PART III, ATTACHMENT 2

APPENDIX III-2B

ACTIVE FACE BERM SIZING CALCULATIONS

ACTIVE FACE BERM SIZING CALCULATIONS

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2/12/21
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Professional Engineering Firm
Registration Number F-2578

INTENDED FOR PERMITTING PURPOSES ONLY
and Figures III-2B-1 to III-2B-7

1.0 OBJECTIVE

Storm water runoff from the active face, or working surface, of a landfill must be contained due to potentially contaminated runoff. The objective is to calculate the required size of the active face berm for a range of active face areas at the Hawthorn Park Recycling and Disposal Facility located in Harris County, Texas.

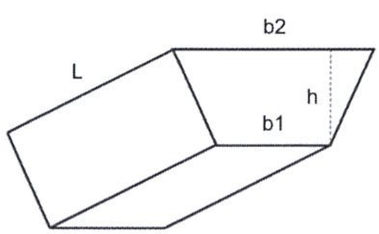
Design a run-on berm upgradient of the open working face of the landfill to prevent contaminating clean surface water with contaminated runoff.

2.0 METHOD

2.1 Run-Off Berm

Total runoff generated from the active face is in a direct relationship between precipitation for a 25-year, 24-hour storm and the varying area of active face, A. Active face berm sizing required will be dependent on the actual active face area, A.

Volume capacity V is a function of the height of the design berm, the toe width of the active face L, and setback distance S. The storage capacity of the active face containment berm is estimated using the cross-section and elevation view of the active face and containment berm and equation for volume of a trapezoidal prism.



$$Volume\ of\ a\ trapezoidal\ prism = L\,\frac{b1 + b2}{2}\,h$$

The volume capacity V must be equal to or greater than the runoff volume R for a certain active face area A. The equations are set equal to solve for the design berm height B. The function can be solved for berm height B using A, S, and L as inputs.

The function is also plotted in graph form and can be used as a tool to estimate the adequate berm height for runoff storage for a selected setback distance, length of berm, and estimated active face area A. The figure selection, for a conservative berm design height, should be conducted as follows:

- Select a Figure (Figures III-2B-1 through III-2B-6) with an active face area A value greater than or equal to the actual in-field active face area
- Use setback S value equal to or less than the actual in-field setback
- Use length of berm L value equal to or less than actual in-field berm length

2.2 Run-On Berm

The typical upgradient run-on berm will be a soil add-on berm forming a triangular drainage swale with side slopes of 3H:1V along the landfill cover and 2H:1V along the soil add-on berm.

Manning's Equation and the Rational Method were used to determine the maximum drainage area that can contribute to a single run-on berm. With the maximum allowable velocity, cross-section design, and channel slope, the maximum peak discharge for the run-on berm was back-calculated using Manning's Equation.

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

where:

Q = Flow Rate (cfs)

A = Cross-sectional area of flow (ft^2)

R = Hydraulic radius (ft)

S = Slope (ft/ft)

n = Manning's coefficient

The HydraFlow Express software used the Manning's equation with manual input for flow rate, slope, and Manning's coefficient n to calculate area of flow, wetted perimeter, hydraulic radius, depth of flow, and velocity of flow. The peak discharge (or flow rate) was iteratively entered into HydraFlow express to determine peak discharge while remaining under the permissible non-erodible velocity or within channel capacity and allowing for at least 0.5 ft of freeboard. When a flow velocity $\leq$ 3.75 ft/s or channel capacity was reached, the input value for flow rate Q (cfs) was taken to be the peak discharge.

With the peak discharge, Q, from Manning's Equation, the Rational Method was used to solve for the maximum contributing drainage area.

$$Q = C\ I\ A$$

where:

Q = Flow Rate (cfs)

C = Runoff coefficient

I = Rainfall Intensity (in/hr)

A = Area (acre)

3.0 ASSUMPTIONS

3.1 Run-Off Berm

The following assumptions and parameters were used in the design of the active face berm:

- Landfill waste slope is 3H:1V; berm slope is 2H:1V
- Minimum of 1.0-ft of freeboard provided with design berm height
- 50 percent run-off from the active face is contained (i.e., 50 percent infiltration)
- Atlas 14 PFDS precipitation data is 11.3 inches (0.94-ft) for a 25-year, 24-hour storm local to project site

3.2 Run-On Berm

The following assumptions and parameters were used in the design of the upgradient run-on berm:

- Landfill cover slope is 3H:1V (one side slope of the drainage swale created by berm)
- Berm slope is 2H:1V (one side slope of the drainage swale created by berm)
- Minimum of 0.50-ft of freeboard provided with run-on berm height for 25-year storm
- Runoff coefficient C = 0.70 for side slope; roughness n = 0.02 for earth-lined surface
- Atlas 14 PFDS precipitation data local to the Hawthorn Park RDF is 9.47 in/hr (0.94-ft) for a 25-year, 10-minute duration event

4.0 CALCULATIONS

4.1 Run-Off Berm

4.1.1 Runoff Volume, R

The runoff, or minimum required volume to be contained, is determined by the equation below for 50% infiltration.

$$R = \frac{1}{2} P\ A$$

P = Precipitation (ft) = 0.94 ft

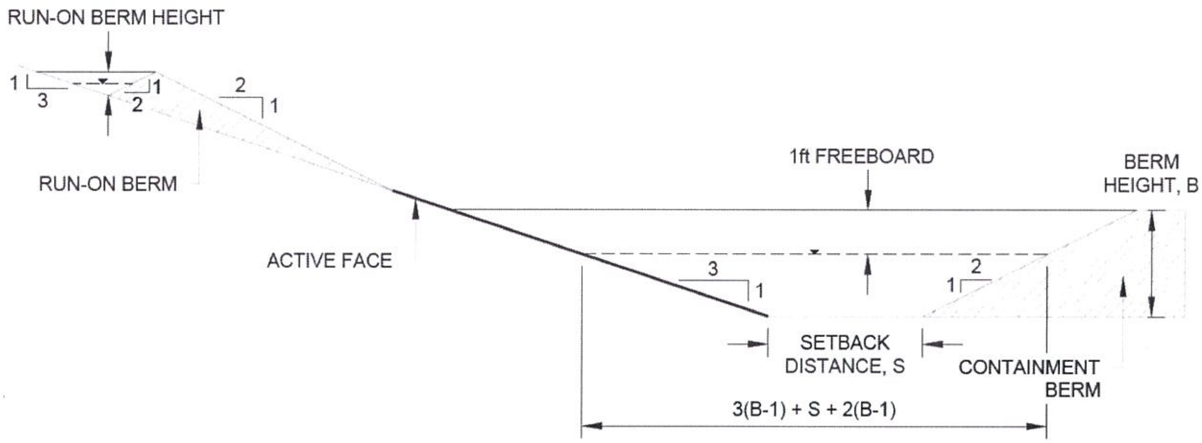
A = Active face area (ft^2)

$$R = \frac{1}{2}(0.94)A = 0.47A$$

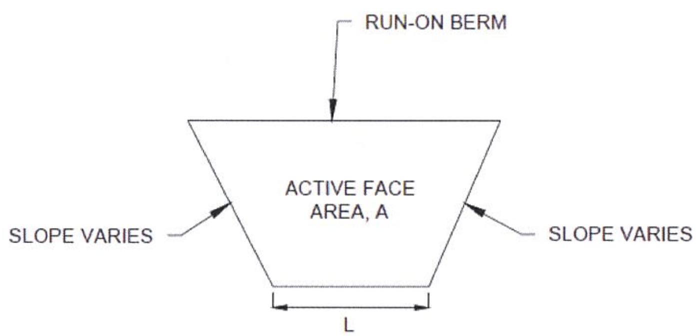
4.1.2 Storage Volume Capacity, V

The volume capacity equation is established using the dimensions of the varying containment berm storage area and the trapezoidal prism equation.

Typical Cross-Section – Active Face and Containment Berm



Typical Elevation – Active Face and Containment Berm



A = Active face area (ft^2)

L = Length of the Active Face Containment Berm (ft)

In the trapezoidal prism equation:

B – 1 = h (height of trapezoid)

S = b1 (base of trapezoid)

3(B-1) + S + 2(B-1) = b2 (base of trapezoid)

Therefore, the function for the volume capacity of the containment berm is:

$$V = L\,\frac{S + [3(B-1) + S + 2(B-1)]}{2}(B-1)$$

$$V = L\,\frac{S + [3B - 3 + S + 2B - 2]}{2}(B - 1) = L\,(2.5B + S - 2.5)(B - 1)$$

$$V = L\,[2.5B^2 + (S - 5)B + (2.5 - S)]$$

4.1.3 Berm Height, B

Set the runoff volume, R equation equal to the storage volume capacity, V equation to solve for berm height, B using the quadratic formula.

$$V = L\,[2.5B^2 + (S - 5) + (2.5 - S)] = 0.47A = R$$

Rearrange the equations into quadratic form:

$$0 = 2.5B^2 + (S - 5)B + (2.5 - S - \frac{0.47A}{L})$$

Therefore, using the quadratic function to solve for a positive value of berm height, B is:

$$B = \frac{(5 - S) + \sqrt{[(S - 5)^2 - 4(2.5)\left(2.5 - S - \frac{0.47A}{L}\right)]}}{5} = \frac{(5 - S) + \sqrt{(S^2 - 10S + 25 - 25 + 10S + \frac{4.7A}{L})}}{5}$$

$$B = \frac{(5 - S) + \sqrt{(S^2 + \frac{4.7A}{L})}}{5}$$

Plot the function of B versus L for select values of S and A. The active face area values analyzed were: 5,000 sqft, 10,000 sqft, 20,000 sqft, 30,000 sqft, 40,000 sqft, and 50,000 sqft. These plot figures are included as a part of this appendix as Figures III-2B-1 through III-2B-6, respectively. Setback values for each active face area were 10 ft, 20 ft, 30 ft, 40 ft, and 50 ft.

