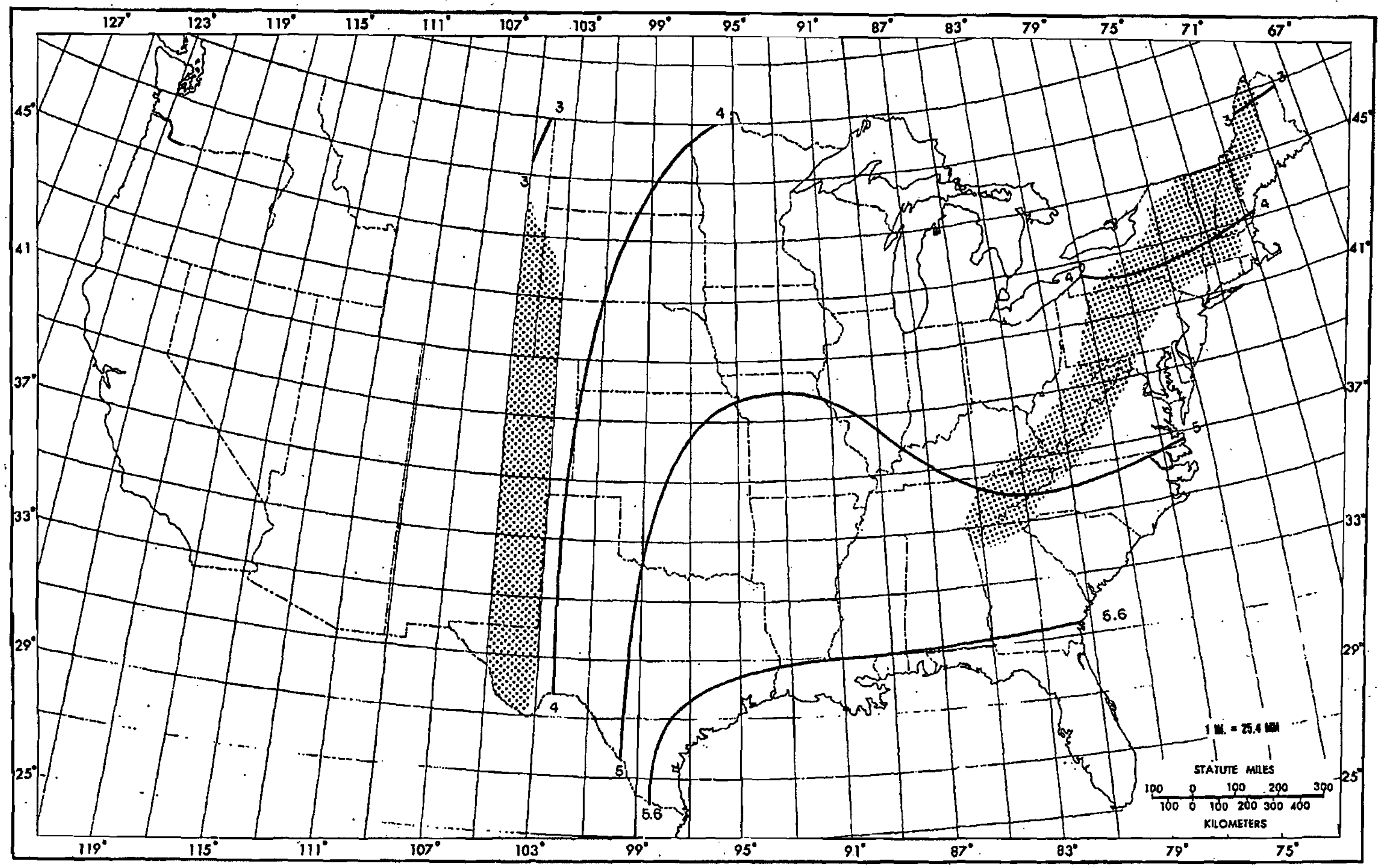

Figure 43.--All-season PMP (in.) for 6 hr 20,000 mi² (51,800 km²).

