| US Army Corps of Engineers Chicago District | PROJECT TITLE: Fort Sheridan 506 | COMPUTED BY: JAF | DATE: | SHEET: 3 of 5 | |
|---|---|---|---|---|---|
| | STRUCTURE TITLE: Schenck Ravine | CHECKED BY: | DATE: | CONTRACT NO: | |

* Estimated stone size
  Target design velocity is 3.0 ft/s. This will be refined during design phase once riffles have been integrated into HEC-RAS model

$$V_d = 1.6V = 1.6(3.0\,ft/s) = 4.8\,ft/s$$

$$D_{30} = C\left[\left(\frac{\gamma_w}{\gamma_s-\gamma_w}\right)^{0.5}\left(\frac{V}{\sqrt{K_1 g d}}\right)\right]^{2.5} = 0.469\left[\left(\frac{62.4}{165-62.4}\right)^{0.5}\left(\frac{4.8}{\sqrt{32.2\cdot 0.5}}\right)\right]^{2.5}$$

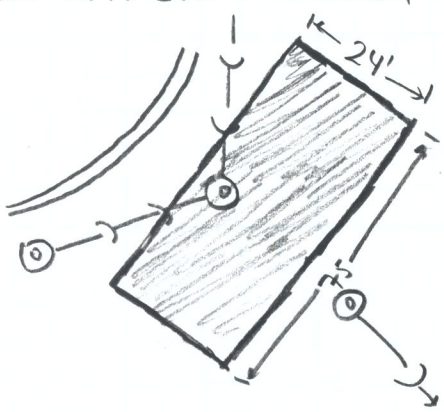
$$= 0.469\left[(0.78)(1.20)\right]^{2.5} = 0.40\,ft$$

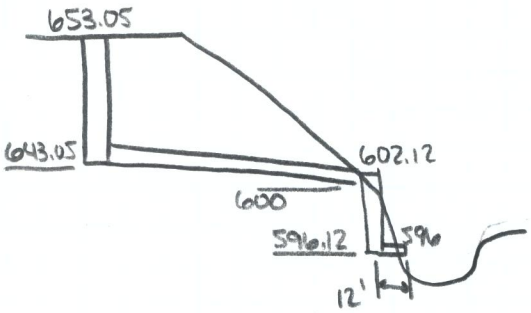
* Use an additional (4) to raise the channel bed from the mouth to XS 182

## Sewer at Mouth of Ravine

* Size for 100-year 24-hour event
  $Q_{allowable} = 3.3\,cfs$

From EPA-SWMM model,




* Provide 8'D × 24' × 75' storage volume
* Provide 6" primary outlet
* Provide 12" overflow 2.5' from top
  ↳ highest reached was +7.3' while overflow invert is at +7.5'
* Provide manhole immediately outside
* $Q_{max-d} = 2.60\,cfs$
  $V_{max-d} = 4.95\,ft/s$
* Locate structure at bottom to dissipate energy
* Locate near start of stone weirs

Size stone for armoring of outfall

$$V_d = 1.6V = 1.6(5\,ft/s) = 8\,ft/s$$

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{2.65-1}\left(\frac{8\,ft/s^2}{2\cdot 32.2\,ft/s}\right)$$

$$= 0.5\,ft$$

* Position stone apron up opposite slope two feet (slope protection)
  Apron width 3' minimum

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## Design Stone Weirs at Mouth

Assumptions:

* Begin weirs at XS192 → length ~ 183 ft.
* Elev. drop = 605.56 - 582.77 = 22.8
* Length btwn structures ~ 8 ft.

This system has not been completely modeled in HEC-RAS. Should it be selected by LS as a viable option, this will be completed. Based on preliminary modeling of the first three structures from the top,

$V_{max} = 2.2\ ft/s$
$d_{max} = 0.75\ ft$

Estimate required stone size:

- Use $V_d = 2.0(V_{max}) = 4.4\ ft/s \sim 5\ ft/s$
- $C = 2(0.375)(1.25)(1)(1)(0.75) = 0.703$

From EM-1110-2-1601 Eqn. 3.3

$$D_{30} = 0.703\left[(0.78)\left(\frac{5\ ft/s}{\sqrt{(32.2\ ft/s^2)(0.75\ ft)}}\right)\right]^{2.5} = 0.394\ ft$$

* For conservative design due to critical nature of this element, use $D_{30} = 0.5\ ft$

Estimate toe scour,

Channel width ~ 3 ft
$D_{MNC} = 0.75\ ft$
$D_{MXB} = 1.14\, D_{MNC}\left(1.72 + \frac{0.0084W}{D_{MNC}}\right)$

$$= 1.14(0.75\ ft)\left(1.72 + \frac{0.0084(3\ ft)}{0.75\ ft}\right) = 1.5\ ft$$

Scour depth = $D_{MXB} - D_{MNC} = 1.5\ ft - 0.75\ ft = 0.75\ ft$.

Total Rock Weir Height

* Assume height above bed = 0.5 ft
* Minimum embedment = 0.9 ft.
* Use 18" base stone to prevent piping & increase stability

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Rock Weir Geometry

Crest Width = $2D_{50} \sim 1.25$ ft.

$$R = \text{rock weir radius} = \frac{L^2}{8M} + \frac{M}{2} = \frac{(3ft^2)}{8(1.90)} + \frac{1.90}{2} = 1.5ft$$

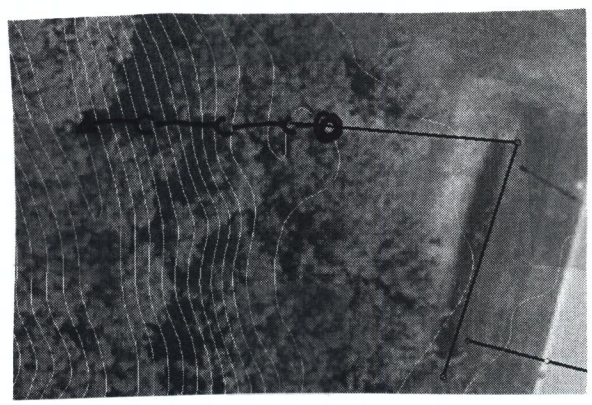
where $L$ = chord length = 3 ft

$M = 3D_{50} = 1.9$ ft

* Provide bank stabilization up ravine slope 3' on either side
* Last weir tapess at 1:10

## Design Reconfiguration for Mid-Reach "Water Quality Feature"

* Approx. 450' d/s of ravine head, feature diverts storm sewer discharge to top of slope



* Current structure uses outlet control to develop any storage volume. Introduce 2" concrete rings
* Approximately 60' from the existing structure, a new basin will be provided.
* From this basin, a new 12" pipe will carry discharge to the floor of the ravine
* Pipe will be run approx. parallel to existing ravine slope
* From SWMM model, the peak velocity for the 100-year 24-hour event is 1.88 ft/s. Existing riffles sized to resist this flow, so placement of riffle at out is recommended.

## Remediation of Failed Structure at Lift Station

* Downstream of the water quality, a lift station was found with a failed curb & gutter and inlet. The tributary area is not large, so suggest repairing curb & gutter and inlet.
* Place inlet invert at ravine's floor & discharge onto stone apron in direction of flow
* Size stone same as riffles to resist in stream velocities; outlet velocities will be quite small

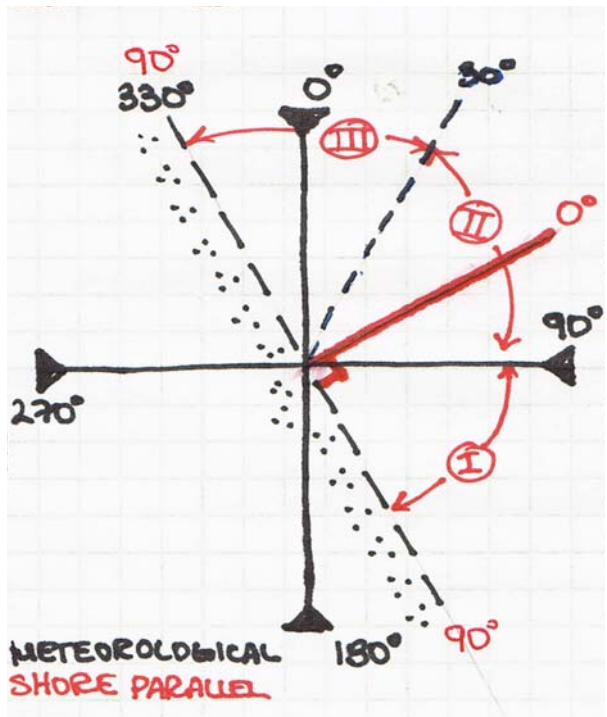
**Estimate Lake Bottom Condition for FS-Level Typical Breakwater**

From a 2010 bathymetric survey, most structures are located in -3.5' LWD water. when placed 75 feet offshore. IGLD85 zero = 577.5ft, so the toe of the structure will be at 571.06ft IGLD85. Converting to meters, the toe will be at will be at 174.97m IGLD85.

**Develop Design Wave Height Conditions**

An analysis based on the new Wave Information Study Lake Michigan 31-year hindcast effort and procedures used by Resio and Vincent (1976) was conducted at site WIS ST94027. The location of the extremes was based on the original Resio and Vincent (1976) Station 33 and accompanying shoreline orientation of 240-degrees (documented in Table E4 of the report).

The meteorological direction convention used in the analysis is illustrated in the figure to the right. Waves from the North come from 0-degrees while waves from the East come from 90-degrees.




• Angle Class I: Mean wave approach angle greater than 30-degrees to right of normal to shore (90- to 150-degrees)
• Angle Class II: Mean wave approach angle within 30-degrees to either side of normal to shore (30-degrees to 90-degrees)
• Angle Class III: Mean wave approach angle greater than 30-degrees to left of normal to shore (330- to 30-degrees)

Analysis of the extreme wave heights yielded the following relationships for the respective angle classes:
Angle Class I: $H_{mo}(m) = 1.5950+0.32990 \cdot \ln[\text{Return Period (years)}]$
Angle Class II: $H_{mo}(m) = 2.1802+0.53953 \cdot \ln[\text{Return Period (years)}]$
Angle Class III: $H_{mo}(m) = 2.9447+0.66038 \cdot \ln[\text{Return Period (years)}]$

To ensure a conservative design, the maximum wave period for the extreme analysis of each angle class will be assumed.

Angle Class I: $T_s = 6.93s$
Angle Class II: $T_s = 8.39s$
Angle Class III: $T_s = 12.29s$

**Develop Design Lake Level Condiitons**

An analysis on the Calumet Harbor lake level data from 1903 to 2010 was performed by Jeff Melby of ERDC . The results of this work included extraction of still-water levels and surge heights for a range of return periods. Using the total lake level value for each return period, a regression equation was developed to estimate two additional return periods not included in the analysis. This equation is as follows:

[Total Water Level] = 581.33 + 0.5245·ln[Return Period]

This data is presented in the table below.

| Return Period | Elevation (ft, IGLD85) SWL+Surge |
|---|---|
| 50-year | 583.3 |
| 25-year | 583.1 |
| 20-year | 582.9 |
| 15-year | 582.8 |
| 10-year | 582.6 |
| 5-year | 582.1 |

The breakwater design is to economically designed considering both initial construction and future maitenance expenses. Combinations of design wave heights and lake levels will be considered to determine the controlling combination for a given exceedance probability of events. From theese values a total project cost can be estimated.

| | | Lake Level | | | | |
|---|---|---|---|---|---|---|
| | | **5-year** | **10-year** | **15-year** | **20-year** | **50-year** |
| | | **0.2** | **0.1** | **0.07** | **0.05** | **0.02** |
| **$H_{mo}$ (ft)** **5-year** | **0.2** | 25 | 50 | 75 | 100 | 250 |
| **10-year** | **0.1** | 50 | 100 | 150 | 200 | 500 |
| **15-year** | **0.067** | 75 | 150 | 225 | 300 | 750 |
| **20-year** | **0.05** | 100 | 200 | 300 | 400 | 1000 |
| **50-year** | **0.02** | 250 | 500 | 750 | 1000 | 2500 |

| | | Angle Class I | | Angle Class II | | Angle Class III | |
|---|---|---|---|---|---|---|---|
| | H:LL | $H_{mo}$ (ft) | LL (ft) | $H_{mo}$ (ft) | LL (ft) | $H_{mo}$ (ft) | LL (ft) |
| 200-yr | 20:10 | 8.48 | 582.6 | 12.46 | 582.6 | 16.15 | 582.6 |
| 200-yr | 10:20 | 7.73 | 582.9 | 11.23 | 582.9 | 14.65 | 582.9 |
| 150-yr | 15:10 | 8.16 | 582.6 | 11.95 | 582.6 | 15.53 | 582.6 |
| 150-yr | 10:15 | 7.73 | 582.8 | 11.23 | 582.8 | 14.65 | 582.8 |
| 100-yr | 20:5 | 8.48 | 582.1 | 12.46 | 582.1 | 16.15 | 582.1 |
| 100-yr | 5:20 | 6.97 | 582.9 | 10.00 | 582.9 | 13.15 | 582.9 |
| 100-yr | 10:10 | 7.73 | 582.6 | 11.23 | 582.6 | 14.65 | 582.6 |
| 75-yr | 15:5 | 8.16 | 582.1 | 11.95 | 582.1 | 15.53 | 582.1 |
| 75-yr | 5:15 | 6.97 | 582.8 | 10.00 | 582.8 | 13.15 | 582.8 |
| 50-yr | 10:5 | 7.73 | 582.1 | 11.23 | 582.1 | 14.65 | 582.1 |
| 50-yr | 5:10 | 6.97 | 582.6 | 10.00 | 582.6 | 13.15 | 582.6 |
| 25-yr | 5:5 | 6.97 | 582.1 | 10.00 | 582.1 | 13.15 | 582.1 |