The function to solve for berm height, B, can also be solved directly with field data for active face area A, length of berm L, and setback distance S.

4.1.4 Example Berm Height Selection

The following is an example of how to use field conditions to estimate the minimum active face berm sizing required to contain runoff using Figures III-2B-1 through III-2B-6 and how to calculate the minimum active face berm sizing using the equation determined in Section 4.1.3 above. See Figure III-2B-7 for the berm height selection using the field data conditions below.

Example Field Conditions:

Active Face Area	**A**	18,000 ft^2
Containment Berm / Toe Width Length	**L**	225 ft
Setback Length	**S**	31 ft

Active Face Area, A = 18,000 ft^2 → Use Figure 3 for A = 20,000 ft^2. Rounding up the active face area value is conservative.

Containment Berm / Toe Width Length, L = 225 ft → Use L = 225 ft

Setback Length, S = 31 ft → Use S = 30 ft. Rounding down the setback length value is conservative.

The function can also be solved directly with field data for A, L, and S:

$$B = \frac{(5 - S) + \sqrt{(S^2 + \frac{4.7A}{L})}}{5}$$

$$B = \frac{(5 - 31) + \sqrt{(31^2 + \frac{4.7(18{,}000)}{225})}}{5} = 2.11ft$$

Berm Height, B:

Using Figures	2.25 ft
Using Equation	2.11 ft

4.2 Run-On Berm

The run-on berms were analyzed for drainage swale slopes at 0.25%, 0.50%, 0.75%, and 1%. The berms were designed to be a maximum 2-ft in height. The following peak discharges for the run-on berm were determined through iteration in HydraFlow Express (using Manning's Equation). The HydraFlow Express output for the run-on berms under the 25-year, 10-minute storm event at various slopes are included in this appendix.

Run-on Berm Input for HydraFlow Express:

Q_{25} (cfs)	Slope %	Side Slope(s)	Min. Depth (ft)	n
16.3	0.25	2.0 ; 3.0	2.00	0.020
16.6	0.50	2.0 ; 3.0	1.85	0.020
9.0	0.75	2.0 ; 3.0	1.50	0.020
6.0	1.00	2.0 ; 3.0	1.30	0.020

Run-On Berm Output Summary from HydraFlow Express:

Q_{25} (cfs)	Slope %	Flow Depth (ft)	Velocity (fps)
16.3	0.25	1.50	2.90
16.6	0.50	1.33	3.75
9.0	0.75	0.98	3.75
6.0	1.00	0.80	3.75

From the maximum peak discharge, the Rational Method is used to back calculate the maximum area.

Rational Method – Area Back Calculation:

Q_{25} (cfs)	I_{25} (in/hr)	C	Area (ac)
16.3	9.47	0.70	2.46
16.6	9.47	0.70	2.50
9.0	9.47	0.70	1.36
6.0	9.47	0.70	0.91

5.0 CONCLUSIONS

For a given active face area, containment berm length, and setback distance, Figures III-2B-1 through III-2B-6 are adequate to provide an estimate of the minimum design berm height. The equation in Section 4.1.3 may also be used to calculate the minimum design berm height to capture the runoff volume.

A typical run-on berm of maximum 2 ft high is proposed. Based on results of the flow capacity analysis in Section 4.2, the maximum drainage area for the proposed run-on control berm will be limited to a maximum 2.50 acres (corresponding to a 0.50% drainage swale slope).

6.0 REFERENCES

1) Surface Water Drainage and Erosional Stability Guidelines for a Municipal Solid Waste Landfill, TCEQ Regulatory Guidance, TCEQ. May 2018

2) Precipitation Frequency Data Server (PFDS), National Oceanic and Atmospheric Administration (NOAA). September 2018

3) Handbook of Applied Hydrology, Flow in Open Channels, Chow, Ven T., David R. Maidment, and Larry W. Mays. 1988.

7.0 ATTACHMENTS

Atlas 14 Rainfall Precipitation Data (NOAA)