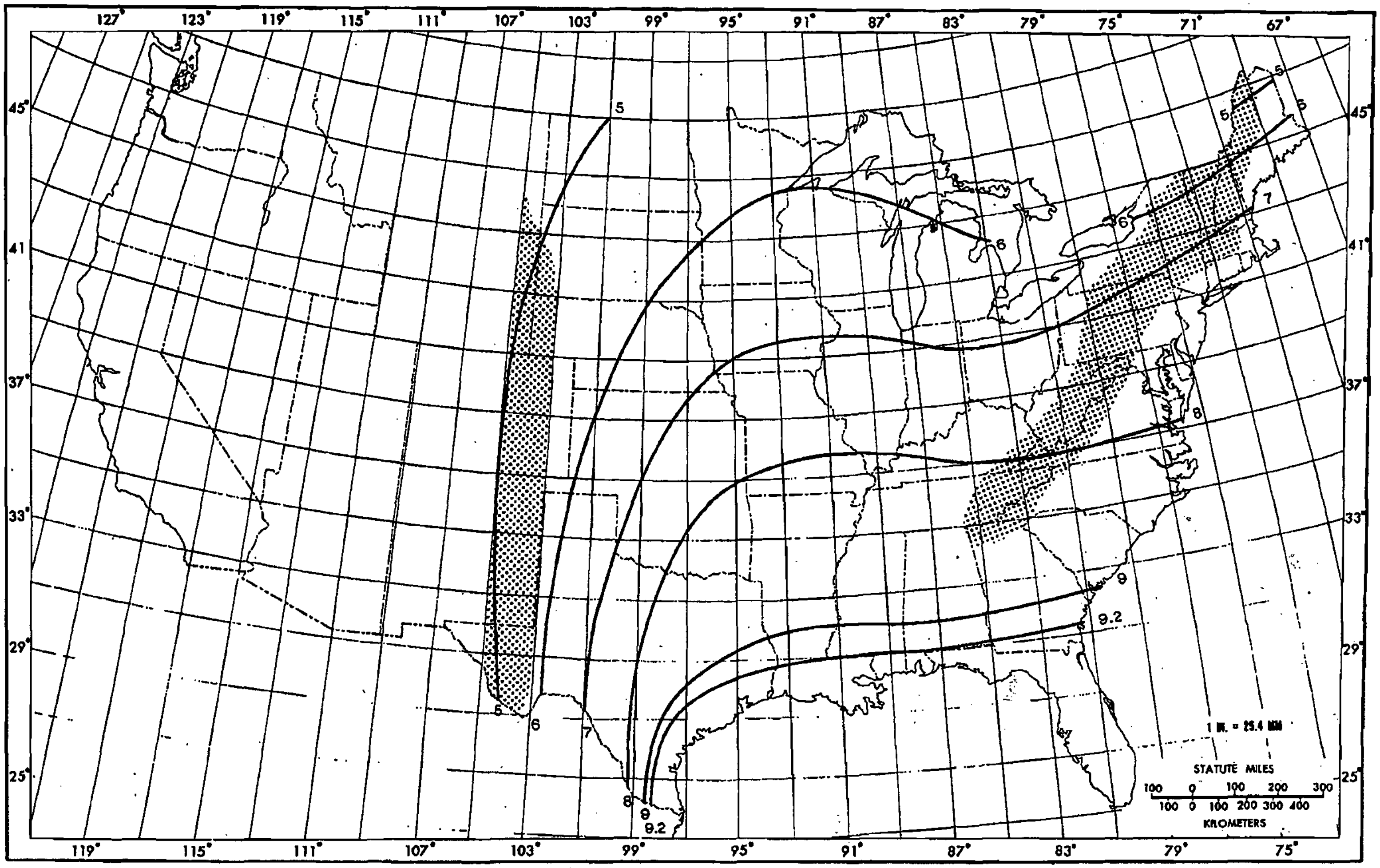

Figure 44.--All-season PMP (in.) for 12 hr 20,000 mi² (51,800 km²).