**Wave Transformation - Deepwater to Nearshore**

| | | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H:LL | WSE | Elev @ Toe | d | $H_{mo}$ | $d/H_{mo}$ | $T_p$ | $L_o$ | $\alpha_o$ | $d/L_o$ |
| | | | (ft) | (ft) | (ft) | (ft) | - | (s) | (ft) | (degrees) | - |
| Angle Class I | 200-yr | 20:10 | 582.6 | 573 | 9.6 | 8.48 | 1.13 | 6.93 | 245.812 | 48.3 | 0.039 |
| | 200-yr | 10:20 | 582.9 | 573 | 9.9 | 7.73 | 1.28 | 6.93 | 245.812 | 48.3 | 0.040 |
| | 150-yr | 15:10 | 582.6 | 573 | 9.6 | 8.16 | 1.18 | 6.93 | 245.812 | 48.3 | 0.039 |
| | 150-yr | 10:15 | 582.8 | 573 | 9.8 | 7.73 | 1.27 | 6.93 | 245.812 | 48.3 | 0.040 |
| | 100-yr | 20:5 | 582.1 | 573 | 9.1 | 8.48 | 1.07 | 6.93 | 245.812 | 48.3 | 0.037 |
| | 100-yr | 5:20 | 582.9 | 573 | 9.9 | 6.97 | 1.42 | 6.93 | 245.812 | 48.3 | 0.040 |
| | 100-yr | 10:10 | 582.6 | 573 | 9.6 | 7.73 | 1.24 | 6.93 | 245.812 | 48.3 | 0.039 |
| | 75-yr | 15:5 | 582.1 | 573 | 9.1 | 8.16 | 1.11 | 6.93 | 245.812 | 48.3 | 0.037 |
| | 75-yr | 5:15 | 582.8 | 573 | 9.8 | 6.97 | 1.41 | 6.93 | 245.812 | 48.3 | 0.040 |
| | 50-yr | 10:5 | 582.1 | 573 | 9.1 | 7.73 | 1.18 | 6.93 | 245.812 | 48.3 | 0.037 |
| | 50-yr | 5:10 | 582.6 | 573 | 9.6 | 6.97 | 1.38 | 6.93 | 245.812 | 48.3 | 0.039 |
| | 25-yr | 5:5 | 582.1 | 573 | 9.1 | 6.97 | 1.30 | 6.93 | 245.812 | 48.3 | 0.037 |
| Angle Class II | 200-yr | 20:10 | 582.6 | 573 | 9.6 | 12.46 | 0.77 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 200-yr | 10:20 | 582.9 | 573 | 9.9 | 11.23 | 0.88 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 150-yr | 15:10 | 582.6 | 573 | 9.6 | 11.95 | 0.80 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 150-yr | 10:15 | 582.8 | 573 | 9.8 | 11.23 | 0.87 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 100-yr | 20:5 | 582.1 | 573 | 9.1 | 12.46 | 0.73 | 8.39 | 360.297 | 0.7 | 0.025 |
| | 100-yr | 5:20 | 582.9 | 573 | 9.9 | 10.00 | 0.99 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 100-yr | 10:10 | 582.6 | 573 | 9.6 | 11.23 | 0.85 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 75-yr | 15:5 | 582.1 | 573 | 9.1 | 11.95 | 0.76 | 8.39 | 360.297 | 0.7 | 0.025 |
| | 75-yr | 5:15 | 582.8 | 573 | 9.8 | 10.00 | 0.98 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 50-yr | 10:5 | 582.1 | 573 | 9.1 | 11.23 | 0.81 | 8.39 | 360.297 | 0.7 | 0.025 |
| | 50-yr | 5:10 | 582.6 | 573 | 9.6 | 10.00 | 0.96 | 8.39 | 360.297 | 0.7 | 0.027 |
| | 25-yr | 5:5 | 582.1 | 573 | 9.1 | 10.00 | 0.91 | 8.39 | 360.297 | 0.7 | 0.025 |
| Angle Class III | 200-yr | 20:10 | 582.6 | 573 | 9.6 | 16.15 | 0.59 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 200-yr | 10:20 | 582.9 | 573 | 9.9 | 14.65 | 0.68 | 12.29 | 773.108 | 39.6 | 0.013 |
| | 150-yr | 15:10 | 582.6 | 573 | 9.6 | 15.53 | 0.62 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 150-yr | 10:15 | 582.8 | 573 | 9.8 | 14.65 | 0.67 | 12.29 | 773.108 | 39.6 | 0.013 |
| | 100-yr | 20:5 | 582.1 | 573 | 9.1 | 16.15 | 0.56 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 100-yr | 5:20 | 582.9 | 573 | 9.9 | 13.15 | 0.75 | 12.29 | 773.108 | 39.6 | 0.013 |
| | 100-yr | 10:10 | 582.6 | 573 | 9.6 | 14.65 | 0.66 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 75-yr | 15:5 | 582.1 | 573 | 9.1 | 15.53 | 0.59 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 75-yr | 5:15 | 582.8 | 573 | 9.8 | 13.15 | 0.75 | 12.29 | 773.108 | 39.6 | 0.013 |
| | 50-yr | 10:5 | 582.1 | 573 | 9.1 | 14.65 | 0.62 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 50-yr | 5:10 | 582.6 | 573 | 9.6 | 13.15 | 0.73 | 12.29 | 773.108 | 39.6 | 0.012 |
| | 25-yr | 5:5 | 582.1 | 573 | 9.1 | 13.15 | 0.69 | 12.29 | 773.108 | 39.6 | 0.012 |

| | | | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H:LL | $y_o$ | C | L | k | $s_{max}$ | $K_r$ | $K_s$ | $H_o'$ | $d/H_o'$ |
| | | | - | (ft/s) | (ft) | ($ft^{-1}$) | - | - | - | (ft) | - |
| Angle Class I | 200-yr | 20:10 | 0.2454 | 16.864 | 116.87 | 0.0538 | 25 | 0.84 | 1.0693 | 7.12 | 1.35 |
| | 200-yr | 10:20 | 0.2531 | 17.103 | 118.52 | 0.053 | 25 | 0.84 | 1.0632 | 6.49 | 1.53 |
| | 150-yr | 15:10 | 0.2454 | 16.864 | 116.87 | 0.0538 | 25 | 0.84 | 1.0693 | 6.86 | 1.40 |
| | 150-yr | 10:15 | 0.2505 | 17.024 | 117.97 | 0.0533 | 25 | 0.84 | 1.0652 | 6.49 | 1.51 |
| | 100-yr | 20:5 | 0.2326 | 16.455 | 114.03 | 0.0551 | 25 | 0.84 | 1.0802 | 7.12 | 1.28 |
| | 100-yr | 5:20 | 0.2531 | 17.103 | 118.52 | 0.053 | 25 | 0.84 | 1.0632 | 5.86 | 1.69 |
| | 100-yr | 10:10 | 0.2454 | 16.864 | 116.87 | 0.0538 | 25 | 0.84 | 1.0693 | 6.49 | 1.48 |
| | 75-yr | 15:5 | 0.2326 | 16.455 | 114.03 | 0.0551 | 25 | 0.84 | 1.0802 | 6.86 | 1.33 |
| | 75-yr | 5:15 | 0.2505 | 17.024 | 117.97 | 0.0533 | 25 | 0.84 | 1.0652 | 5.86 | 1.67 |
| | 50-yr | 10:5 | 0.2326 | 16.455 | 114.03 | 0.0551 | 25 | 0.84 | 1.0802 | 6.49 | 1.40 |
| | 50-yr | 5:10 | 0.2454 | 16.864 | 116.87 | 0.0538 | 25 | 0.84 | 1.0693 | 5.86 | 1.64 |
| | 25-yr | 5:5 | 0.2326 | 16.455 | 114.03 | 0.0551 | 25 | 0.84 | 1.0802 | 5.86 | 1.55 |
| Angle Class II | 200-yr | 20:10 | 0.1674 | 17.089 | 143.38 | 0.0438 | 25 | 0.96 | 1.1534 | 11.96 | 0.80 |
| | 200-yr | 10:20 | 0.1726 | 17.339 | 145.47 | 0.0432 | 25 | 0.96 | 1.1461 | 10.78 | 0.92 |
| | 150-yr | 15:10 | 0.1674 | 17.089 | 143.38 | 0.0438 | 25 | 0.96 | 1.1534 | 11.47 | 0.84 |
| | 150-yr | 10:15 | 0.1709 | 17.256 | 144.78 | 0.0434 | 25 | 0.96 | 1.1485 | 10.78 | 0.91 |
| | 100-yr | 20:5 | 0.1587 | 16.663 | 139.8 | 0.0449 | 25 | 0.96 | 1.1663 | 11.96 | 0.76 |
| | 100-yr | 5:20 | 0.1726 | 17.339 | 145.47 | 0.0432 | 25 | 0.96 | 1.1461 | 9.60 | 1.03 |
| | 100-yr | 10:10 | 0.1674 | 17.089 | 143.38 | 0.0438 | 25 | 0.96 | 1.1534 | 10.78 | 0.89 |
| | 75-yr | 15:5 | 0.1587 | 16.663 | 139.8 | 0.0449 | 25 | 0.96 | 1.1663 | 11.47 | 0.79 |
| | 75-yr | 5:15 | 0.1709 | 17.256 | 144.78 | 0.0434 | 25 | 0.96 | 1.1485 | 9.60 | 1.02 |
| | 50-yr | 10:5 | 0.1587 | 16.663 | 139.8 | 0.0449 | 25 | 0.96 | 1.1663 | 10.78 | 0.84 |
| | 50-yr | 5:10 | 0.1674 | 17.089 | 143.38 | 0.0438 | 25 | 0.96 | 1.1534 | 9.60 | 1.00 |
| | 25-yr | 5:5 | 0.1587 | 16.663 | 139.8 | 0.0449 | 25 | 0.96 | 1.1663 | 9.60 | 0.95 |
| Angle Class III | 200-yr | 20:10 | 0.078 | 17.349 | 213.22 | 0.0295 | 25 | 0.8 | 1.3646 | 12.92 | 0.74 |
| | 200-yr | 10:20 | 0.0805 | 17.61 | 216.43 | 0.029 | 25 | 0.8 | 1.355 | 11.72 | 0.84 |
| | 150-yr | 15:10 | 0.078 | 17.349 | 213.22 | 0.0295 | 25 | 0.8 | 1.3646 | 12.42 | 0.77 |
| | 150-yr | 10:15 | 0.0796 | 17.524 | 215.37 | 0.0292 | 25 | 0.8 | 1.3582 | 11.72 | 0.84 |
| | 100-yr | 20:5 | 0.074 | 16.902 | 207.73 | 0.0302 | 25 | 0.8 | 1.3816 | 12.92 | 0.70 |
| | 100-yr | 5:20 | 0.0805 | 17.61 | 216.43 | 0.029 | 25 | 0.8 | 1.355 | 10.52 | 0.94 |
| | 100-yr | 10:10 | 0.078 | 17.349 | 213.22 | 0.0295 | 25 | 0.8 | 1.3646 | 11.72 | 0.82 |
| | 75-yr | 15:5 | 0.074 | 16.902 | 207.73 | 0.0302 | 25 | 0.8 | 1.3816 | 12.42 | 0.73 |
| | 75-yr | 5:15 | 0.0796 | 17.524 | 215.37 | 0.0292 | 25 | 0.8 | 1.3582 | 10.52 | 0.93 |
| | 50-yr | 10:5 | 0.074 | 16.902 | 207.73 | 0.0302 | 25 | 0.8 | 1.3816 | 11.72 | 0.78 |
| | 50-yr | 5:10 | 0.078 | 17.349 | 213.22 | 0.0295 | 25 | 0.8 | 1.3646 | 10.52 | 0.91 |
| | 25-yr | 5:5 | 0.074 | 16.902 | 207.73 | 0.0302 | 25 | 0.8 | 1.3816 | 10.52 | 0.87 |