Handbook of Applied Hydrology

HydraFlow Express – Run-On Berms

APPENDIX III-2B

FIGURES

FIGURE III-2B-1
Active Face Area = 5,000 sqft

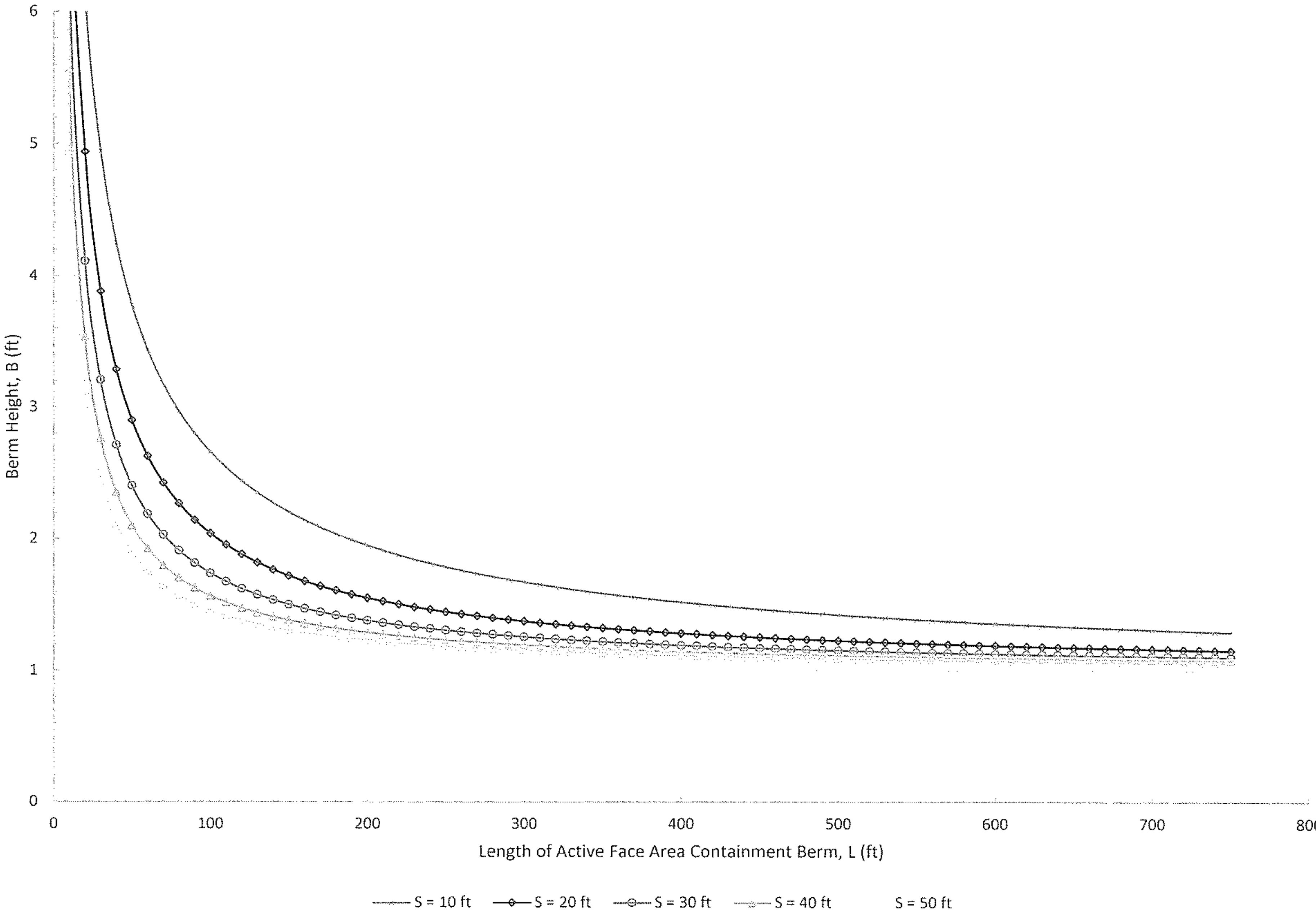


FIGURE III-2B-2

Active Face Area = 10,000 sqft

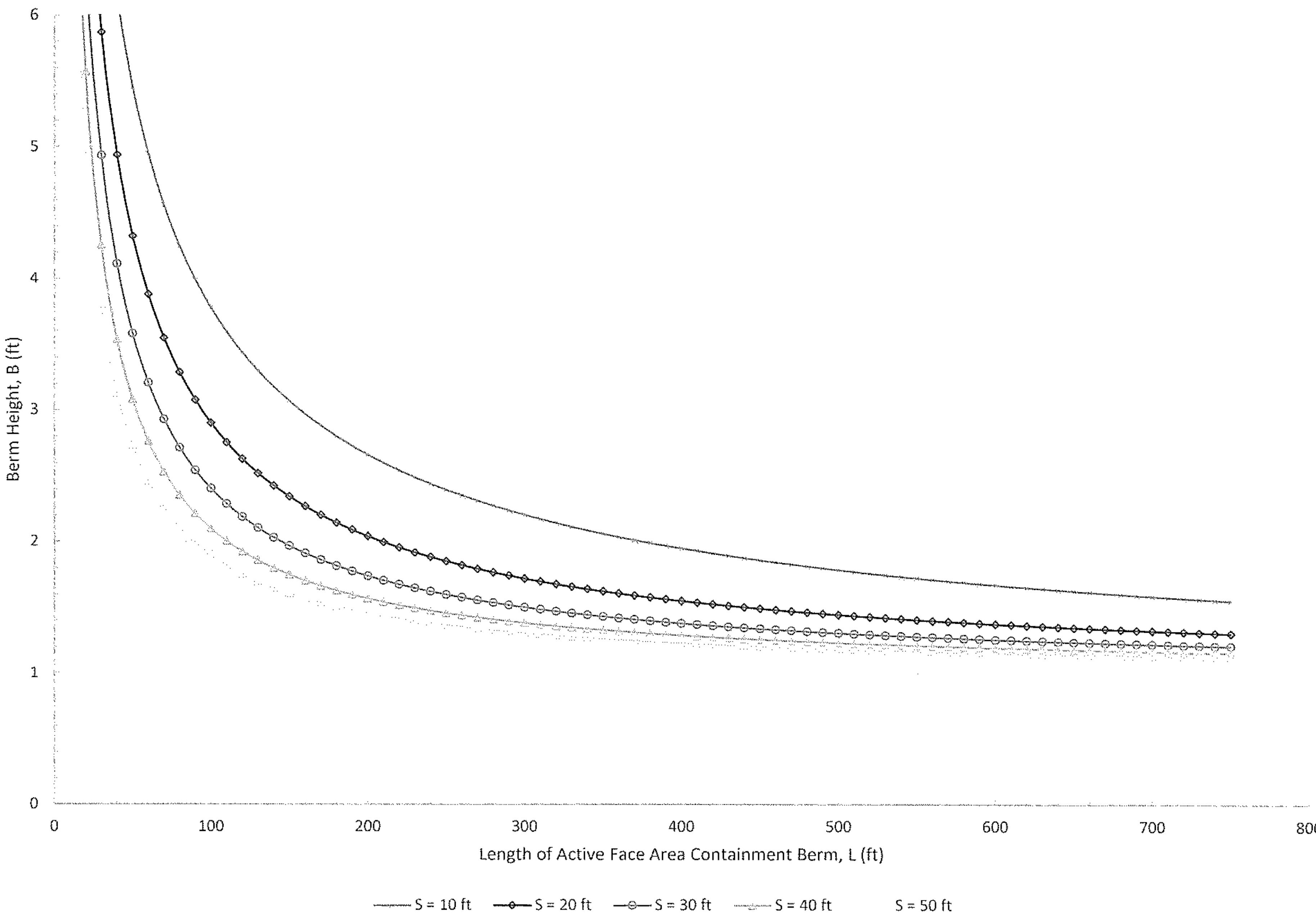


FIGURE III-2B-3