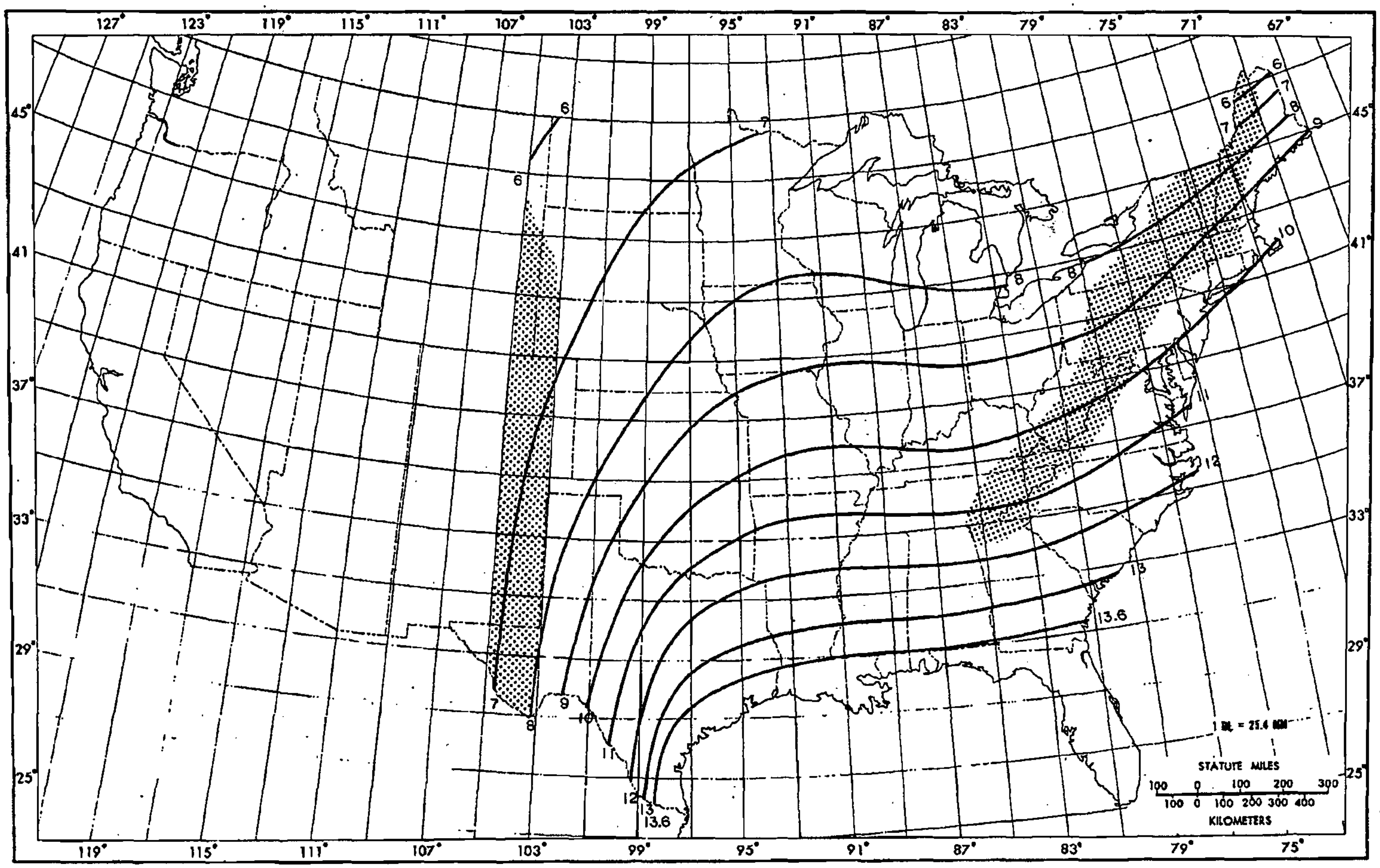

Figure 45.--All-season PMP (in.) for 24 hr 20,000 mi² (51,800 km²).