| | | | (19) | (20) | (21) | (22) | (23) | (24) | (25) | (26) | (27) | (29) | (30) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H:LL | $H_o'/L_o$ | m | $\beta_o$ | $\beta_1$ | $\beta_{max}$ | $H_{1/3}$ | | | | $H_{s,des}$ | $\alpha_p$ |
| | | | - | (ft/ft) | - | - | - | (ft) | (ft) | (ft) | (ft) | (ft) | (degrees) |
| Angle Class I | 200-yr | 20:10 | 0.029 | 0.013 | 0.111 | 0.549 | 0.922 | 6.06 | 6.57 | 7.62 | 6.06 | 6.06 | 20 |
| | 200-yr | 10:20 | 0.026 | 0.013 | 0.115 | 0.549 | 0.947 | 6.18 | 6.15 | 6.90 | 6.15 | 6.15 | 20 |
| | 150-yr | 15:10 | 0.028 | 0.013 | 0.112 | 0.549 | 0.932 | 6.04 | 6.39 | 7.33 | 6.04 | 6.04 | 20 |
| | 150-yr | 10:15 | 0.026 | 0.013 | 0.115 | 0.549 | 0.947 | 6.13 | 6.15 | 6.91 | 6.13 | 6.13 | 20 |
| | 100-yr | 20:5 | 0.029 | 0.013 | 0.111 | 0.549 | 0.922 | 5.79 | 6.56 | 7.69 | 5.79 | 5.79 | 20 |
| | 100-yr | 5:20 | 0.024 | 0.013 | 0.119 | 0.549 | 0.976 | 6.14 | 5.72 | 6.23 | 5.72 | 5.72 | 20 |
| | 100-yr | 10:10 | 0.026 | 0.013 | 0.115 | 0.549 | 0.947 | 6.02 | 6.15 | 6.94 | 6.02 | 6.02 | 20 |
| | 75-yr | 15:5 | 0.028 | 0.013 | 0.112 | 0.549 | 0.932 | 5.77 | 6.39 | 7.41 | 5.77 | 5.77 | 20 |
| | 75-yr | 5:15 | 0.024 | 0.013 | 0.119 | 0.549 | 0.976 | 6.08 | 5.72 | 6.24 | 5.72 | 5.72 | 20 |
| | 50-yr | 10:5 | 0.026 | 0.013 | 0.115 | 0.549 | 0.947 | 5.74 | 6.15 | 7.01 | 5.74 | 5.74 | 20 |
| | 50-yr | 5:10 | 0.024 | 0.013 | 0.119 | 0.549 | 0.976 | 5.97 | 5.72 | 6.27 | 5.72 | 5.72 | 20 |
| | 25-yr | 5:5 | 0.024 | 0.013 | 0.119 | 0.549 | 0.976 | 5.70 | 5.72 | 6.33 | 5.70 | 5.70 | 20 |
| Angle Class II | 200-yr | 20:10 | 0.033 | 0.013 | 0.105 | 0.549 | 0.920 | 6.53 | 11.00 | 13.79 | 6.53 | 6.53 | 0 |
| | 200-yr | 10:20 | 0.030 | 0.013 | 0.109 | 0.549 | 0.920 | 6.62 | 9.92 | 12.35 | 6.62 | 6.62 | 0 |
| | 150-yr | 15:10 | 0.032 | 0.013 | 0.107 | 0.549 | 0.920 | 6.50 | 10.55 | 13.23 | 6.50 | 6.50 | 0 |
| | 150-yr | 10:15 | 0.030 | 0.013 | 0.109 | 0.549 | 0.920 | 6.56 | 9.92 | 12.38 | 6.56 | 6.56 | 0 |
| | 100-yr | 20:5 | 0.033 | 0.013 | 0.105 | 0.549 | 0.920 | 6.26 | 11.00 | 13.95 | 6.26 | 6.26 | 0 |
| | 100-yr | 5:20 | 0.027 | 0.013 | 0.114 | 0.549 | 0.945 | 6.53 | 9.07 | 11.00 | 6.53 | 6.53 | 0 |
| | 100-yr | 10:10 | 0.030 | 0.013 | 0.109 | 0.549 | 0.920 | 6.45 | 9.92 | 12.43 | 6.45 | 6.45 | 0 |
| | 75-yr | 15:5 | 0.032 | 0.013 | 0.107 | 0.549 | 0.920 | 6.22 | 10.55 | 13.38 | 6.22 | 6.22 | 0 |
| | 75-yr | 5:15 | 0.027 | 0.013 | 0.114 | 0.549 | 0.945 | 6.48 | 9.07 | 11.03 | 6.48 | 6.48 | 0 |
| | 50-yr | 10:5 | 0.030 | 0.013 | 0.109 | 0.549 | 0.920 | 6.18 | 9.92 | 12.57 | 6.18 | 6.18 | 0 |
| | 50-yr | 5:10 | 0.027 | 0.013 | 0.114 | 0.549 | 0.945 | 6.37 | 9.07 | 11.07 | 6.37 | 6.37 | 0 |
| | 25-yr | 5:5 | 0.027 | 0.013 | 0.114 | 0.549 | 0.945 | 6.10 | 9.07 | 11.20 | 6.10 | 6.10 | 0 |
| Angle Class III | 200-yr | 20:10 | 0.017 | 0.013 | 0.137 | 0.549 | 1.081 | 7.04 | 13.97 | 17.63 | 7.04 | 7.04 | 9 |
| | 200-yr | 10:20 | 0.015 | 0.013 | 0.142 | 0.549 | 1.113 | 7.10 | 13.04 | 15.88 | 7.10 | 7.10 | 9 |
| | 150-yr | 15:10 | 0.016 | 0.013 | 0.139 | 0.549 | 1.094 | 6.99 | 13.59 | 16.95 | 6.99 | 6.99 | 9 |
| | 150-yr | 10:15 | 0.015 | 0.013 | 0.142 | 0.549 | 1.113 | 7.04 | 13.04 | 15.92 | 7.04 | 7.04 | 9 |
| | 100-yr | 20:5 | 0.017 | 0.013 | 0.137 | 0.549 | 1.081 | 6.76 | 13.97 | 17.85 | 6.76 | 6.76 | 9 |
| | 100-yr | 5:20 | 0.014 | 0.013 | 0.148 | 0.549 | 1.148 | 6.99 | 12.07 | 14.25 | 6.99 | 6.99 | 9 |
| | 100-yr | 10:10 | 0.015 | 0.013 | 0.142 | 0.549 | 1.113 | 6.93 | 13.04 | 15.99 | 6.93 | 6.93 | 9 |
| | 75-yr | 15:5 | 0.016 | 0.013 | 0.139 | 0.549 | 1.094 | 6.72 | 13.59 | 17.16 | 6.72 | 6.72 | 9 |
| | 75-yr | 5:15 | 0.014 | 0.013 | 0.148 | 0.549 | 1.148 | 6.93 | 12.07 | 14.29 | 6.93 | 6.93 | 9 |
| | 50-yr | 10:5 | 0.015 | 0.013 | 0.142 | 0.549 | 1.113 | 6.66 | 13.04 | 16.19 | 6.66 | 6.66 | 9 |
| | 50-yr | 5:10 | 0.014 | 0.013 | 0.148 | 0.549 | 1.148 | 6.83 | 12.07 | 14.35 | 6.83 | 6.83 | 9 |
| | 25-yr | 5:5 | 0.014 | 0.013 | 0.148 | 0.549 | 1.148 | 6.55 | 12.07 | 14.53 | 6.55 | 6.55 | 9 |

**Summary of the Wave Transformation Columns**

Column (1): Design Water Surface Elevation , WSE

From analysis of Calumet Harbor gage data

Column (2): Lake Bed Elevation at Toe of the Structure

Estimated based on proposed location and bathymetric survey conducted in 2010

Column (3): Depth Relative to Toe of Structure, d

= [Column (1)] - [Column (2)]

Column (4): Spectral Significant Wave Height, $H_{mo}$

From hindcast analysis for recently completed WIS

Column (5): Ratio of Depth to Spectral Significant Wave Height

$$\frac{d}{H_{mo}} = \frac{Column_3}{Column_4}$$

Column (6): Peak Wave Period, $T_p$

From hindcast analysis for recently completed WIS

Column (7): Deep Water Wave Length, $L_o$

$$L_o = \frac{g}{2\pi} T^2$$

Column (8): Deep Water Wave Angle, $\alpha_o$

Hindcast analysis for the site included a list of the top ten wave events for each angle class. The values for the design approach direction are the average approach direction of these ten events for each angle class. Directions were translated from meteorological direction to an angle relative to shore parallel (i.e. $0^o$ is shore parallel).

Column (9): Ratio of Depth to Deep Water Wave Length

$$\frac{d}{L_o} = \frac{Column_3}{Column_7}$$

Column (10): Hunt's Approximation Parameter, $y_o$

$$y_o \equiv \frac{2\pi d}{L_o}$$

Column (11): Wave Celerity, C

$$\frac{C^2}{gd} = \left[ y_o + \left(1 + 0.6522 y_o + 0.4622 y_o^2 + 0.0864 y_o^4 + 0.0675 y_o^5\right)^{-1} \right]^{-1}$$

Column (12): Wave Length, L

L = C·T

Column (13): Wave Number, k

$$k = \frac{2\pi}{L}$$

Column (14): Spreading Parameter, $s_{max}$

Using Figure 2.13 from Goda (2010), $s_{max}$ varies between approximately 17 and 47. Assume that $s_{max}$ equals 25.

Column (15): Refraction Coefficient, $K_r$

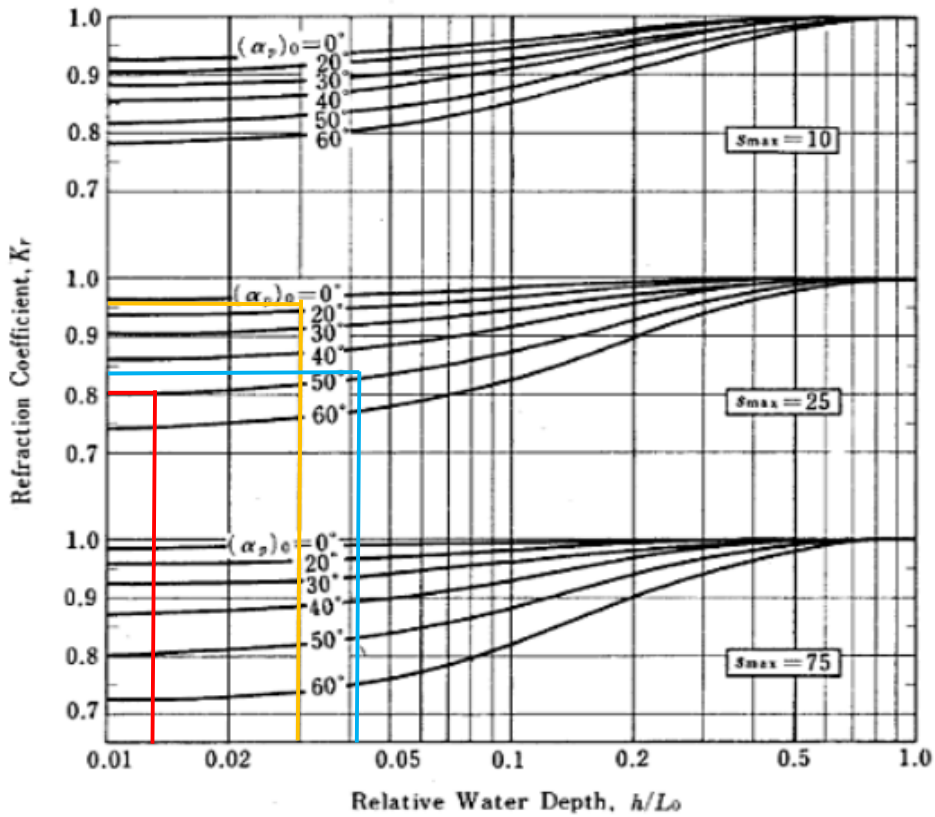



Fig. 3.10 Refraction coefficient of random sea waves on a coast with straight, parallel depth-contours.[17]

Column (16): Shoaling Coefficient, $K_s$

$$K_s = \left[\left(1 + \frac{2kd}{\sinh(2kd)}\right)\tanh(kd)\right]^{-1/2}$$

Column (17): Equivalent Deep Water Wave Height, $H_o'$

$$H_o' = H_o \cdot K_r = Column_5 \times Column_11$$

Column (18): Ratio of Depth to Equivalent Wave Height

$$\frac{d}{H_o'} = \frac{Column_3}{Column_17}$$

Column (19): Ratio of Equivalent Deep Water Wave Height to Deep Water Wavelength

$$\frac{H_o'}{L_o} = \frac{Column_17}{Column_7}$$

Column (20): Beach Slope, m

Estimated based on proposed location and bathymetric survey conducted in 2010

Column (21): Coefficient for approximate estimation of wave height within surf zone, $\beta_o$

$$\beta_o = 0.028\left(\frac{H_o'}{L_o}\right)^{-0.38} \exp\left(20 \cdot \tan^{1.5}\theta\right)$$

Column (22): Coefficient for approximate estimation of wave height within surf zone, $\beta_1$

$$\beta_1 = 0.52 \exp\left[4.2 \tan\theta\right]$$

Column (23): Coefficient for approximate estimation of wave height within surf zone, $\beta_{max}$

$$\beta_{\max} = \max\left\{0.92, 0.32\left(\frac{H_o'}{L_o}\right)^{-0.29} \exp\left[2.4 \tan\theta\right]\right\}$$

Column (24): Significant Wave Height within Surf Zone, Calculation #1

$$H_{1/3} = \beta_o H_o' + \beta_1 d$$

Column (25): Significant Wave Height within Surf Zone, Calculation #2

$$H_{1/3} = \beta_{\max} H_o'$$

Column (26): Significant Wave Height within Surf Zone, Calculation #3

$$H_{1/3} = K_s H_o'$$

Column (27): Signifcant Wave Height within Surf Zone

Significant wave height within the surf zone is the minimum of the three values previously

Column (28): Depth-Limited Wave Height at Toe of Breakwater

$$H_{sb} = 0.56 \cdot d_b \cdot \exp\left[3.5 \cdot m\right]$$

Column (29): Design Significant Wave Height

Design signifcant wave height is the minimum of the signficant wave height developed through

Column (30): Approach Angle after Refraction, $\alpha_p$

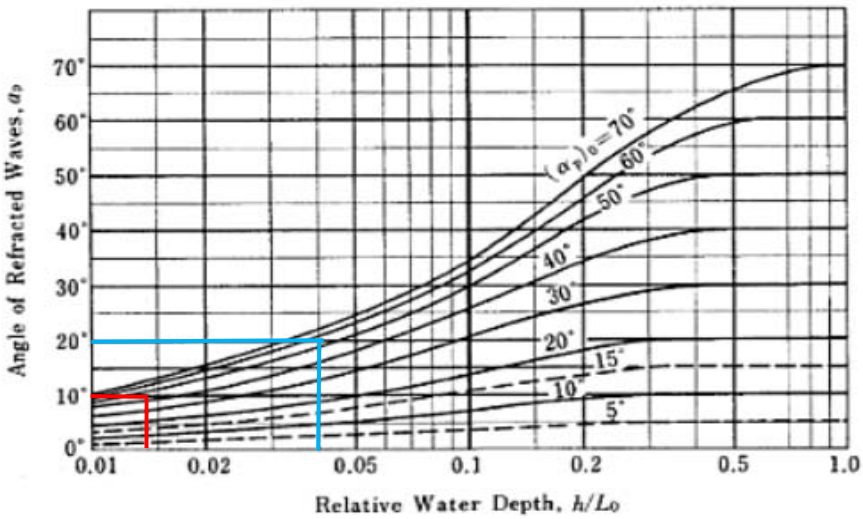



Fig. 3.11 Variation of predominant direction of random sea waves due to refraction on a coast with straight, parallel depth-contours.