Active Face Area = 20,000 sqft

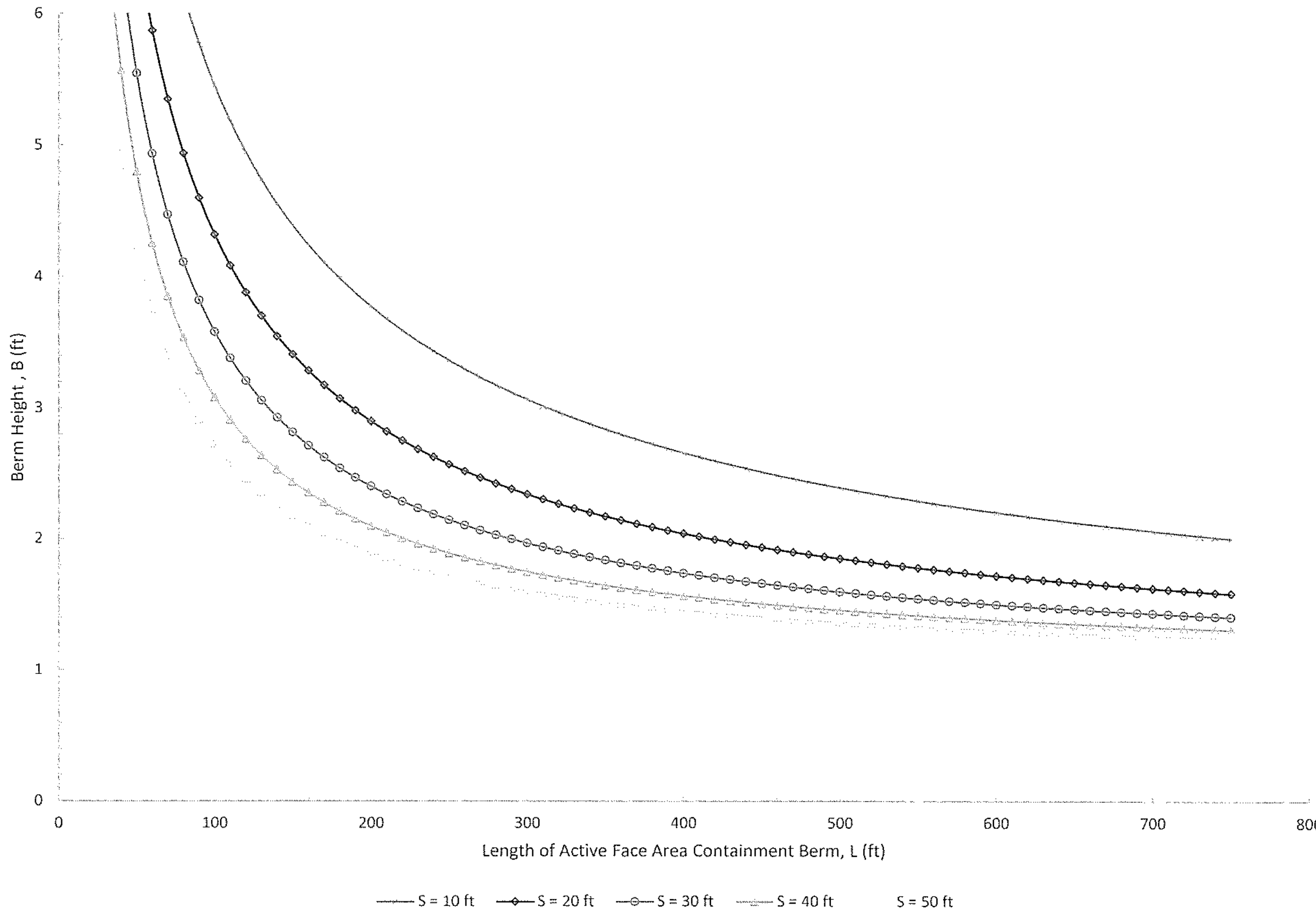


FIGURE III-2B-4

Active Face Area = 30,000 sqft

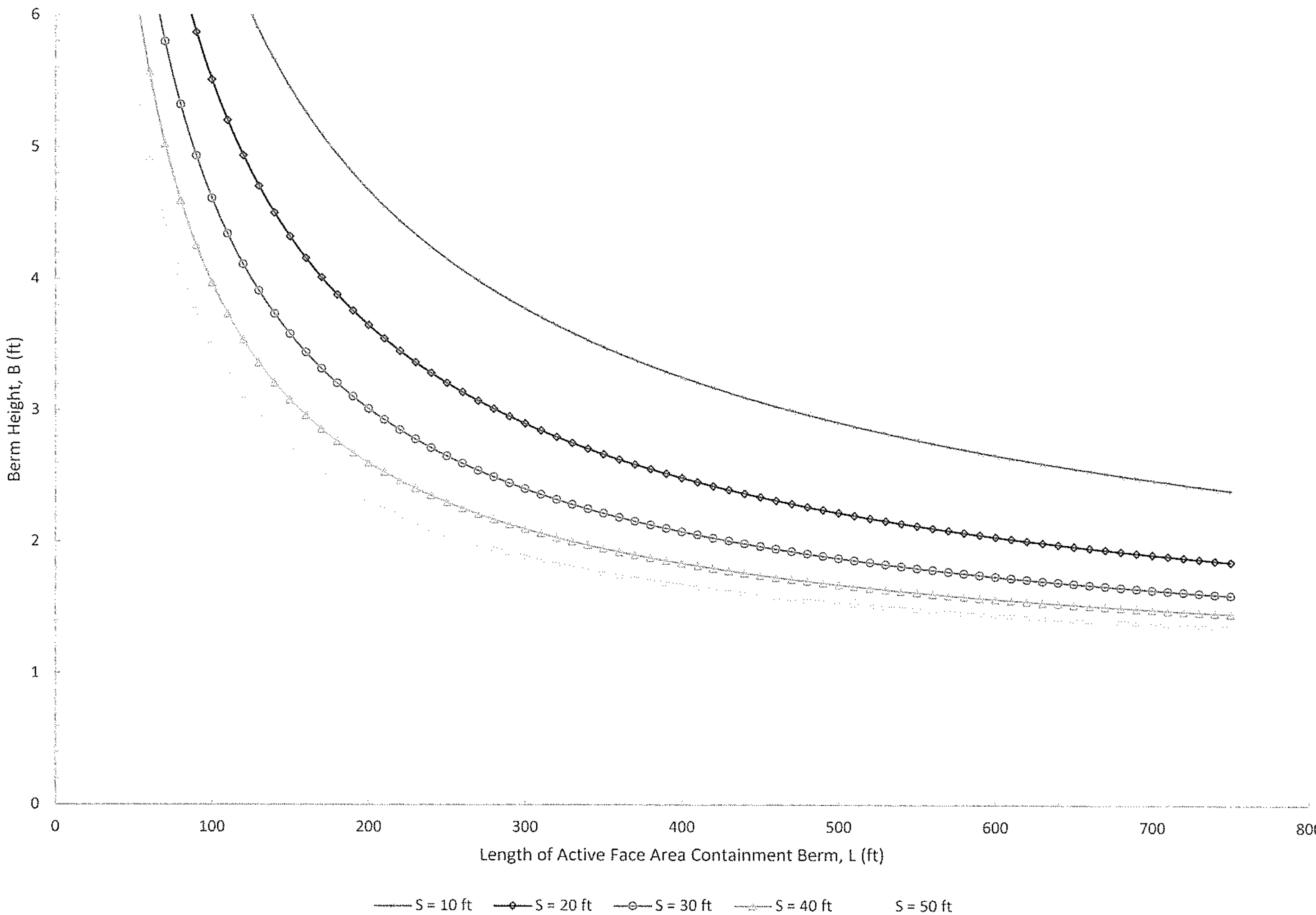


FIGURE III-2B-5
Active Face Area = 40,000 sqft

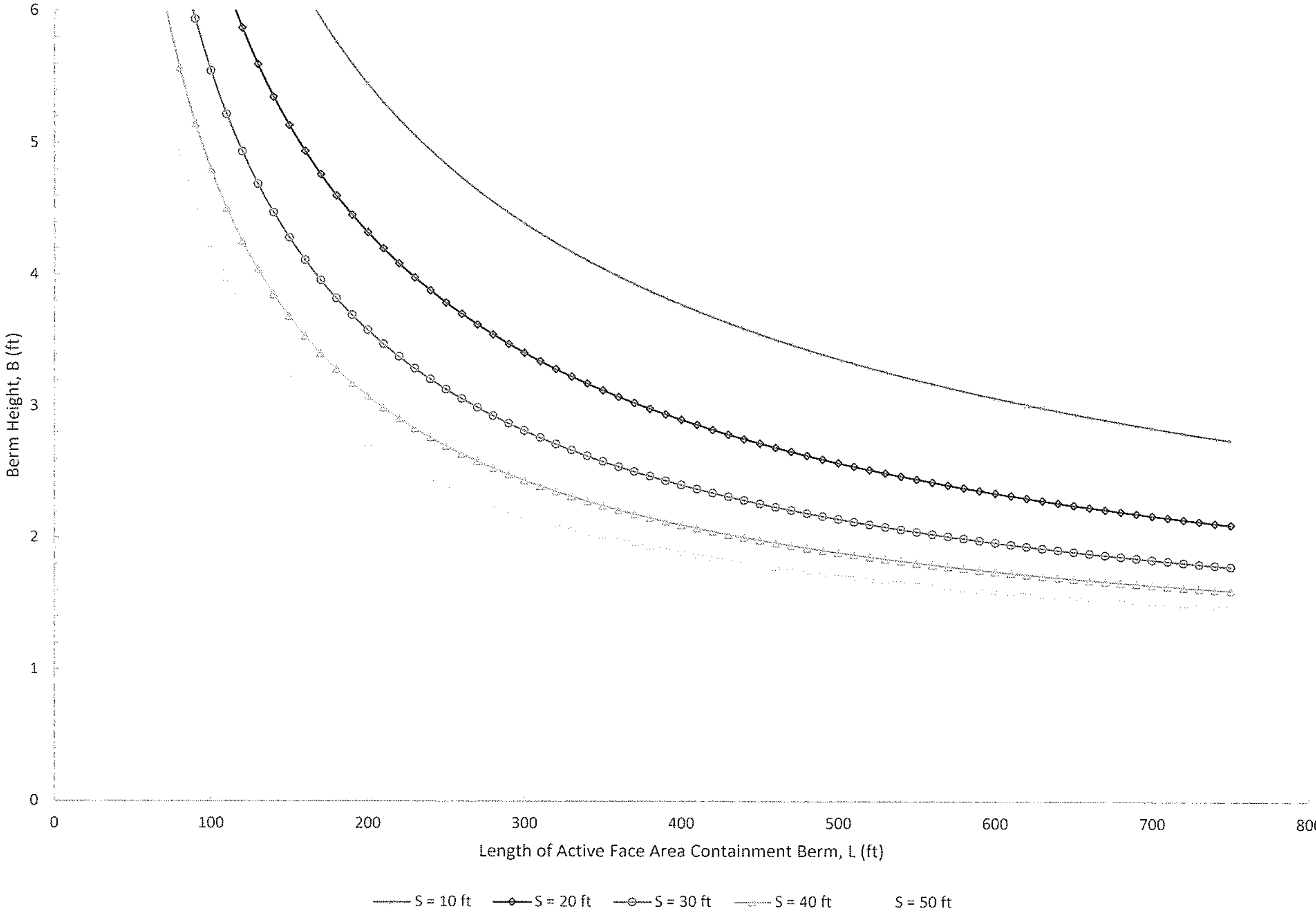
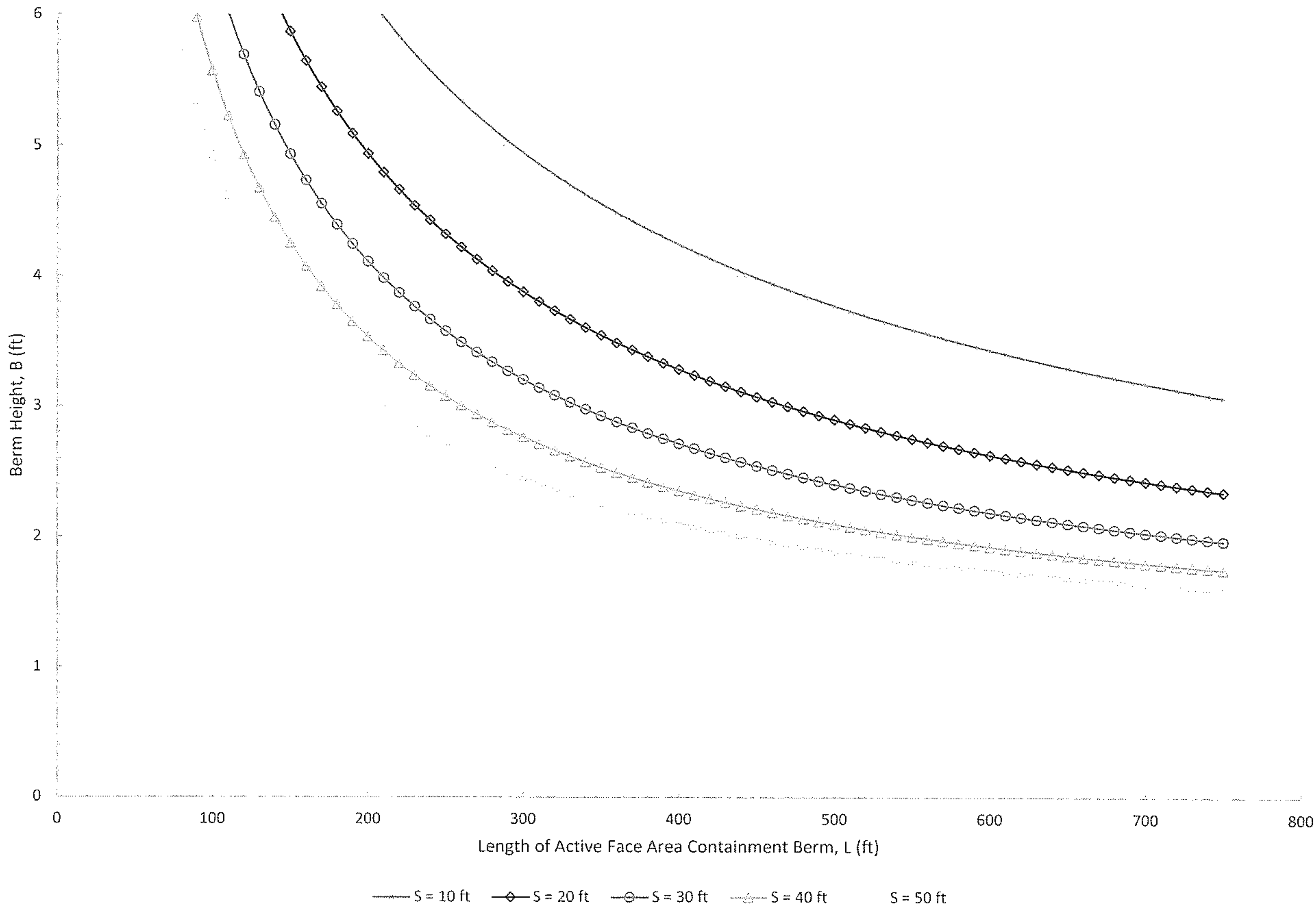