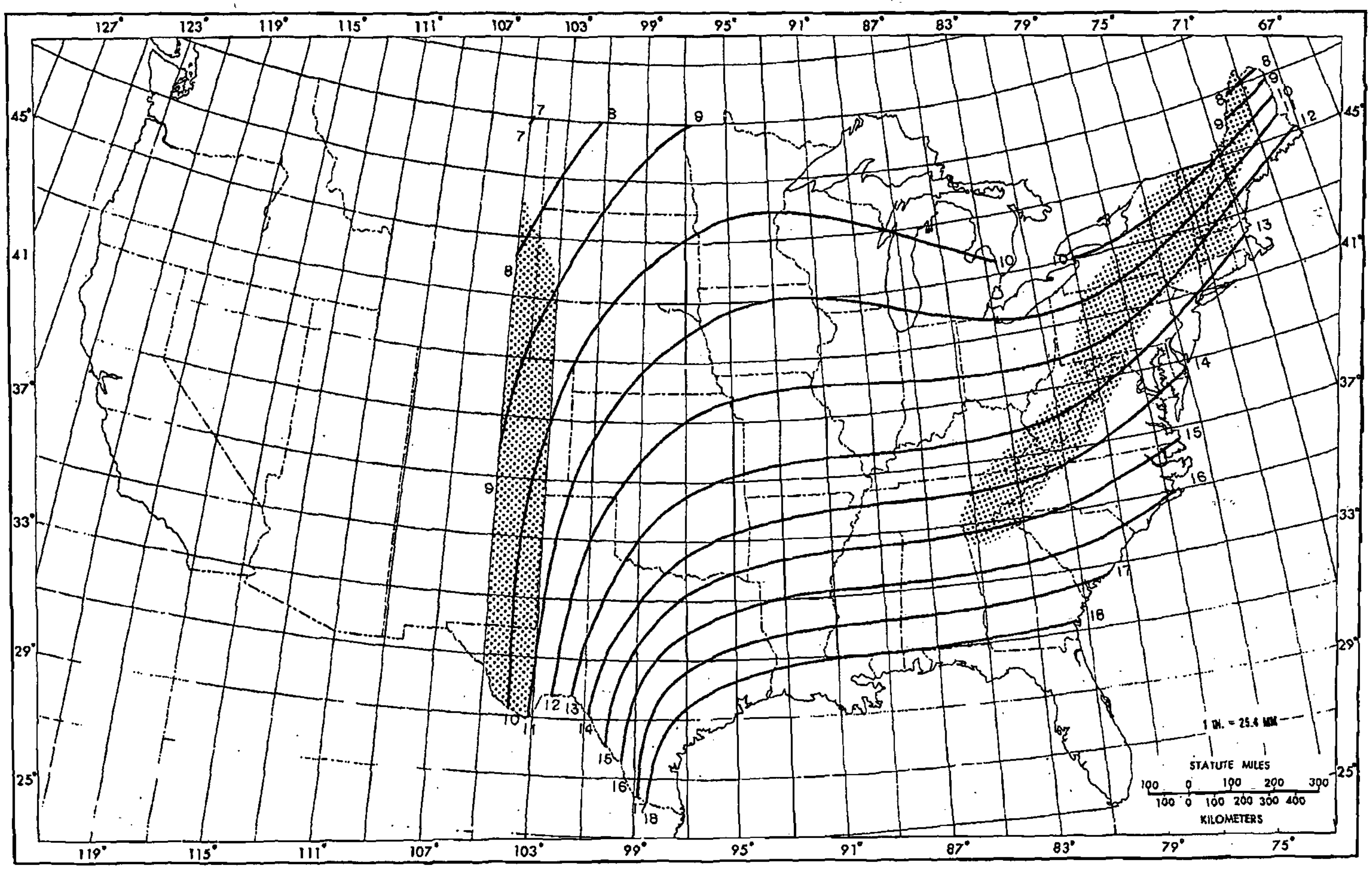

Figure 46.--All-season PMP (in.) for 48 hr 20,000 mi^2 (51,800 km^2).