**Design Wave Parameters**

| | | H:LL | (1) $H_s$ (ft) | (2) $H_s$ (m) | (3) $T_p$ (s) | (4) $T_m$ (s) | (5) $\alpha_p$ (deg) |
|---|---|---|---|---|---|---|---|
| Angle Class I | 200-yr | 20:10 | 6.06 | 1.85 | 6.93 | 5.68 | 20 |
| | 200-yr | 10:20 | 6.15 | 1.87 | 6.93 | 5.68 | 20 |
| | 150-yr | 15:10 | 6.04 | 1.84 | 6.93 | 5.68 | 20 |
| | 150-yr | 10:15 | 6.13 | 1.87 | 6.93 | 5.68 | 20 |
| | 100-yr | 20:5 | 5.79 | 1.76 | 6.93 | 5.68 | 20 |
| | 100-yr | 5:20 | 5.72 | 1.74 | 6.93 | 5.68 | 20 |
| | 100-yr | 10:10 | 6.02 | 1.83 | 6.93 | 5.68 | 20 |
| | 75-yr | 15:5 | 5.77 | 1.76 | 6.93 | 5.68 | 20 |
| | 75-yr | 5:15 | 5.72 | 1.74 | 6.93 | 5.68 | 20 |
| | 50-yr | 10:5 | 5.74 | 1.75 | 6.93 | 5.68 | 20 |
| | 50-yr | 5:10 | 5.72 | 1.74 | 6.93 | 5.68 | 20 |
| | 25-yr | 5:5 | 5.70 | 1.74 | 6.93 | 5.68 | 20 |
| Angle Class II | 200-yr | 20:10 | 6.53 | 1.99 | 8.39 | 6.88 | 0 |
| | 200-yr | 10:20 | 6.62 | 2.02 | 8.39 | 6.88 | 0 |
| | 150-yr | 15:10 | 6.50 | 1.98 | 8.39 | 6.88 | 0 |
| | 150-yr | 10:15 | 6.56 | 2.00 | 8.39 | 6.88 | 0 |
| | 100-yr | 20:5 | 6.26 | 1.91 | 8.39 | 6.88 | 0 |
| | 100-yr | 5:20 | 6.53 | 1.99 | 8.39 | 6.88 | 0 |
| | 100-yr | 10:10 | 6.45 | 1.97 | 8.39 | 6.88 | 0 |
| | 75-yr | 15:5 | 6.22 | 1.90 | 8.39 | 6.88 | 0 |
| | 75-yr | 5:15 | 6.48 | 1.98 | 8.39 | 6.88 | 0 |
| | 50-yr | 10:5 | 6.18 | 1.88 | 8.39 | 6.88 | 0 |
| | 50-yr | 5:10 | 6.37 | 1.94 | 8.39 | 6.88 | 0 |
| | 25-yr | 5:5 | 6.10 | 1.86 | 8.39 | 6.88 | 0 |
| Angle Class III | 200-yr | 20:10 | 7.04 | 2.14 | 12.29 | 10.08 | 9 |
| | 200-yr | 10:20 | 7.10 | 2.16 | 12.29 | 10.08 | 9 |
| | 150-yr | 15:10 | 6.99 | 2.13 | 12.29 | 10.08 | 9 |
| | 150-yr | 10:15 | 7.04 | 2.15 | 12.29 | 10.08 | 9 |
| | 100-yr | 20:5 | 6.76 | 2.06 | 12.29 | 10.08 | 9 |
| | 100-yr | 5:20 | 6.99 | 2.13 | 12.29 | 10.08 | 9 |
| | 100-yr | 10:10 | 6.93 | 2.11 | 12.29 | 10.08 | 9 |
| | 75-yr | 15:5 | 6.72 | 2.05 | 12.29 | 10.08 | 9 |
| | 75-yr | 5:15 | 6.93 | 2.11 | 12.29 | 10.08 | 9 |
| | 50-yr | 10:5 | 6.66 | 2.03 | 12.29 | 10.08 | 9 |
| | 50-yr | 5:10 | 6.83 | 2.08 | 12.29 | 10.08 | 9 |
| | 25-yr | 5:5 | 6.55 | 2.00 | 12.29 | 10.08 | 9 |

**Assumed Contstants**

| | | |
|---|---|---|
| Density of Stone = | 2650 | $kg/m^3$ |
| | 165 | $lb/ft^3$ |
| Density of Water = | 1000 | $kg/m^3$ |
| | 62.4 | $lb/ft^3$ |
| Gravity, g = | 9.81 | $m/s^2$ |
| $\Delta = S_r - 1 =$ | 1.65 | |

**Assumed Design Parameters**

| | | |
|---|---|---|
| Nominal Damage, $S_a$ = | 2 | No Damage |
| Permeability, $P_b$ = | 0.4 | Coarse Core Layers (Std) |
| No. of Waves, $N_w$ = | 7500 | waves |

**Assumed Partial Safety Factors**

| | Surging | Plunging | |
|---|---|---|---|
| $\sigma'_{FHs}$ = | 0.05 | | (Assumes HQ Wave Data) |
| $P_f$ = | 0.4 | | |
| $\gamma_H$ = | 1 | 1 | |
| $\gamma_Z$ = | 1.08 | 1.08 | |

**Required Crest Elevation - Based on Maximum Observed Overtopping at Forest Park, Lake Forest**

| | | | (6) | (7) | (8) | (9) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H:LL | $L_{om}$ | $L_{op}$ | $s_{om}$ | $s_{op}$ | tan α | $\xi_{op}$ | $\gamma_r$ | $\gamma_b$ | $\gamma_h$ | $\gamma_\beta$ | $R_c$ | | q |
| | | | (m) | (m) | - | - | - | - | - | - | - | - | (m) | (ft) | ($m^3$/s/m) |
| Angle Class I | 200-yr | 20:10 | 50.42 | 74.98 | 0.037 | 0.025 | 0.500 | 3.185 | 0.55 | 1 | 1 | 0.970 | 0.43 | 1.40 | 0.510 |
| | 200-yr | 10:20 | 50.42 | 74.98 | 0.037 | 0.025 | 0.500 | 3.163 | 0.55 | 1 | 1 | 0.970 | 0.34 | 1.10 | 0.671 |
| | 150-yr | 15:10 | 50.42 | 74.98 | 0.037 | 0.025 | 0.500 | 3.190 | 0.55 | 1 | 1 | 0.970 | 0.43 | 1.40 | 0.506 |
| | 150-yr | 10:15 | 50.42 | 74.98 | 0.037 | 0.025 | 0.500 | 3.168 | 0.55 | 1 | 1 | 0.970 | 0.37 | 1.20 | 0.615 |
| | 100-yr | 20:5 | 50.42 | 74.98 | 0.035 | 0.024 | 0.500 | 3.260 | 0.55 | 1 | 1 | 0.970 | 0.58 | 1.90 | 0.296 |
| | 100-yr | 5:20 | 50.42 | 74.98 | 0.035 | 0.023 | 0.500 | 3.280 | 0.55 | 1 | 1 | 0.970 | 0.34 | 1.10 | 0.564 |
| | 100-yr | 10:10 | 50.42 | 74.98 | 0.036 | 0.024 | 0.500 | 3.197 | 0.55 | 1 | 1 | 0.970 | 0.43 | 1.40 | 0.500 |
| | 75-yr | 15:5 | 50.42 | 74.98 | 0.035 | 0.023 | 0.500 | 3.265 | 0.55 | 1 | 1 | 0.970 | 0.58 | 1.90 | 0.293 |
| | 75-yr | 5:15 | 50.42 | 74.98 | 0.035 | 0.023 | 0.500 | 3.280 | 0.55 | 1 | 1 | 0.970 | 0.37 | 1.20 | 0.518 |
| | 50-yr | 10:5 | 50.42 | 74.98 | 0.035 | 0.023 | 0.500 | 3.273 | 0.55 | 1 | 1 | 0.970 | 0.58 | 1.90 | 0.289 |
| | 50-yr | 5:10 | 50.42 | 74.98 | 0.035 | 0.023 | 0.500 | 3.280 | 0.55 | 1 | 1 | 0.970 | 0.43 | 1.40 | 0.437 |
| | 25-yr | 5:5 | 50.42 | 74.98 | 0.034 | 0.023 | 0.500 | 3.286 | 0.55 | 1 | 1 | 0.970 | 0.58 | 1.90 | 0.282 |
| Angle Class II | 200-yr | 20:10 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.715 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.638 |
| | 200-yr | 10:20 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.691 | 0.55 | 1 | 1 | 1.000 | 0.34 | 1.10 | 0.818 |
| | 150-yr | 15:10 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.725 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.631 |
| | 150-yr | 10:15 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.706 | 0.55 | 1 | 1 | 1.000 | 0.37 | 1.20 | 0.746 |
| | 100-yr | 20:5 | 73.90 | 109.90 | 0.026 | 0.017 | 0.500 | 3.796 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.392 |
| | 100-yr | 5:20 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.714 | 0.55 | 1 | 1 | 1.000 | 0.34 | 1.10 | 0.795 |
| | 100-yr | 10:10 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.738 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.619 |
| | 75-yr | 15:5 | 73.90 | 109.90 | 0.026 | 0.017 | 0.500 | 3.806 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.387 |
| | 75-yr | 5:15 | 73.90 | 109.90 | 0.027 | 0.018 | 0.500 | 3.730 | 0.55 | 1 | 1 | 1.000 | 0.37 | 1.20 | 0.725 |
| | 50-yr | 10:5 | 73.90 | 109.90 | 0.025 | 0.017 | 0.500 | 3.820 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.378 |
| | 50-yr | 5:10 | 73.90 | 109.90 | 0.026 | 0.018 | 0.500 | 3.762 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.600 |
| | 25-yr | 5:5 | 73.90 | 109.90 | 0.025 | 0.017 | 0.500 | 3.846 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.363 |
| Angle Class III | 200-yr | 20:10 | 158.57 | 235.83 | 0.014 | 0.009 | 0.500 | 5.243 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.768 |
| | 200-yr | 10:20 | 158.57 | 235.83 | 0.014 | 0.009 | 0.500 | 5.220 | 0.55 | 1 | 1 | 1.000 | 0.34 | 1.10 | 0.958 |
| | 150-yr | 15:10 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.259 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.757 |
| | 150-yr | 10:15 | 158.57 | 235.83 | 0.014 | 0.009 | 0.500 | 5.241 | 0.55 | 1 | 1 | 1.000 | 0.37 | 1.20 | 0.880 |
| | 100-yr | 20:5 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.348 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.491 |
| | 100-yr | 5:20 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.260 | 0.55 | 1 | 1 | 1.000 | 0.34 | 1.10 | 0.926 |
| | 100-yr | 10:10 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.282 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.741 |
| | 75-yr | 15:5 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.365 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.482 |
| | 75-yr | 5:15 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.281 | 0.55 | 1 | 1 | 1.000 | 0.37 | 1.20 | 0.850 |
| | 50-yr | 10:5 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.390 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.470 |
| | 50-yr | 5:10 | 158.57 | 235.83 | 0.013 | 0.009 | 0.500 | 5.324 | 0.55 | 1 | 1 | 1.000 | 0.43 | 1.40 | 0.713 |
| | 25-yr | 5:5 | 158.57 | 235.83 | 0.013 | 0.008 | 0.500 | 5.434 | 0.55 | 1 | 1 | 1.000 | 0.58 | 1.90 | 0.449 |

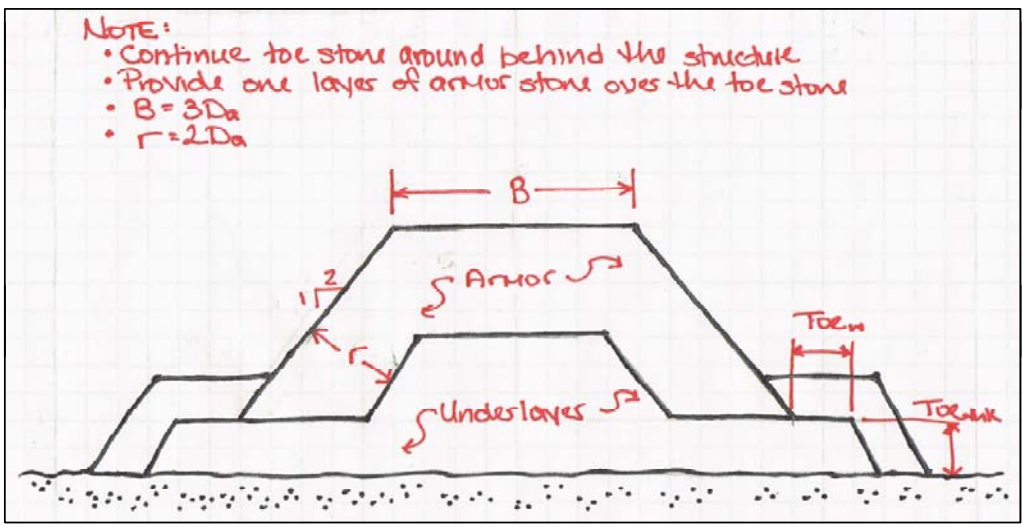
**Breakwater Design**

| | | H:LL | (20) $H_{0.1}$ (ft) | (21) $K_D$ - | (22) $M_{50}$ (ton) | (23) $D_{50}$ (ft) | (24) B (ft) | (25) r (ft) | (26) $Toe_W$ (ft) | (27) $Toe_{thk}$ (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Angle Class I | 200-yr | 20:10 | 7.70 | 2.00 | 2.1 | 2.9 | 8.82 | 5.88 | 2.94 | 1.96 |
| | 200-yr | 10:20 | 7.81 | 2.00 | 2.2 | 3.0 | 8.94 | 5.96 | 2.98 | 1.99 |
| | 150-yr | 15:10 | 7.67 | 2.00 | 2.1 | 2.9 | 8.79 | 5.86 | 2.93 | 1.95 |
| | 150-yr | 10:15 | 7.78 | 2.00 | 2.2 | 3.0 | 8.91 | 5.94 | 2.97 | 1.98 |
| | 100-yr | 20:5 | 7.35 | 2.00 | 1.8 | 2.8 | 8.42 | 5.61 | 2.81 | 1.87 |
| | 100-yr | 5:20 | 7.26 | 2.00 | 1.8 | 2.8 | 8.32 | 5.54 | 2.77 | 1.85 |
| | 100-yr | 10:10 | 7.64 | 2.00 | 2.0 | 2.9 | 8.75 | 5.83 | 2.92 | 1.94 |
| | 75-yr | 15:5 | 7.33 | 2.00 | 1.8 | 2.8 | 8.39 | 5.59 | 2.80 | 1.86 |
| | 75-yr | 5:15 | 7.26 | 2.00 | 1.8 | 2.8 | 8.32 | 5.54 | 2.77 | 1.85 |
| | 50-yr | 10:5 | 7.29 | 2.00 | 1.8 | 2.8 | 8.35 | 5.57 | 2.78 | 1.86 |
| | 50-yr | 5:10 | 7.26 | 2.00 | 1.8 | 2.8 | 8.32 | 5.54 | 2.77 | 1.85 |
| | 25-yr | 5:5 | 7.23 | 2.00 | 1.7 | 2.8 | 8.29 | 5.52 | 2.76 | 1.84 |
| Angle Class II | 200-yr | 20:10 | 8.29 | 2.00 | 2.6 | 3.2 | 9.50 | 6.33 | 3.17 | 2.11 |
| | 200-yr | 10:20 | 8.40 | 2.00 | 2.7 | 3.2 | 9.62 | 6.42 | 3.21 | 2.14 |
| | 150-yr | 15:10 | 8.25 | 1.60 | 3.2 | 3.4 | 10.18 | 6.79 | 3.39 | 2.26 |
| | 150-yr | 10:15 | 8.33 | 2.00 | 2.7 | 3.2 | 9.54 | 6.36 | 3.18 | 2.12 |
| | 100-yr | 20:5 | 7.94 | 2.00 | 2.3 | 3.0 | 9.10 | 6.07 | 3.03 | 2.02 |
| | 100-yr | 5:20 | 8.30 | 2.00 | 2.6 | 3.2 | 9.51 | 6.34 | 3.17 | 2.11 |
| | 100-yr | 10:10 | 8.19 | 2.00 | 2.5 | 3.1 | 9.39 | 6.26 | 3.13 | 2.09 |
| | 75-yr | 15:5 | 7.90 | 2.00 | 2.3 | 3.0 | 9.05 | 6.04 | 3.02 | 2.01 |
| | 75-yr | 5:15 | 8.23 | 2.00 | 2.6 | 3.1 | 9.43 | 6.28 | 3.14 | 2.09 |
| | 50-yr | 10:5 | 7.85 | 1.60 | 2.8 | 3.2 | 9.68 | 6.45 | 3.23 | 2.15 |
| | 50-yr | 5:10 | 8.09 | 2.00 | 2.4 | 3.1 | 9.27 | 6.18 | 3.09 | 2.06 |
| | 25-yr | 5:5 | 7.74 | 2.00 | 2.1 | 3.0 | 8.87 | 5.91 | 2.96 | 1.97 |
| Angle Class III | 200-yr | 20:10 | 8.94 | 2.00 | 3.3 | 3.4 | 10.24 | 6.82 | 3.41 | 2.27 |
| | 200-yr | 10:20 | 9.01 | 2.00 | 3.4 | 3.4 | 10.32 | 6.88 | 3.44 | 2.29 |
| | 150-yr | 15:10 | 8.88 | 2.00 | 3.2 | 3.4 | 10.17 | 6.78 | 3.39 | 2.26 |
| | 150-yr | 10:15 | 8.94 | 2.00 | 3.3 | 3.4 | 10.24 | 6.83 | 3.41 | 2.28 |
| | 100-yr | 20:5 | 8.59 | 2.00 | 2.9 | 3.3 | 9.84 | 6.56 | 3.28 | 2.19 |
| | 100-yr | 5:20 | 8.88 | 2.00 | 3.2 | 3.4 | 10.17 | 6.78 | 3.39 | 2.26 |
| | 100-yr | 10:10 | 8.80 | 2.00 | 3.1 | 3.4 | 10.08 | 6.72 | 3.36 | 2.24 |
| | 75-yr | 15:5 | 8.53 | 2.00 | 2.9 | 3.3 | 9.77 | 6.52 | 3.26 | 2.17 |
| | 75-yr | 5:15 | 8.81 | 2.00 | 3.1 | 3.4 | 10.09 | 6.73 | 3.36 | 2.24 |
| | 50-yr | 10:5 | 8.46 | 2.00 | 2.8 | 3.2 | 9.69 | 6.46 | 3.23 | 2.15 |
| | 50-yr | 5:10 | 8.67 | 2.00 | 3.0 | 3.3 | 9.93 | 6.62 | 3.31 | 2.21 |
| | 25-yr | 5:5 | 8.32 | 2.00 | 2.6 | 3.2 | 9.53 | 6.35 | 3.18 | 2.12 |