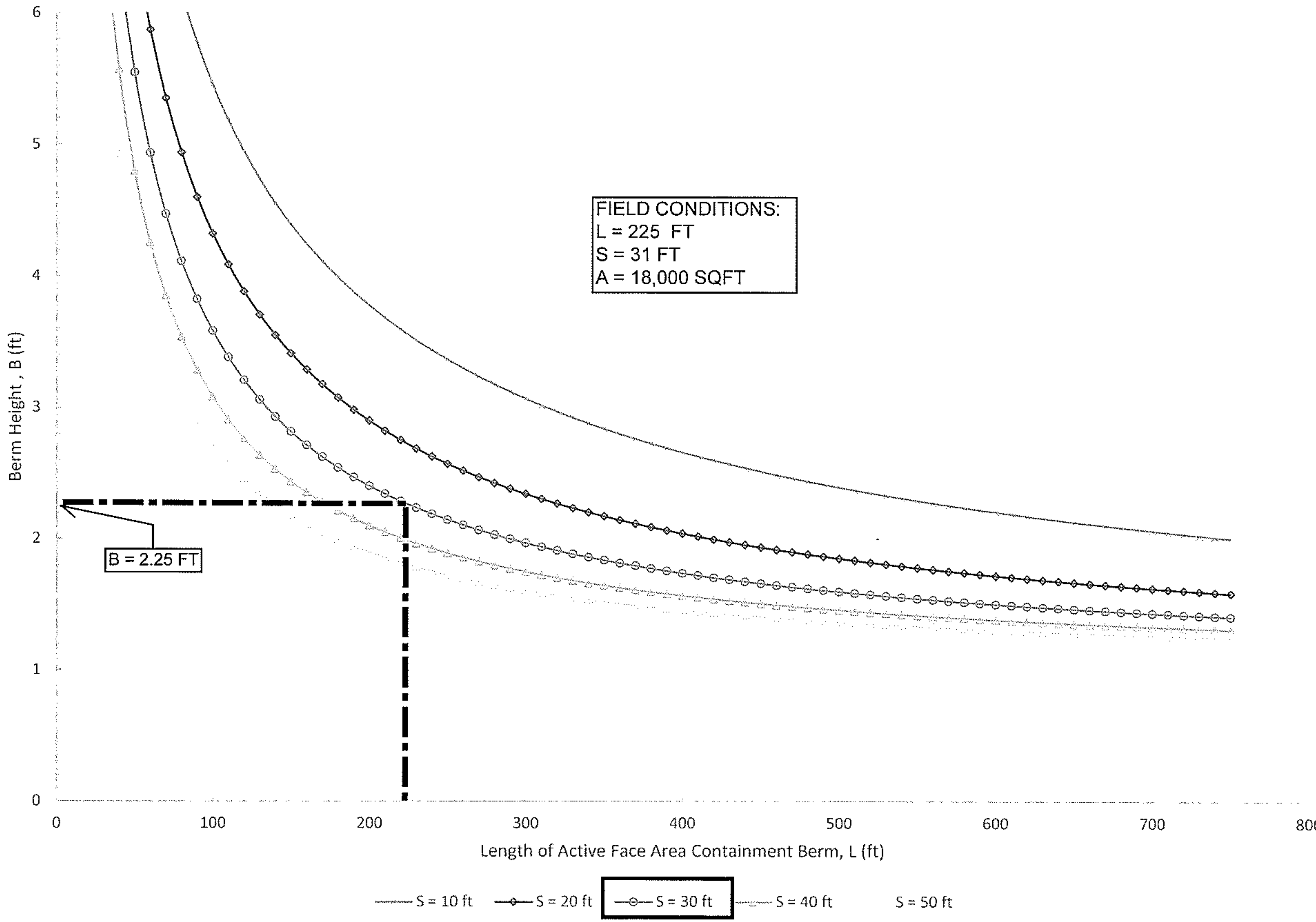
FIGURE III-2B-6
Active Face Area = 50,000 sqft



FIGU[illegible] III-2B-7

EXAMPLE BERM HEIGHT SELECTION

Active Face Area = 20,000 sqft



APPENDIX III-2B

ATTACHMENTS

Atlas 14 Point Precipitation Frequency Estimates (NOAA)
Handbook of Applied Hydrology (Chow, Ven T., et al)
HydraFlow Express – Run-On Berms

NOAA Atlas 14, Volume 11, Version 2
Location name: Houston, Texas, USA*
Latitude: 29.8531°, Longitude: -95.5602°
Elevation: m/ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF tabular | PF graphical | Maps & aerials

PF tabular

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

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	5.95 (4.51-7.87)	6.97 (5.33-9.11)	8.62 (6.56-11.3)	9.98 (7.50-13.3)	11.9 (8.63-16.3)	13.3 (9.43-18.8)	14.8 (10.2-21.5)	16.4 (11.0-24.4)	18.5 (12.0-28.6)	20.2 (12.8-32.0)
10-min	4.72 (3.57-6.23)	5.53 (4.22-7.22)	6.85 (5.21-9.00)	7.95 (5.97-10.6)	9.47 (6.90-13.0)	10.7 (7.55-15.1)	11.8 (8.17-17.2)	13.0 (8.75-19.4)	14.6 (9.47-22.4)	15.7 (9.96-24.9)
15-min	4.01 (3.04-5.30)	4.67 (3.57-6.12)	5.76 (4.39-7.57)	6.66 (5.00-8.87)	7.90 (5.74-10.8)	8.84 (6.25-12.5)	9.80 (6.76-14.2)	10.8 (7.28-16.1)	12.2 (7.94-18.8)	13.3 (8.43-21.0)
30-min	2.88 (2.18-3.80)	3.34 (2.55-4.37)	4.09 (3.12-5.38)	4.71 (3.53-6.28)	5.56 (4.03-7.60)	6.19 (4.37-8.71)	6.85 (4.72-9.93)	7.59 (5.11-11.3)	8.66 (5.63-13.4)	9.54 (6.04-15.1)
60-min	1.89 (1.43-2.50)	2.21 (1.69-2.89)	2.73 (2.08-3.59)	3.17 (2.38-4.22)	3.77 (2.73-5.15)	4.22 (2.97-5.93)	4.70 (3.24-6.81)	5.26 (3.54-7.85)	6.11 (3.97-9.43)	6.82 (4.32-10.8)
2-hr	1.14 (0.866-1.50)	1.38 (1.05-1.77)	1.76 (1.34-2.29)	2.09 (1.57-2.77)	2.57 (1.87-3.50)	2.95 (2.09-4.14)	3.38 (2.34-4.88)	3.90 (2.63-5.79)	4.70 (3.06-7.23)	5.39 (3.42-8.48)
3-hr	0.827 (0.630-1.09)	1.03 (0.777-1.31)	1.33 (1.02-1.73)	1.61 (1.22-2.13)	2.03 (1.48-2.76)	2.37 (1.69-3.33)	2.77 (1.92-3.99)	3.25 (2.19-4.80)	3.99 (2.61-6.13)	4.64 (2.95-7.28)
6-hr	0.477 (0.365-0.623)	0.617 (0.461-0.765)	0.815 (0.623-1.05)	1.01 (0.762-1.33)	1.30 (0.955-1.77)	1.55 (1.11-2.17)	1.85 (1.29-2.65)	2.20 (1.49-3.24)	2.74 (1.80-4.20)	3.22 (2.05-5.03)
12-hr	0.271 (0.208-0.352)	0.358 (0.267-0.438)	0.479 (0.368-0.614)	0.599 (0.456-0.786)	0.785 (0.582-1.07)	0.949 (0.685-1.33)	1.14 (0.799-1.63)	1.37 (0.929-2.00)	1.71 (1.13-2.61)	2.01 (1.29-3.13)
24-hr	0.155 (0.119-0.200)	0.208 (0.155-0.252)	0.281 (0.217-0.358)	0.355 (0.271-0.463)	0.469 (0.351-0.639)	0.573 (0.416-0.802)	0.694 (0.487-0.987)	0.828 (0.565-1.21)	1.03 (0.677-1.56)	1.19 (0.768-1.85)
2-day	0.088 (0.068-0.113)	0.120 (0.089-0.144)	0.164 (0.127-0.208)	0.208 (0.160-0.271)	0.279 (0.211-0.381)	0.345 (0.253-0.483)	0.418 (0.295-0.593)	0.492 (0.336-0.713)	0.592 (0.391-0.889)	0.669 (0.432-1.03)
3-day	0.064 (0.050-0.082)	0.087 (0.065-0.104)	0.119 (0.092-0.151)	0.151 (0.116-0.196)	0.202 (0.153-0.276)	0.249 (0.184-0.349)	0.301 (0.213-0.426)	0.351 (0.241-0.508)	0.418 (0.276-0.626)	0.467 (0.303-0.721)
4-day	0.051 (0.040-0.066)	0.070 (0.052-0.083)	0.095 (0.073-0.119)	0.119 (0.092-0.155)	0.158 (0.120-0.215)	0.194 (0.143-0.271)	0.233 (0.165-0.329)	0.271 (0.186-0.391)	0.321 (0.213-0.480)	0.358 (0.232-0.552)
7-day	0.034 (0.026-0.043)	0.045 (0.034-0.054)	0.060 (0.047-0.075)	0.074 (0.058-0.096)	0.097 (0.074-0.131)	0.117 (0.087-0.163)	0.139 (0.099-0.196)	0.161 (0.111-0.232)	0.190 (0.126-0.283)	0.212 (0.138-0.325)
10-day	0.026 (0.021-0.034)	0.034 (0.026-0.042)	0.045 (0.035-0.057)	0.056 (0.043-0.072)	0.072 (0.054-0.096)	0.086 (0.063-0.118)	0.101 (0.072-0.142)	0.116 (0.080-0.167)	0.136 (0.091-0.203)	0.152 (0.099-0.232)
20-day	0.017 (0.014-0.022)	0.022 (0.017-0.027)	0.028 (0.022-0.035)	0.033 (0.026-0.042)	0.041 (0.031-0.055)	0.048 (0.036-0.066)	0.055 (0.040-0.078)	0.063 (0.044-0.090)	0.073 (0.049-0.108)	0.080 (0.052-0.122)
30-day	0.014 (0.011-0.018)	0.017 (0.013-0.021)	0.021 (0.017-0.027)	0.025 (0.020-0.032)	0.031 (0.023-0.040)	0.035 (0.026-0.048)	0.040 (0.028-0.055)	0.044 (0.031-0.064)	0.051 (0.034-0.075)	0.055 (0.036-0.084)
45-day	0.012 (0.009-0.015)	0.014 (0.011-0.017)	0.017 (0.014-0.021)	0.020 (0.015-0.025)	0.024 (0.018-0.031)	0.027 (0.020-0.036)	0.029 (0.021-0.041)	0.032 (0.023-0.046)	0.036 (0.024-0.054)	0.039 (0.026-0.060)
60-day	0.010 (0.008-0.013)	0.012 (0.010-0.015)	0.015 (0.012-0.019)	0.017 (0.013-0.022)	0.020 (0.015-0.026)	0.022 (0.016-0.030)	0.024 (0.017-0.034)	0.026 (0.018-0.037)	0.029 (0.020-0.043)	0.031 (0.020-0.047)