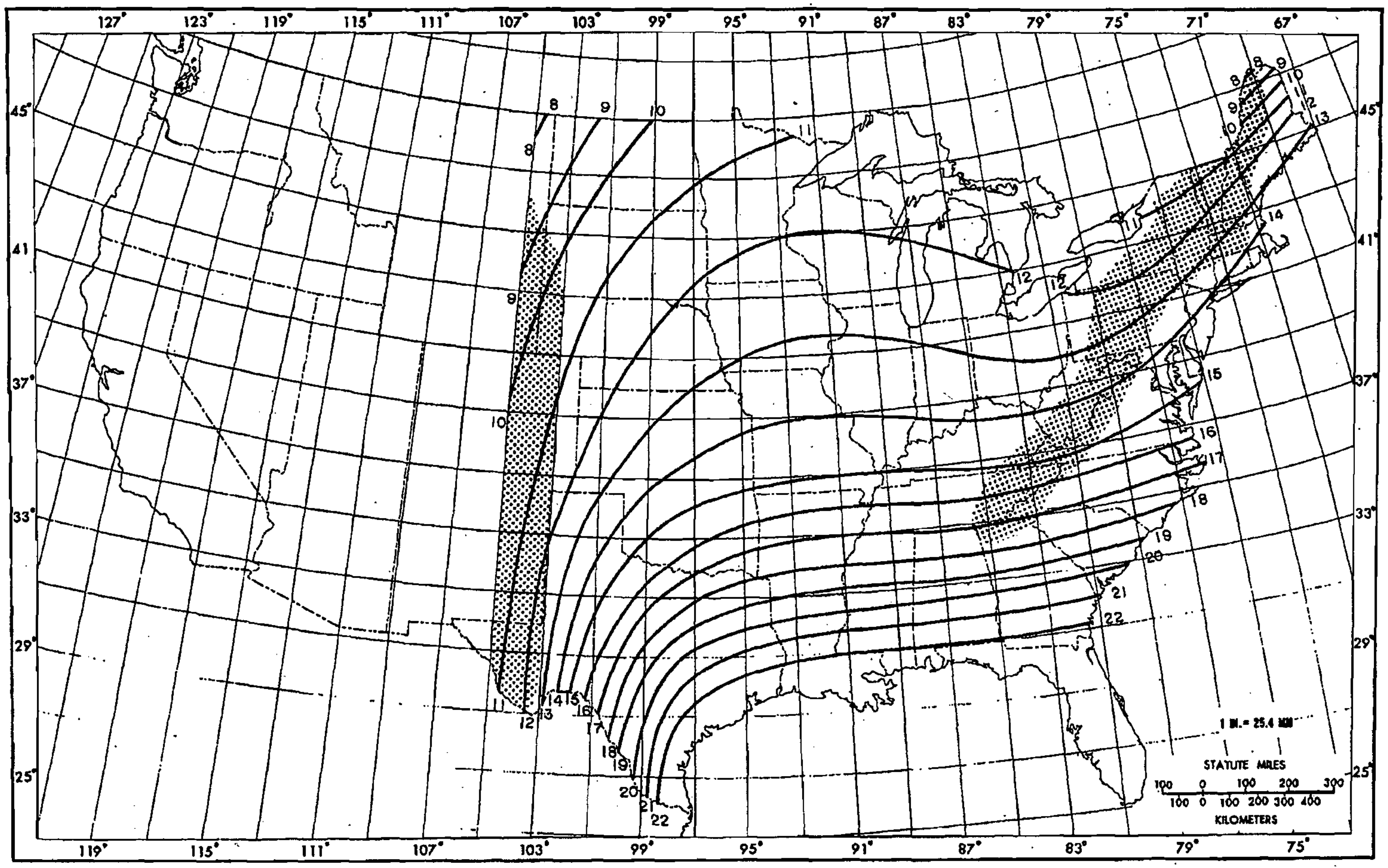

Figure 47.--All-season PMP (in.) for 72 hr 20,000 mi^2 (51,800 km^2).

Appendix D
Closure Implementation Cost Estimate