**Summary of Design Conditions for Return Period Events**

The preceding pages considered a variety of conditions that, when combined, translate to a given recurrance interval. The optimum design for a given recurrance interval was established to assuming a combination of the highest crest elevation and largest stone size for a given interval. These combinations are summarized

| Return Period | Crest Elev. (ft) | Total Ht. (ft) | $D_{50}$ (ft) | B (ft) | r (ft) | $Toe_W$ (ft) | $Toe_{thk}$ (ft) |
|---|---|---|---|---|---|---|---|
| 200-yr | 584.0 | 11.0 | 3.4 | 10.2 | 6.8 | 3.4 | 2.27 |
| 150-yr | 584.0 | 11.0 | 3.4 | 10.2 | 6.8 | 3.4 | 2.27 |
| 100-yr | 584.0 | 11.0 | 3.4 | 10.2 | 6.8 | 3.4 | 2.27 |
| 75-yr | 584.0 | 11.0 | 3.4 | 10.2 | 6.8 | 3.4 | 2.27 |
| 50-yr | 584.0 | 11.0 | 3.3 | 9.9 | 6.6 | 3.3 | 2.20 |
| 25-yr | 584.0 | 11.0 | 3.2 | 9.6 | 6.4 | 3.2 | 2.13 |



**Summary of the Structure Design Columns**

Column (1): Significant Wave Height at the Toe of the Breakwater, $H_s$

From "Wave Transformation" worksheet, Column (29)

Column (2): Significant Wave Height at the Toe of the Breakwater, $H_s$ converted to meters

= [Column (1)] x 0.3048

Column (3): Wave Period Associated with the Spectral Peak in Deep Water, $T_p$

From "Wave Transformation" worksheet, Column (6)

Column (4): Mean Wave Period, $T_m$

= [Column (3)] x 0.82

Column (5): Ratio of Depth to Spectral Significant Wave Height

From "Wave Transformation" worksheet, Column (30)

Column (6): Mean Deep Water Wave Length, $L_{om}$

$$L_{om} = \frac{g}{2\pi} T_m^{\ 2}$$

Column (7): Peak Deep Water Wave Length, $L_{op}$

$$L_{op} = \frac{g}{2\pi} T_p^{\ 2}$$

Column (8): Mean Deep Water Wave Steepness, $s_{om}$

$$s_{om} = \frac{H_s}{L_{om}}$$

Column (9): Peak Deep Water Wave Steepness, $s_{op}$

$$s_{op} = \frac{H_s}{L_{op}}$$

Column (10): Mean Deep Water Wave Steepness, $s_m$ (Using untruncated wave height)

$$s_m = \frac{H_{s-des}}{L_{om}}$$

Column (11): tan α

Tangent of the angle of the structure

Column (12): Surf Similarity Parameter (Based on Peak Deep Water Wave Steepness), $\xi_{op}$

$$\xi_{op} = \frac{\tan\theta}{\sqrt{s_{op}}}$$

Column (13): Surface Roughness Recution Factor, $\gamma_r$

From Table VI-5-3, 2 or more layers of rock, $\gamma_r = 0.50$

Column (14): Berm Influence Factor, $\gamma_b$

From Equations VI-5-8 and VI-5-9. Assumed to equal 1 (i.e. no berm)

Column (15): Influence of Shallow Water on Runup, $\gamma_h$

$$\gamma_h = \frac{H_{2\%}}{1.4H_s}$$

Column (16): Influence of Angle of Attack on Runup, $\gamma_\beta$

| | | | |
|---|---|---|---|
| | $\gamma_\beta = 1.0$ | for | $0° \le \beta \le 10°$ |
| Long-crest ed waves | $\gamma_\beta = \cos(\beta - 10°)$ | for | $10° \le \beta \le 63°$ |
| | $\gamma_\beta = 0.6$ | for | $\beta > 63°$ |
| Short-crested waves | $\gamma_\beta = 1 - 0.0022\beta$ | | |

Column (17): Wave Runup on the Structure, $R_c$

Value is found using Excel's SOLVER such that the overtopping rate is equivalent to that of maximum observed overtopping rate (based on the same overtopping formulation) at the Forest Park breakwater system in Lake Forest, Illinois

Column (18): Wave Runup on the Structure, $R_c$ converted to meters

= [Column (17)] x 0.3048

Column (19): Overtopping Rate, q (Based on Formula by van der Meer and Janssen, 1995)

Since $\xi_{op} > 2$ for all conditions considered,

$$\frac{q}{\sqrt{gH_s^3}} = 0.2\exp\left(-2.6\frac{R_c}{H_s}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta}\right) \qquad \text{Eqn. VI-5-25}$$

Column (20): Critical Value, Surf Similarity Parameter, $\xi_{mc}$

$$\xi_{mc} = \left[6.2P_b^{0.31}\sqrt{\tan\theta}\right]^{\frac{1}{(P_b+0.5)}}$$

Column (21): Surf Similarity Parameter, $\xi_m$

$$\xi_m = \frac{\tan\theta}{\sqrt{s_m}}$$

Column (22): van der Meer Formulation for Stone Sizing (Plunging Breakers)

$$= 6.2P_b^{0.18}\left(\frac{S_a}{\sqrt{N_w}}\right)^{0.2}\xi^{-0.5}$$

Column (23): van der Meer Formulation for Stone Sizing (Surging Breakers)

$$= 1.0P_b^{-0.13}\left(\frac{S_a}{\sqrt{N_w}}\right)^{0.2}\xi_m^{P_b}\sqrt{\cot\theta}$$

Column (24): Significant Wave Height within Surf Zone, NO TRUNCATION, $H_{s\text{-}des}$

From "Wave Transformation" worksheet, Column (27)

Column (25): Armor Stone Diameter, $D_a$

$$D_a = \frac{H_{s-des}}{\Delta[Column(22) \cdot or \cdot Column(23)]}$$

Column (26): Armor Stone Diameter, $D_a$ converted to feet

= [Column (25)] x 0.3048

Column (27): van der Meer Reduction Factor Coefficient, $R_p$*

$$R_p^* = \left(\frac{R_c}{H_{s-des}}\right)\left(\frac{s_{op}}{2\pi}\right)^{0.5}$$

Column (28): van der Meer Reduction Factor, r

$$r = \left[1.25 - 4.8R_p^*\right]^{-1}$$

Column (29): Armor Stone Diameter with Reduction Factor, $D_a'$

$D_a' = r \cdot D_a$

Column (30): Armor Stone Diameter with Reduction Factor, $D_a'$ converted to feet

= [Column (29)] x 0.3048

Column (31): Crest Width, B

$B = 3 \cdot D_a$

Column (32): Primary Armor Thickness, r

$r = 2 \cdot D_a$

Column (33): Stone Toe Bench Width, $Toe_w$

$$Toe_w = \frac{r}{2}$$

Column (34): Stone Toe Bench Thickness, $Toe_{thk}$

$$Toe_{thk} = \frac{2}{3} Toe_w$$

## Revetment Sizing

### Design Event

Use 20yr. HW & 10yr. wave

At the shoreline, $H_s = 0.5M \sim 1.64 ft$

Use safety factor of 1.5 → $H_{s,d} = 2.5 ft$

### Stone Sizing

$$W_{50} = \frac{\gamma_s H_d^3}{K_D\left(\frac{\gamma_s}{\gamma_w}-1\right)^3 \cot\theta} = \frac{(165\,lb/ft^3)(2.5ft)^3}{2.1\left[\frac{165\,lb/ft^3}{62.4\,lb/ft^3}-1\right]^3(1)} = 276\,lb$$

$$D_{50} = \left(\frac{276\,lb}{165\,lb/ft^3}\right)^{1/3} = 1.2\,ft.$$

### Wave Overstopping

Target $q = 0.05$ (no damage condition)

$$S_{op} = \frac{2\pi H_s}{g(T_p^2)} = \frac{2\pi(2.5ft)}{(32.2\frac{ft}{s^2})(12.2s)^2} = 0.0033$$

$$\varepsilon_{op} = \frac{\tan\alpha}{\sqrt{S_{op}}} = \frac{1}{\sqrt{0.0033}} = 17.41$$

$$\gamma_r \gamma_b \gamma_h \gamma_\beta = 0.5$$

$$\frac{q}{\sqrt{gH_s^3}} = a\exp\left(-b\frac{R_c}{H_s}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta}\right)$$

$$\frac{0.05}{\sqrt{(32.2\frac{ft}{s^2})(2.5ft)^3}} = 0.013\exp\left(-2.6\frac{R_c}{(2.5ft)}\frac{1}{0.5}\right)$$

$$0.1715 = \exp(-0.5R_c)$$

$$R_c = 3.53\,ft$$

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|---|---|---|---|---|---|
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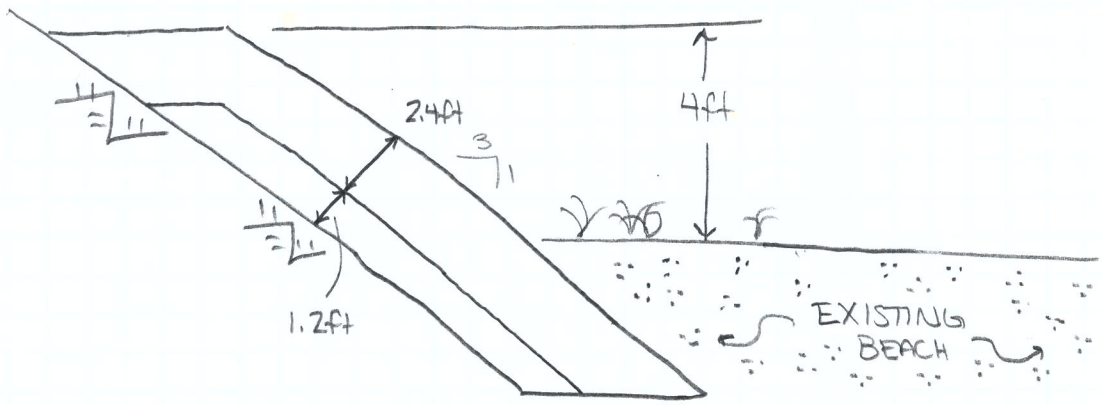
## Typical Profile




Armor Layer:

$D_{50} = 1.2\,ft$

$W_{50} = (1.2\,ft)^3(165\,lb/ft^3) = 285^{\#}$

Underlayment

$\frac{W_{50}}{10} = \frac{285^{\#}}{10} \sim 29^{\#}$

$D_{50} = \left(\frac{29^{\#}}{165\,lb/ft^3}\right)^{1/3} = 0.6\,ft$

* Use $H_D$ as estimated scour depth $\rightarrow d_s = 2.5\,ft$

Total height of structure = 6.5ft.

# Appendix L.

## PLAN FORMULATION MEASURES DESIGN CALCULATION SHEETS

McCormick/Janes Ravine
MacArthur Ravine
Scotts/Hutchinson Ravine
Bartlett Ravine
Van Horne Ravine
Schenck Ravine

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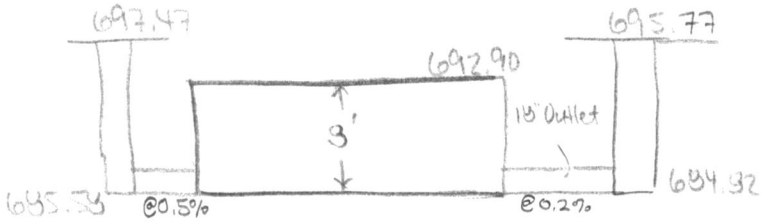
## Option #1: In-Ravine Pipe

* Must provide storage to alleviate flooding at the head of the southern leg of the southern tributary.