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

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

Please refer to NOAA Atlas 14 document for more information.

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PF graphical

NATIONAL OCEANIC ATMOSPHERIC ADMINISTRATION (NOAA)

NOAA Atlas 14, Volume 11, Version 2
Location name: Houston, Texas, USA*
Latitude: 29.8531°, Longitude: -95.5602°
Elevation: 114.7 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

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

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.496** (0.376-0.656)	**0.581** (0.444-0.759)	**0.718** (0.547-0.943)	**0.832** (0.625-1.11)	**0.990** (0.719-1.36)	**1.11** (0.786-1.57)	**1.23** (0.851-1.79)	**1.37** (0.918-2.03)	**1.55** (1.00-2.38)	**1.69** (1.07-2.67)
10-min	**0.786** (0.595-1.04)	**0.921** (0.703-1.20)	**1.14** (0.869-1.50)	**1.33** (0.995-1.77)	**1.58** (1.15-2.17)	**1.78** (1.26-2.51)	**1.97** (1.36-2.86)	**2.17** (1.46-3.23)	**2.43** (1.58-3.74)	**2.62** (1.66-4.14)
15-min	**1.00** (0.759-1.32)	**1.17** (0.893-1.53)	**1.44** (1.10-1.89)	**1.67** (1.25-2.22)	**1.97** (1.43-2.71)	**2.21** (1.56-3.12)	**2.45** (1.69-3.55)	**2.71** (1.82-4.03)	**3.06** (1.99-4.71)	**3.33** (2.11-5.26)
30-min	**1.44** (1.09-1.90)	**1.67** (1.27-2.19)	**2.05** (1.56-2.69)	**2.36** (1.77-3.14)	**2.78** (2.01-3.80)	**3.10** (2.18-4.36)	**3.43** (2.36-4.97)	**3.80** (2.55-5.66)	**4.33** (2.82-6.68)	**4.77** (3.02-7.54)
60-min	**1.89** (1.43-2.50)	**2.21** (1.69-2.89)	**2.73** (2.08-3.59)	**3.17** (2.38-4.22)	**3.77** (2.73-5.15)	**4.22** (2.97-5.93)	**4.70** (3.24-6.81)	**5.26** (3.54-7.85)	**6.11** (3.97-9.43)	**6.82** (4.32-10.8)
2-hr	**2.28** (1.73-3.00)	**2.77** (2.10-3.55)	**3.51** (2.68-4.58)	**4.17** (3.15-5.54)	**5.13** (3.74-7.00)	**5.90** (4.18-8.28)	**6.76** (4.68-9.76)	**7.80** (5.26-11.6)	**9.40** (6.13-14.5)	**10.8** (6.85-17.0)
3-hr	**2.48** (1.89-3.26)	**3.10** (2.33-3.92)	**4.00** (3.06-5.19)	**4.84** (3.66-6.41)	**6.08** (4.45-8.29)	**7.12** (5.07-9.99)	**8.31** (5.76-12.0)	**9.74** (6.58-14.4)	**12.0** (7.82-18.4)	**13.9** (8.86-21.9)
6-hr	**2.85** (2.18-3.73)	**3.69** (2.76-4.58)	**4.88** (3.73-6.28)	**6.02** (4.57-7.93)	**7.77** (5.72-10.6)	**9.28** (6.65-13.0)	**11.1** (7.70-15.9)	**13.2** (8.92-19.4)	**16.4** (10.8-25.1)	**19.3** (12.3-30.1)
12-hr	**3.26** (2.51-4.24)	**4.32** (3.21-5.28)	**5.78** (4.43-7.40)	**7.22** (5.50-9.47)	**9.46** (7.01-12.9)	**11.4** (8.25-16.0)	**13.8** (9.62-19.7)	**16.5** (11.2-24.1)	**20.6** (13.6-31.4)	**24.2** (15.5-37.7)
24-hr	**3.71** (2.86-4.81)	**5.00** (3.72-6.04)	**6.75** (5.20-8.60)	**8.51** (6.51-11.1)	**11.3** (8.42-15.3)	**13.8** (9.99-19.2)	**16.7** (11.7-23.7)	**19.9** (13.6-29.0)	**24.7** (16.2-37.3)	**28.6** (18.4-44.5)
2-day	**4.22** (3.26-5.43)	**5.78** (4.28-6.90)	**7.87** (6.08-9.97)	**10.0** (7.68-13.0)	**13.4** (10.1-18.3)	**16.6** (12.1-23.2)	**20.1** (14.1-28.5)	**23.6** (16.1-34.2)	**28.4** (18.8-42.7)	**32.1** (20.8-49.7)
3-day	**4.60** (3.57-5.91)	**6.30** (4.69-7.51)	**8.58** (6.65-10.8)	**10.9** (8.39-14.1)	**14.5** (11.0-19.8)	**18.0** (13.2-25.1)	**21.7** (15.3-30.7)	**25.3** (17.3-36.6)	**30.1** (19.9-45.0)	**33.6** (21.8-51.9)
4-day	**4.93** (3.83-6.32)	**6.68** (5.01-8.00)	**9.07** (7.05-11.5)	**11.5** (8.84-14.8)	**15.2** (11.5-20.7)	**18.6** (13.7-26.0)	**22.4** (15.8-31.6)	**26.0** (17.9-37.6)	**30.8** (20.4-46.1)	**34.4** (22.3-53.0)
7-day	**5.69** (4.44-7.28)	**7.50** (5.70-9.07)	**10.0** (7.83-12.7)	**12.5** (9.67-16.1)	**16.3** (12.4-22.0)	**19.7** (14.5-27.3)	**23.4** (16.6-33.0)	**27.1** (18.6-39.0)	**31.9** (21.2-47.6)	**35.6** (23.1-54.6)
10-day	**6.34** (4.96-8.10)	**8.19** (6.28-9.96)	**10.8** (8.48-13.7)	**13.4** (10.4-17.2)	**17.2** (13.0-23.1)	**20.6** (15.2-28.4)	**24.2** (17.2-34.0)	**27.9** (19.2-40.0)	**32.7** (21.8-48.7)	**36.4** (23.7-55.8)
20-day	**8.39** (6.59-10.7)	**10.3** (8.05-12.7)	**13.2** (10.4-16.7)	**15.9** (12.4-20.4)	**19.8** (15.0-26.4)	**23.1** (17.1-31.6)	**26.6** (19.0-37.2)	**30.1** (20.9-43.2)	**34.8** (23.3-51.7)	**38.4** (25.1-58.6)
30-day	**10.1** (7.97-12.8)	**12.1** (9.56-15.1)	**15.3** (12.1-19.2)	**18.0** (14.1-23.1)	**22.0** (16.7-29.1)	**25.3** (18.6-34.4)	**28.6** (20.5-39.9)	**32.0** (22.3-45.8)	**36.5** (24.6-54.2)	**40.0** (26.2-60.9)
45-day	**12.6** (9.98-16.0)	**14.8** (11.8-18.6)	**18.4** (14.6-23.1)	**21.4** (16.7-27.3)	**25.5** (19.3-33.6)	**28.7** (21.1-38.8)	**31.8** (22.8-44.3)	**35.0** (24.5-50.0)	**39.2** (26.4-58.0)	**42.4** (27.8-64.3)
60-day	**14.9** (11.8-18.8)	**17.3** (13.9-21.7)	**21.3** (17.0-26.7)	**24.5** (19.2-31.1)	**28.7** (21.7-37.6)	**31.8** (23.5-42.9)	**34.8** (25.0-48.4)	**37.8** (26.5-54.0)	**41.7** (28.2-61.6)	**44.5** (29.3-67.5)

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

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%.

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of bed roughness (Fig. 7-9) changes from dunes through transition to plane bed or standing waves, the magnitude of Manning n decreases by approximately 50 per cent.

Table 7-5. Manning Roughness Coefficients for Various Boundaries

Boundary	*Manning roughness n, $ft^{1/6}$*
Very smooth surfaces such as glass, plastic, or brass	0.010
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition—some growth	0.025
Winding natural streams and canals in poor condition—considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	0.040-0.050
Alluvial channels, sand bed, no vegetation	
1. Lower regime	
Ripples	0.017-0.028
Dunes	0.018-0.035
2. Washed-out dunes or transition	0.014-0.024
3. Upper regime	
Plane bed	0.011-0.015
Standing waves	0.012-0.016
Antidunes	0.012-0.020

C. Natural Channels

The natural shape of an open channel may be markedly different from simple geometric shapes. However, it is usually possible to break down the complex shape of a natural open channel into simple elementary shapes for analysis. For example, consider Fig. 7-10, in which flow occurs not only in the main channel, but also in the

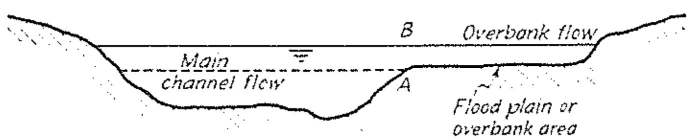
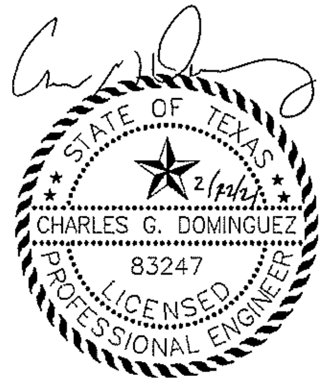


FIG. 7-10. Cross section of a natural stream channel.

overbank or flood-plain area. In this case, the hydraulic radius R, which would be obtained by using the area and the wetted perimeter for the entire section, would not be truly representative of the flow. Furthermore, the grain roughness, the form roughness, and hence the roughness coefficient in the overbank area are usually different from the coefficient in the main channel. Therefore such a section should be divided along AB and treated as two separate sections. The plane AB, however, is not considered as a part of the wetted perimeter, since there is no appreciable shear in this plane.

Along a natural channel, there are frequently pools with a flatter slope, and riffles or rapids with a steeper slope, than the average slope of the channel taken over an appreciable distance. Therefore care must be taken in studies of natural streams to consider the correct slope for the particular discharge and particular reach of the stream in question. In computing the flow by a uniform-flow equation, the slope of the water surface, or more precisely the slope of the energy grade line of the flow, is generally



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For Part III, Attachment 2, Appendix III-2B:
Hydraflow Express Run-on Berms dated
September 9, 2020

HYDRAFLOW EXPRESS

RUN-ON BERMS

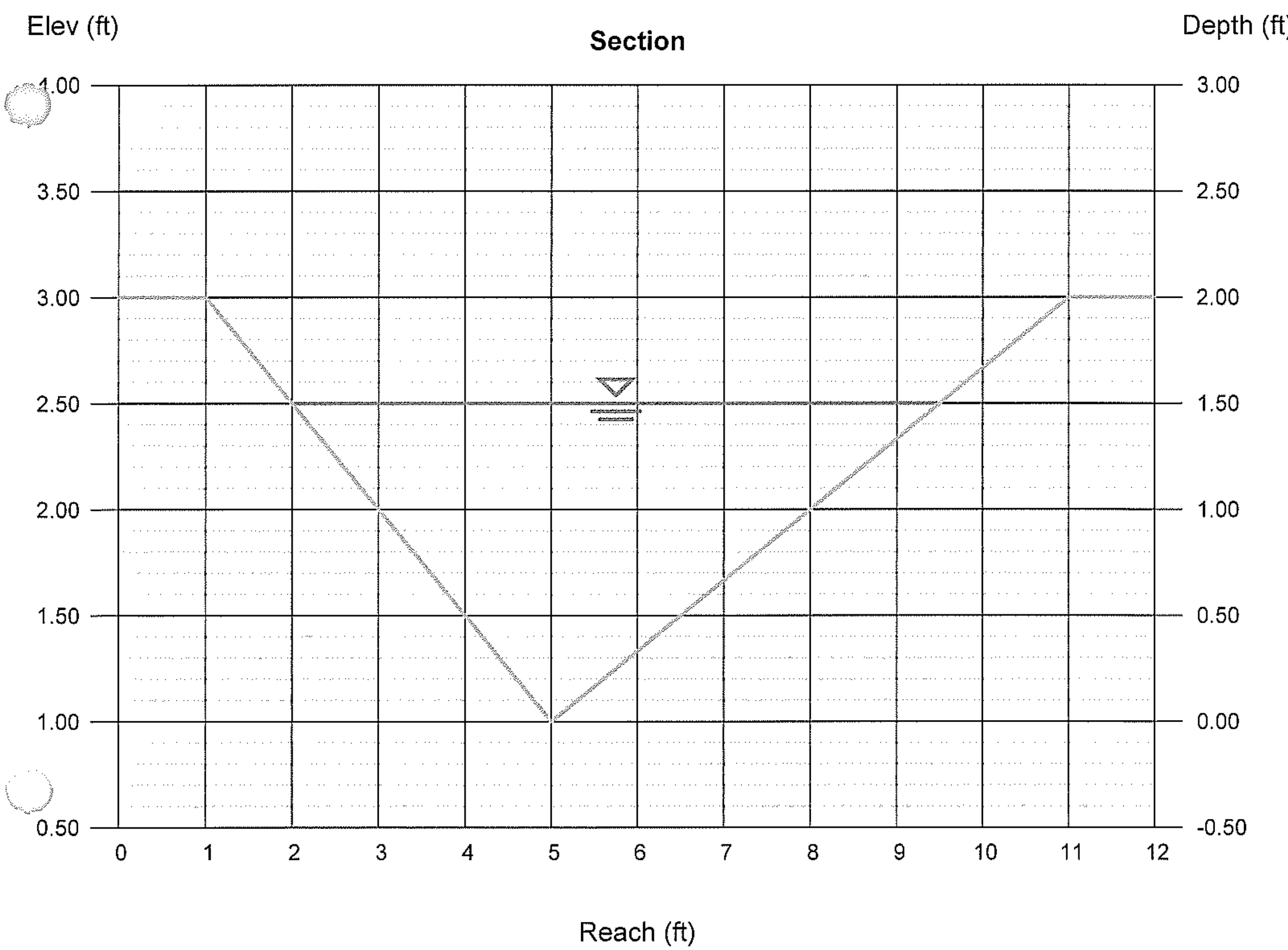
HAWTHORN PARK RDF

Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 9 2020

Run-on Berm (0.25%)

Triangular		**Highlighted**	
Side Slopes (z:1)	= 2.00, 3.00	Depth (ft)	= 1.50
Total Depth (ft)	= 2.00	Q (cfs)	= 16.30
		Area (sqft)	= 5.62
Invert Elev (ft)	= 1.00	Velocity (ft/s)	= 2.90
Slope (%)	= 0.25	Wetted Perim (ft)	= 8.10
N-Value	= 0.020	Crit Depth, Yc (ft)	= 1.22
		Top Width (ft)	= 7.50
Calculations		EGL (ft)	= 1.63
Compute by:	Known Q		
Known Q (cfs)	= 16.30		