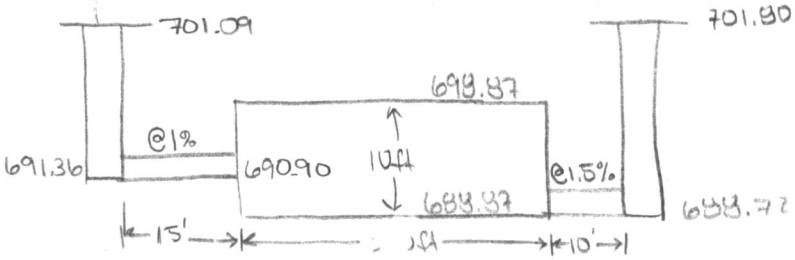
### Storage Leg P7/P8




* For 100-year event, only 63% of storage used, it should be adequate
* Use (3) 8'×10' - 400ft box culvert.

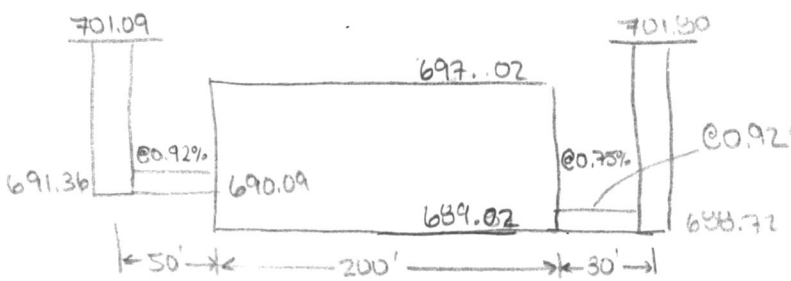
### Storage Along Leg P14 + P13

- Box at P7/P8 causes charging of the lines, need supplementary storage




* Use (2) 8'×10' - 570ft box culvert.

### Storage Along Leg P12




* Use (2) 8'×10' - 200' box culverts
* Use 6" outlet connected to existing 10" line
* @0.92% → 100-year 24-hour used 60% volume

## Treatment at Outlet of Pipe

* Terminate pipe prior to confluence of Janes & McCormick Ravine, ~ 375ft U/S of the mouth.

$Q_{max} = 78.5$ cfs $\quad Q_d = 1.2Q = 94.2$ cfs
$V_{max} = 7.12$ ft/s $\quad V_d = 1.2V = 8.54$ ft/s
$t = 120$ min (75-79 cfs)
$D = 4.5$ ft. $\quad \frac{d}{D} = 0.58 \rightarrow \frac{R_h}{D} = 0.2728 \rightarrow R_h = 1.228$ ft.
$d_{max} = 2.6$ ft.

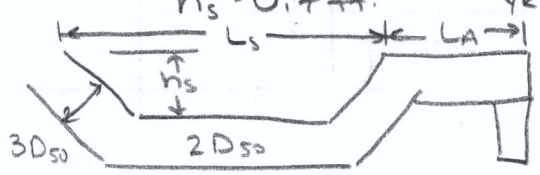
From HEC-14, Scour Hole Dimension Estimation
$h_s = 4.7$ ft $\quad L_s = 40.2$ ft
$W = 18.9$ ft $\quad L_{max} = 16.1$ ft.

From HEC-14, Eqn. 10.1 & 10.3

$$\frac{h_s}{Y_e} = 0.86\left(\frac{D_{50}}{Y_e}\right)^{-0.55}\left(\frac{V_0}{\sqrt{gY_e}}\right) - C_0$$

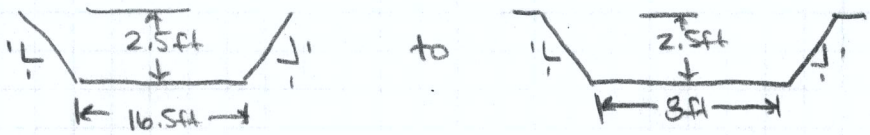
where $h_s = 4.7$ ft $\quad g = 32.2$ ft/s$^2$
$Y_e = 2.6$ ft $\quad C_0 = 2.08$
$V_0 = 8.54$ ft/s

Use $D_{50} = 0.25$ ft $\quad \frac{D_{50}}{Y_e} = 0.10$ OK! $\quad \frac{h_s}{D_{50}} = 2.79 \geq 2$ OK!
$h_s = 0.7$ ft.




$L_s = 10h_s = 7$ ft or $3W_0 = 13.5$ ft
$L_A = 5h_s = 3.5$ or $W_0 = 4.5$ ft.
$L_B = 15h_s = 10.5$ ft or $4W_0 = 18$ ft

* Provide Channel Transition.




$d_{max} = 1.5$ ft
$V_{max} = 7$ ft/s

* Calculate needed Stone Size in Channel

$$K_1 = \sqrt{1 - \frac{\sin^2 45}{\sin^2 40}} = 0.62$$

$$D_{30} = (2)(0.375)(1.0)(1.0)(1.5)\left[(0.78)\left(\frac{7\text{ ft/s}}{\sqrt{0.62 \cdot 32.12 \cdot 1.5}}\right)\right]^{2.5}$$
$= 1.2$ ft.

Use 18" thickness for 50 feet.

* Continue 8' wide trapezoidal armored channel to outlet

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Provide Stone Riffles after Ape

* Assume that we still have plunge pool & tapes to 8' wide channel
* Estimate velocity as 8 ft/s
* Elevation drop = 589.58 - 580.88 = 8.7 ft

$S_o = \frac{8.7ft}{441.80} = 0.0196 \qquad S_f = 0.01$

$H = (0.0196 - 0.01)(441.8) = 4.28ft$

$\frac{H}{h} = \frac{4.28ft}{0.5ft} = 8.56 \rightarrow$ use (9) 6" structures spaced every 49ft.

* Estimate stone size

$V_d = 1.2V = 9.6 ft/s$

$C = (2)(0.375)(1)(1)(1.0) = 0.75$

$D_{30} = (0.75)\left[(0.78)\left(\frac{9.6ft/s}{\sqrt{(32.2\frac{ft}{s^2})(1)}}\right)\right]^{2.5} = 1.5ft.$

* Estimate Elevation at the Confluence:

$589.58 - (0.01)(217.38) - (4)(0.5) = 585.40$

Provide Stone Riffles for Janes Ravine

* 592.21 - 585.41 = 6.8 ft.
* Assume 1% slope = (217ft)(0.01) = 2.17 feet
* H = 4.63 feet
* Use 9" drop btwn structures

$\frac{H}{h} = \frac{4.63 feet}{0.75ft} = 6.2 \rightarrow$ use 6 structures

Spacing $\frac{217ft}{6} = 36ft.$

* Estimate Stone Size.

$V = 5.3\frac{ft}{s} \quad V_d = 1.2V = 6.4 ft/s$

$C = 1.125$

$D_{30} = 1.125\left[(0.78)(0.95)\right]^{2.5} = 0.53ft.$

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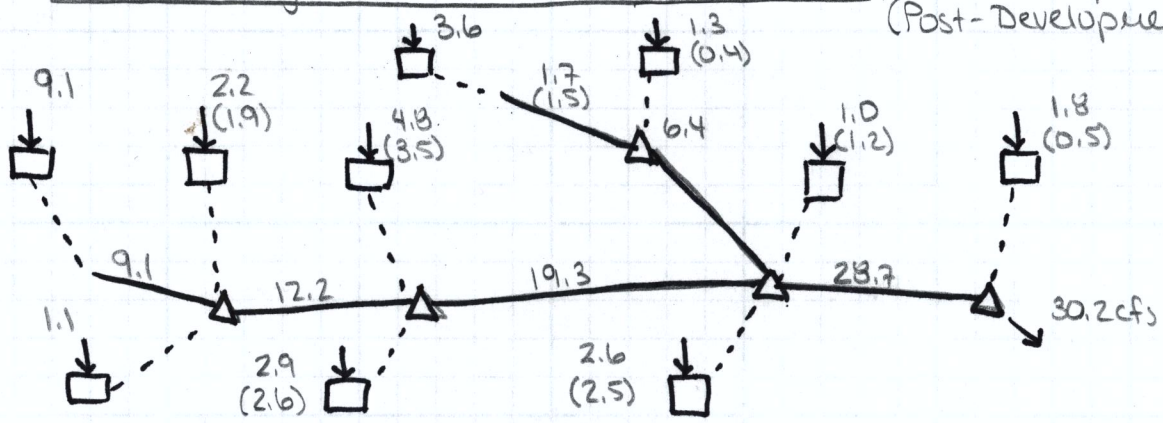
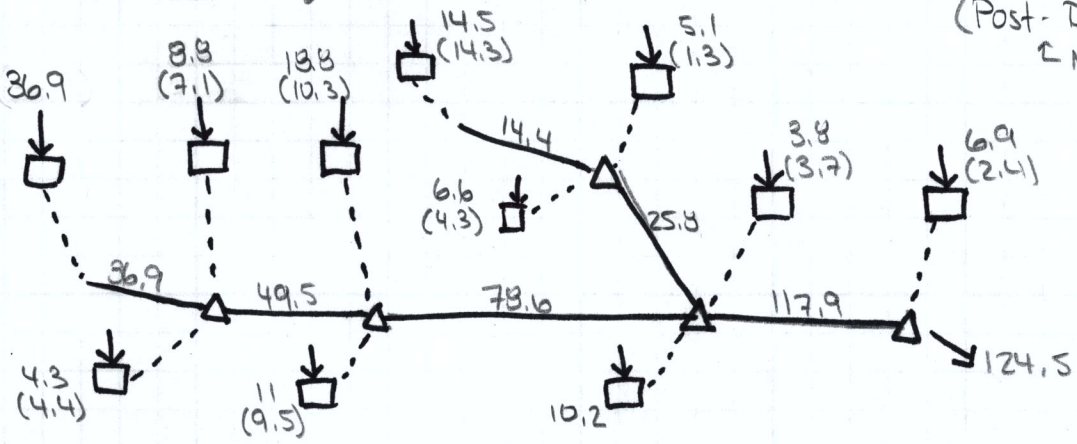
## Option #2: Attenuation & Ravine Reinforcement

### Peak Discharges from HMS Model (2-yr. 12-hr) Pre-Development (Post-Development)



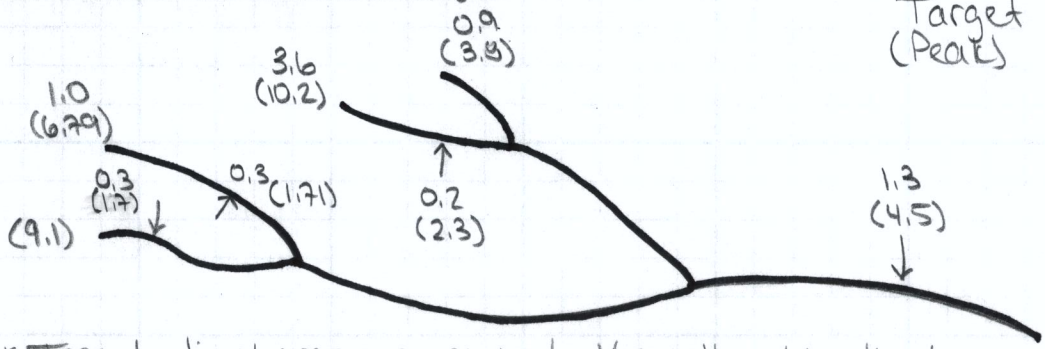

### Peak Discharges from HMS Model (100-yr. 24-hr.) Pre-Development (Post-Development)

← No Sewer Flow




### Allowable Peak Discharges

Target (Peak)




← Target discharges represent the allowable discharges from the storm sewer systems. They are the difference between existing subbasin discharge and pre-developed condition. Where multiple storm sewers are involved, the ratios of drainage areas are used to distribute flow quantities.

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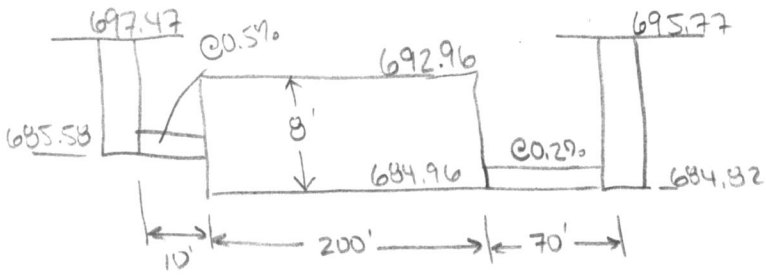
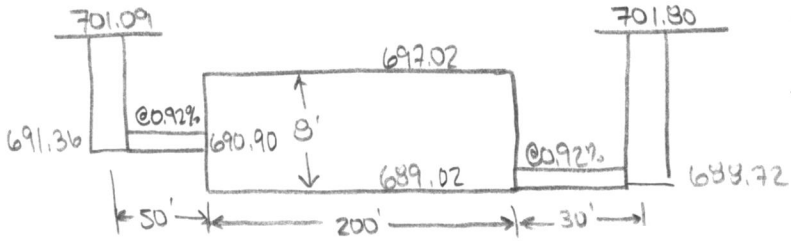
## Head - South Leg of South Trib

### Storage Along Leg P7/P8 (HsLsT-1)

* Box culverts (3) 8'x10' - 200' & 4" outlet (no O.F.)

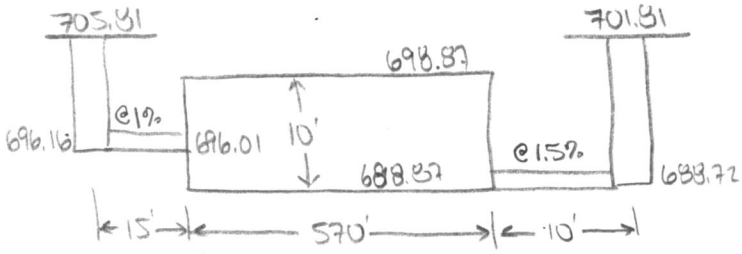



### Storage Along Leg P12 (HsLsT-2)



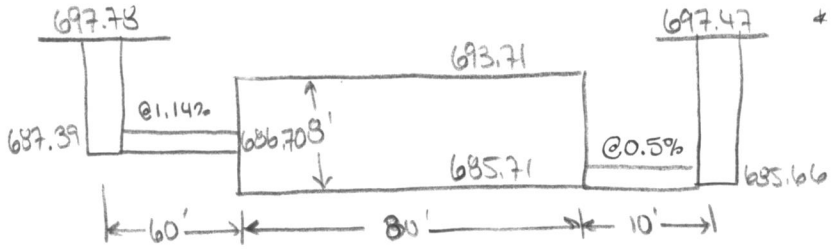

* Use (3) 8'x10' box culverts
* Use 6" outlet connected to existing 10" line (no OF)
* Covers over the san. sewer

### Storage Along Leg P13 & P14 (HsLsT-3)




* Use (3) 8'x10' box culverts
* Use 6" outlet connected to existing 10" line (no OF)

### Storage Along Leg P3/P4 (HsLsT-4)




* Use (1) 8'x10' box culverts
* Use 8" outlet (No OF)

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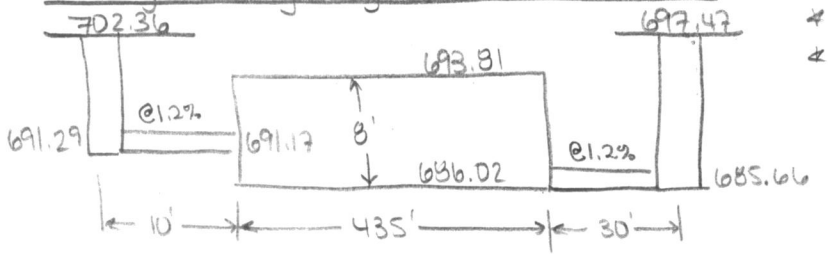
| | STRUCTURE TITLE: McCormick Ravine | CHECKED BY: | DATE: | CONTRACT NO: |

## Storage Along Leg P5/P6 (HsLST-5)

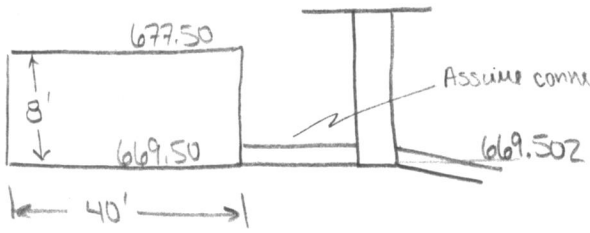



* Use (2) 8'×10' box culverts
* Use 10" outlet (no OF)

$Q_{max}$ = 13 cfs for 3 hrs } 100-year 24-hr.
$V_{max}$ = 7.1 ft/s

$Q_{max}$ = 5 cfs for 1.5 hrs } 2-year 12-hr.
$V_{max}$ = 5.7 ft/s

## Subbasin - South Leg of South Tributary




* Use (1) 8'×10'-40' box culverts
* Use 4" outlet

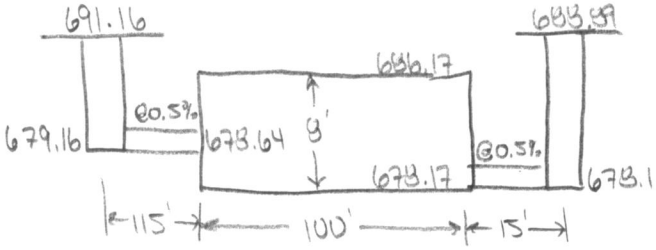
Assume connection extremely short; slope negligible.

$Q_{max}$ = 1.1 cfs for 3 hrs } 100-year 24 hr.
$V_{max}$ = 9.9 ft/s

$Q_{max}$ = 0.51 cfs for 1.5 hrs } 2 yr 12-hr.
$V_{max}$ = 8.11 ft/s

## Head - North Leg of South Tributary

### Storage Along West Leg P7 (HnLST)




* Use (2) 8'×10'-100' box culverts

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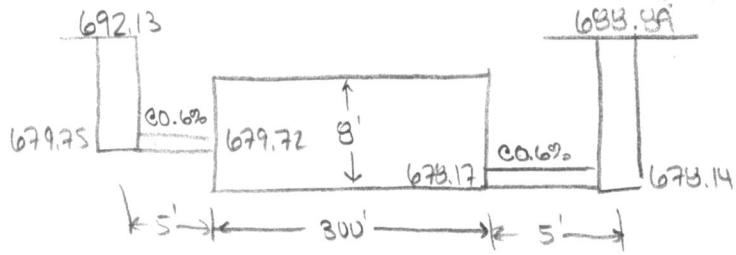
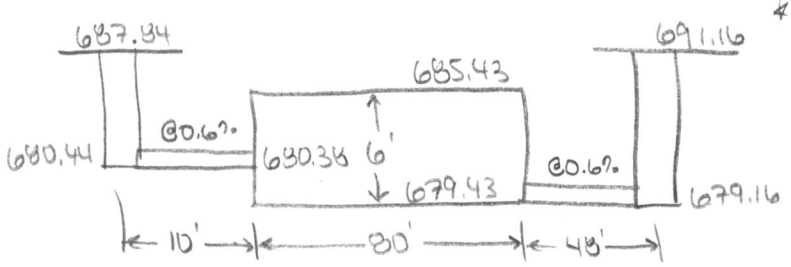
## Storage Along East Leg P2 - HnLsT




* Use (2) 8'×10' - 300' box culverts

## Storage Along West Leg P6 - HnLsT

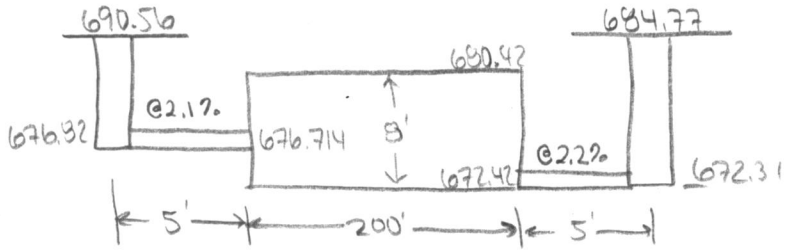



* Use (1) 6'×8' - 80' box culverts

$Q_{MAX}$ = 3.2 cfs, $V_{MAX}$ = 3.3 ft/s } 100yr. 24hr.

$Q_{MAX}$ = 1.8 cfs for 2.5hrs, $V_{MAX}$ = 2.8 ft/s } 2yr 12hr.

## Subbasin - North Leg of South Tributary



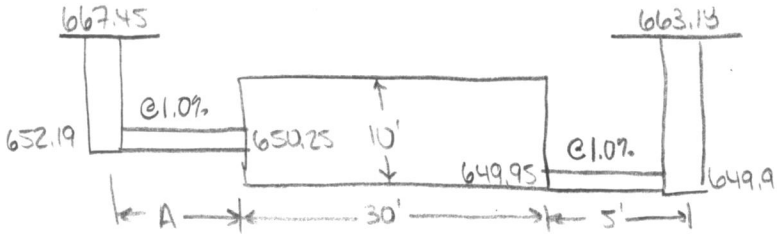

* Use (2) 8'×10' - 200' box culverts
* Install 6" reducer in structure on slope.

$Q_{MAX}$ = 1.80 cfs for 3 hrs, $V_{MAX}$ = 10.82 ft/s } 100yr 24hr.

$Q_{MAX}$ = 1 cfs for 1.5hrs, $V_{MAX}$ = 8.9 ft/s } 2yr 12hr.

## Subbasin - South Leg of North Tributary

### Storage Along West Leg




* Use (2) 8'×10' box culverts 30' long
* Install second structure on other side of tree along A

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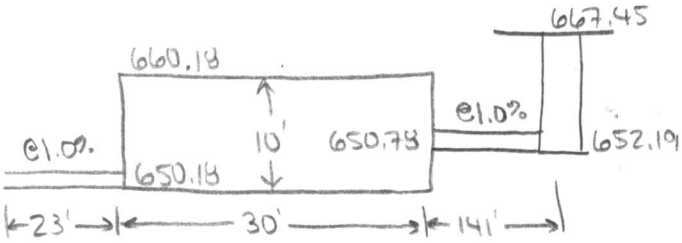



* Use 4" outflow w/ 6" overflow set 7' above base
* Install 4" reducer in structure on slope

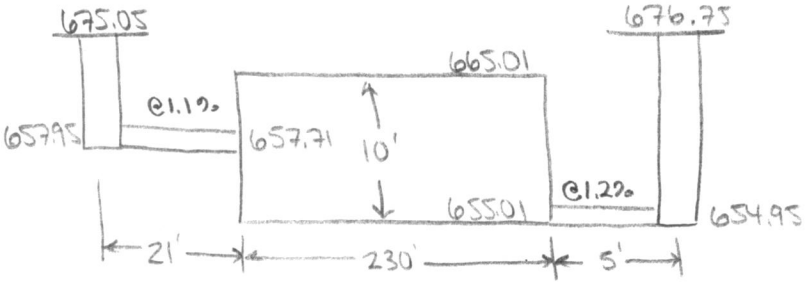
$Q_{max}$ = 2.71 cfs for 2.5hrs. } 100yr 24hr.
$V_{max}$ = 16.4 ft/s

$Q_{max}$ = 1.0cfs for 1.5hrs } 2yr 12hr.
$V_{max}$ = 12.2 ft/s

## Head - South Leg of North Tributary

### Storage Along P6 - HsLnT

* Use (5) 3'×10' - 230' box culverts

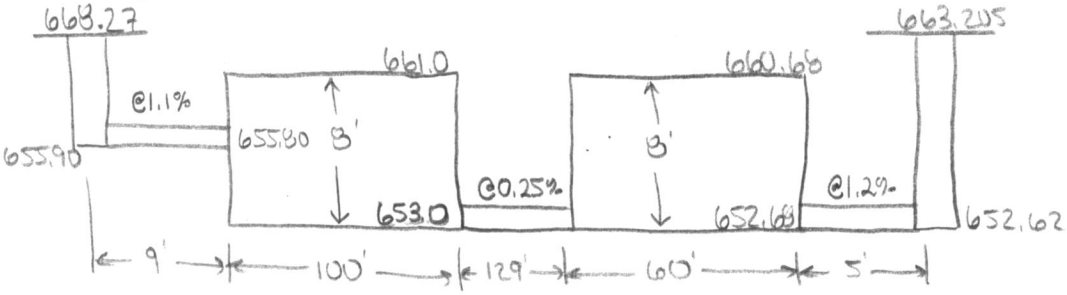



$Q_{max}$ = 8.61 cfs for t = 3.5hrs } 100yr. 24hr.
$V_{max}$ = 7.08 ft/s

$Q_{max}$ = 3.6cfs for 2hr. } 2yr. 12hr.
$V_{max}$ = 5.9 ft/s

## Head - North Leg of North Tributary

### Storage in P2 - HnLnT




* Use (4) 8'×10' box culvests

$Q_{max}$ = 2.5 cfs for 3hrs. } 100yr 24hr.
$V_{max}$ = 6.22 ft/s

$Q_{max}$ = 1.2cfs for 3hrs } 2yr 12hr.
$V_{max}$ = 5.2 ft/s

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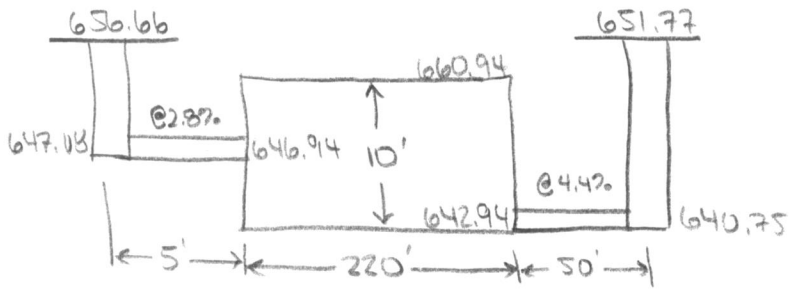
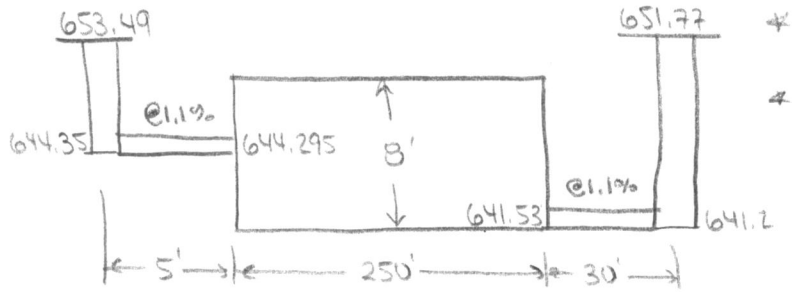
## Near Head

### Storage in Leg P12

* Use (2) 8'×10'-220' box culverts.

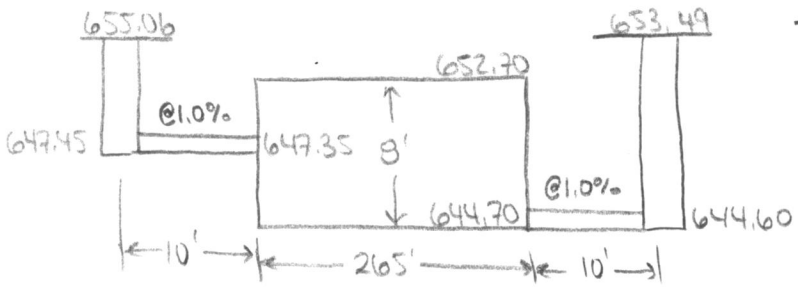



### Storage in Leg P7 - Near Head




* Use (2) 8'×8'-250' box culverts
* Would need to be installed over the san sewer

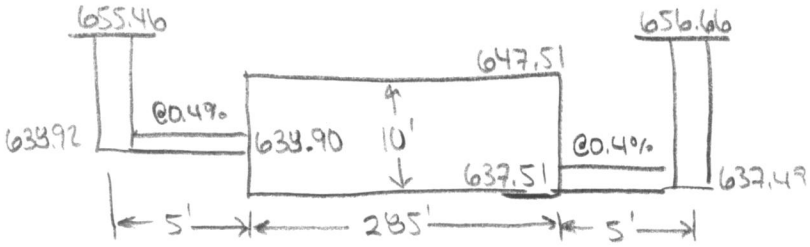
### Storage in Leg P6 - Near Head




* Use (2) 8'×8'-265' box culverts

### Storage in P15 - Near Head

* Use (2) 8'×10'-285' box culverts




$Q_{max}$ = 3.4 cfs for 2.5 hr. } 100 yr - 24 hr.
$V_{max}$ = 17 ft/s

$Q_{max}$ = 1.7 cfs for 1.5 hr. } 2 yr. 12 hr.
$V_{max}$ = 14 ft/s

## South Leg of South Tributary

### Riprap Apron at Mouth:

* Based on Velocity:

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{2.65-1}\left[\frac{7.1\,ft^2/s^2}{2\cdot 32.2\,ft/s^2}\right] = 0.32\,ft$$

* Based on Flow:

$$D_{50} = 0.02D\left(\frac{Q}{D^{2.5}}\right)\left(\frac{D}{TW}\right) = 0.02(1.5ft)\left[\frac{13\,cfs}{1.5ft^{2.5}}\right]\left(\frac{1}{0.4}\right) = 0.6\,ft.$$

* Existing apron should be adequate.