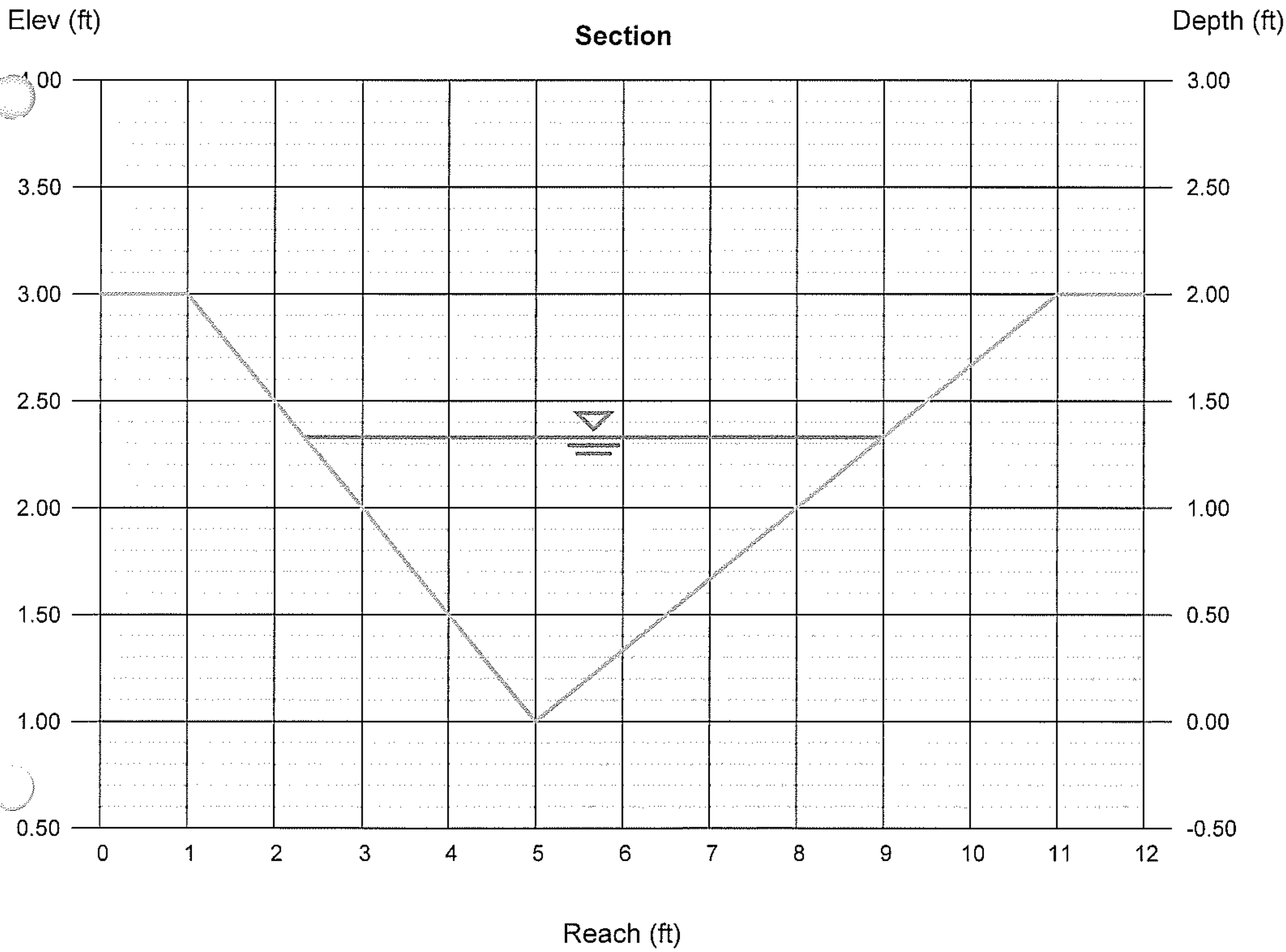


Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 9 2020

un-on Berm (0.50%)

Triangular		**Highlighted**	
Side Slopes (z:1)	= 2.00, 3.00	Depth (ft)	= 1.33
Total Depth (ft)	= 2.00	Q (cfs)	= 16.60
		Area (sqft)	= 4.42
Invert Elev (ft)	= 1.00	Velocity (ft/s)	= 3.75
Slope (%)	= 0.50	Wetted Perim (ft)	= 7.18
N-Value	= 0.020	Crit Depth, Yc (ft)	= 1.23
		Top Width (ft)	= 6.65
Calculations		EGL (ft)	= 1.55
Compute by:	Known Q		
Known Q (cfs)	= 16.60		



Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. — Wednesday, Sep 9 2020

un-on Berm (0.75%)

Triangular

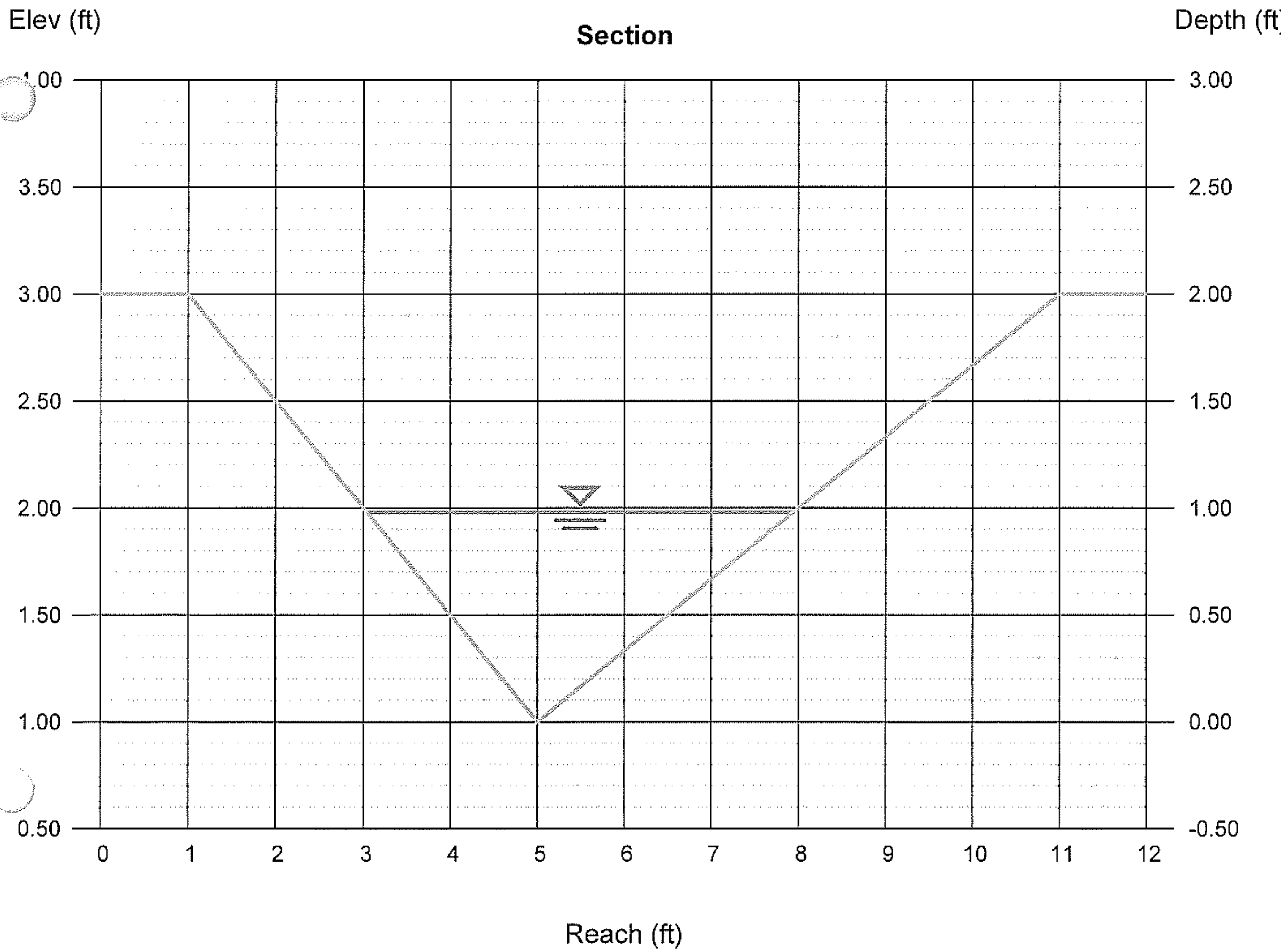
Side Slopes (z:1)	= 2.00, 3.00
Total Depth (ft)	= 2.00
Invert Elev (ft)	= 1.00
Slope (%)	= 0.75
N-Value	= 0.020

Calculations

Compute by:	Known Q
Known Q (cfs)	= 9.00

Highlighted

Depth (ft)	= 0.98
Q (cfs)	= 9.000
Area (sqft)	= 2.40
Velocity (ft/s)	= 3.75
Wetted Perim (ft)	= 5.29
Crit Depth, Yc (ft)	= 0.96
Top Width (ft)	= 4.90
EGL (ft)	= 1.20



Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 9 2020

un-on Berm (1.00%)

Triangular
Side Slopes (z:1) = 2.00, 3.00
Total Depth (ft) = 2.00

Invert Elev (ft) = 1.00
Slope (%) = 1.00
N-Value = 0.020

Calculations
Compute by: Known Q
Known Q (cfs) = 6.00

Highlighted
Depth (ft) = 0.80
Q (cfs) = 6.000
Area (sqft) = 1.60
Velocity (ft/s) = 3.75
Wetted Perim (ft) = 4.32
Crit Depth, Yc (ft) = 0.82
Top Width (ft) = 4.00
EGL (ft) = 1.02