### Riffle Spacing

* Used to raise channel invert
* Place (2) riffles spaced every 150 ft., 12" high
* Set first at outfall of SLST subbasin
* width ~ 5 to 10 ft
* Estimate stone size:

$$V_d = 1.6V = 1.6(3.5\,ft/s) = 5.6\,ft/s$$

$$D_{30} = 0.6\left[(0.78)\left(\frac{5.6}{\sqrt{32.2\cdot 0.1}}\right)\right]^{2.5} = 0.3\,ft$$

### Plunge Pool at Mouth of SSLST

$Q_{max} = 1.1\,cfs$ for 180 min

From HEC-14, Eqn. 10.1 & 10.3

$$\frac{h_s}{Y_e} = 0.86\left(\frac{D_{50}}{Y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gY_e}}\right) - C_o$$

Step 1) Compute culvert outlet velocity, $V_o$ & $Y_o$

Step 2) Select riprap size $D_{50}$ & $h_s/Y_e$

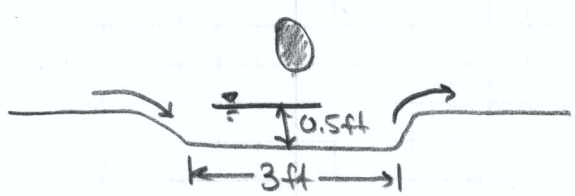
→ Verify $\frac{h_s}{D_{50}} \geq 2$ & $\frac{D_{50}}{Y_e} \geq 0.1$

Step 3) Determine $L_s = 10h_s$

$L_B = 15h_s$

$W_B$

* Use depth = 0.5 ft
  width = 3 ft.
  Length = 6.7 ft
  $D_{50}$ = 0.3 ft



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## Riffle Spacing

For 4000 to 4236 & 4236 to 4506, need to raise invert 1.5 feet

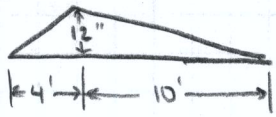
→ Add riffles at 4131 & 4346

→ Height = 1.5 ft.

$V_d = 1.6V = 1.6(5.0\,\frac{ft}{s}) = 8\,\frac{ft}{s}$

$$D_{30} = 0.6\left[(0.78)\left(\frac{8.0\,\frac{ft}{s}}{\sqrt{32.2\,ft/s^2}}\right)\right]^{2.5} = 0.8\,ft.$$

* Excavate backfilled dump in ravine
* Place grade control riffle at 4506




Use $D_{30} = 0.8\,ft.$

For 3915 to 2938

$$S_o = \frac{647.68 - 630.02}{898.37 - 111.85} = 0.0225 \qquad S_f = 0.01$$

$H = (0.0225 - 0.01)(1058.97\,ft) \approx 14\,ft$

Use (14) 12" riffles spaced every 75 feet using $D_{50} = 0.8\,ft$ stone.

## North Leg of South Tributary

### Plunge Pool at Mouth

Q = 8.6 cfs for t = 3.5 hrs.

Use same method as before,

depth = 0.5 ft

width = 5 ft.

$D_{50} = 0.5\,ft$

$L_a = 2.5\,ft$

$L_s = 5\,ft.$

### Riffles

* XS 1688 to 1259

$$S_{target} = \frac{6666.26 - 6665.38}{1326.54 - 1256.54} = 0.013 \qquad S_o = 0.03$$

$H = (0.03 - 0.013)(181.5) = 3.25\,ft.$

Use 4 structures dropping 10" per riffle.

$D_{30} = 0.3\,ft$

Space every 45 feet

* XS1259 to 643

$S_f = 0.02$ $\quad H = (0.037 - 0.02)(548.8\,ft) = 9.33\,ft$

$S_o = 0.037$

Use (10) 12" riffles spaced every 55 feet

Use $D_{30} = 0.5$ ft.

## Mid-Reach Outfall

* Armor the base of the outfall structure; need to reinforce the existing headwall structure

$S_o = 0.23$

$q = \frac{2.71\,cfs}{3.5\,ft} = 0.78\,\frac{cfs}{ft}$

$$D_{30} = \frac{1.95\,(0.23)^{0.555}\,(0.78)^{2/3}}{(32.2\,ft/s^2)^{1/3}} = 0.3\,ft.$$

* Assume thickness = 0.6 ft
* Extend riprap to the toe of the riffle & up several feet of the opposite side.

## End of South Tributary

$\Sigma Q = 56.6$ cfs

### Riffles

$S_f = 0.005$

$S_o = 0.013$

$H = (0.013 - 0.005)(1440.8) = 11.53$ ft.

Use (12) 12" structures spaced every 120 feet.

$d = 1.5\,f \quad V_d = 1.6V = 1.6(6\,ft/s) = 9.6\,ft/s$

$C = (2)(0.375)(1.5\,ft) = 1.125$

$$D_{30} = 1.125\left[(0.78)\left(\frac{9.6\,ft/s}{\sqrt{32.2 \cdot 1.5}}\right)\right]^{2.5} = 1.4\,ft$$

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## South Leg of North Tributary

### Plunge Pool at the Head

Q = 8.6 cfs for 3.5 hrs.

From HEC-14, Eqn. 10.1 & 10.3

① $V_o = 7.1$ ft/s  $y_o = 0.82$ ft.

② $D_{50\,min} = 0.25$ ft.

$\frac{D_{50}}{y_e} = 0.305$ OK!  $\frac{h_s}{D_{50}} = 4$ OK!

③ $h_s = 1.0$ ft.

$L_s = 1$ ft

$L_B = 1.5$ ft.

* Use depth = 0.5 ft

width = 5 ft.

Length = 4 ft.

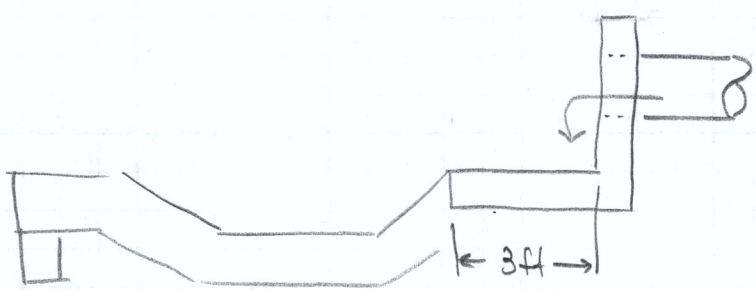
$D_{50} \approx 0.5$ ft.

$L_a = 5h_s = 5$ ft.

$W_o = 2.75$ ft.

$$D_{50} = \frac{0.692}{2.65-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{1.65}\left(\frac{7.1\,\frac{ft}{s}^2}{2 \cdot 32.2\,\frac{ft}{s^2}}\right) = 0.33$$

* Pour new headwall & apron




### Riffles

XS 1665 to 879

$S_f = \frac{621.61 - 619.46}{66.29} = 0.0324 \Rightarrow$ Use $S_f = 0.02$

$S_o = 0.0455$

$H = (0.0455 - 0.02)(920.7 - 134.75) = 20.04$ ft

Use 18" drops $\rightarrow \frac{20\text{ft}}{1.5\text{ft}} \Rightarrow$ use 14 structures

Spacing $= \frac{920.7 - 134.8}{14} = 56$ ft

* Assume $D_{30} = 0.5$ ft.

## Mid-Reach Outfall

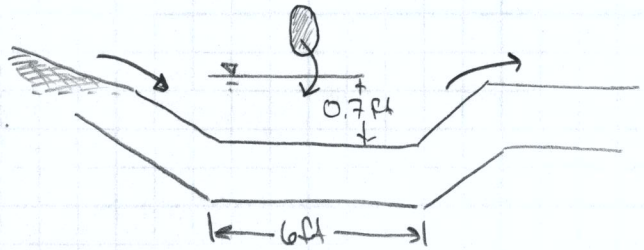
$Q = 15.81$ cfs for $t = 420$ min

From HEC-14, Eqn. 10.1 & 10.3

① $V_o = 17 \frac{ft}{s}$ $\quad Y_e = 0.22$ ft.

② $\frac{h_s}{D_{50}} = 4$ OK $\quad \frac{D_{50}}{Y_e} = 1.136$ OK

Use depth = 0.7 ft
width = 6 ft
length = 6.5 ft
$D_{50}$ = 0.25 ft.




## North Leg of North Tributary

$Q_{max} = 2.5$ cfs

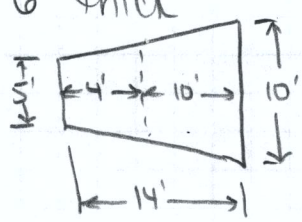
* Keep existing outfall structure
* Place riprap apron at the end

$$D_{50} = \frac{0.692}{1.65}\left(\frac{6.22^2}{2 \cdot 32.2}\right) = 0.25 \text{ ft}$$

$$D_{50} = 0.02(1.75)\left[\frac{2.5}{1.75^{2.5}}\right]^{4/3}\left(\frac{1}{0.4}\right) = 0.05 \text{ ft}$$

Use 3" stone 6" thick

* Install as 12" riffle




## Riffles

$S_o = 0.1032$

$S_f = 0.05$

$H = (0.1032 - 0.05)(360.35) = 19.2$ ft → use 18" structures (need 13 structures)

$X = \frac{360.35}{13} = 27$ feet.

$V = 4$ ft/s $\quad d = 0.5$ ft.

$D_{30} = 0.3$ ft.

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## End of North Tributary

$Q_{tot} = (15.81) + (8.7) + (4) = 28.51$ cfs

### Riffles

$S_o = 0.033$
$S_f = 0.013$

$H = (0.033 - 0.013)(653.2) = 13$ ft

Use (13) 12" riffles

$X = \frac{L}{H} = \frac{653.2 ft}{13} = 50.2$ ft

$V = 5$ ft/s  $d = 1$ ft

$D_{30} = 0.5$ ft

## Main Reach

$Q_{start} = 56.6 + 28.51 + 3.7 = 88.81$ cfs
Out-Head = 3.37 cfs
$Q_{out} = 88.81 + 3.37 - 2.4 = 94.6$ cfs

### Riffles

XS 1180 to 751

$S_o = 0.023$
$S_f = 0.0054$

$H = (0.023 - 0.0054)(1113.32 - 684.28 + 75.2) = 8.87$ ft ~ 9 ft

Use 12" riffles  $X = \frac{L}{H} = \frac{504.24 ft}{9} = 56$ ft

$V = 5 \frac{ft}{s}$  $d = 1.2$ ft

$D_{30} = 0.4$ ft

### Plunge Pool (Mid-Reach)

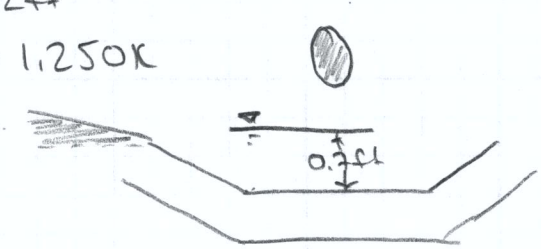
$Q = 3.32$ cfs for $t = 240$ min

From HEC-14, Eqn. 10.1 & 10.3

① $V_o = 17 \frac{ft}{s}$  $Y_e = 0.2$ ft

② $\frac{h_s}{D_{50}} = 4$ OK  $\frac{D_{50}}{Y_e} = 1.250$ OK

* Use depth = 0.7 ft.
width = 6 ft.
length = 6.5 ft.
$D_{50} = 0.4$ ft



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Riffles

XS751.73 to 269.03

$S_o = 0.0126$ $\quad H = (0.0126 - 0.0054)(751.73) = 5.41 \sim 6$

$S_f = 0.0054$

$X = \frac{L}{H} = \frac{751.73}{6} = 125.3\ ft$

Use (6) 12" riffles spaced every 125.3 ft.

$V = 5\frac{ft}{s}$ $\quad d = 1.2ft$

$D_{30} = 0.4ft$

Confluence Treatment

$\frac{4ft}{0.2} = 20ft$

$Q_{tot} = (70cfs) + (94.6\ cfs) = 164.6\ cfs$

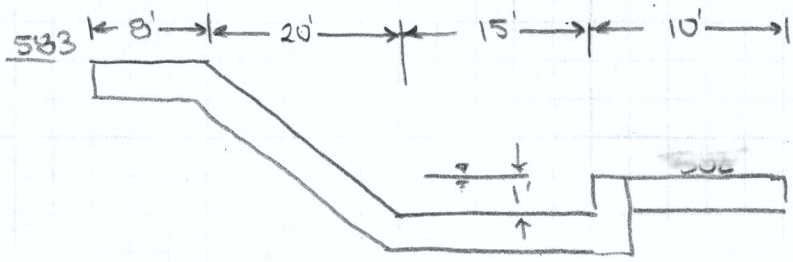
$q = \frac{164.6\ cfs}{10ft} = 16.5\ \frac{cfs}{ft}$

$q_{conc} = 1.25q = 20.7\ \frac{cfs}{ft}$

$$D_{30} = \frac{1.95\, S^{0.555}\, q^{2/3}}{g^{1/3}} = \frac{1.95\,(0.2)^{0.555}\,(20.7\ \frac{cfs}{ft})^{2/3}}{(32.2\ ft/s^2)^{1/3}} = 1.9\ ft.$$

Thickness $= 1.5D_{50} = 3ft$

Apron at Bottom → use 15' apron w/ 1' sill



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## Janes Ravine

$S_o = 0.0373$

$S_f = 0.01$

$H = (0.0373 - 0.01)(214.32) = 5.85ft \sim 6ft.$

Use (6) 12" structures

Spacing $\frac{214.32}{6} = 35.7ft.$

$D_{30} = 0.4ft.$

## Option #3: Mouth Treatment Only

* Remove the existing structures at confluence and replace with steeper armored slope.
* Reinforce approaches w/ riffles.

### Short Armored Slope

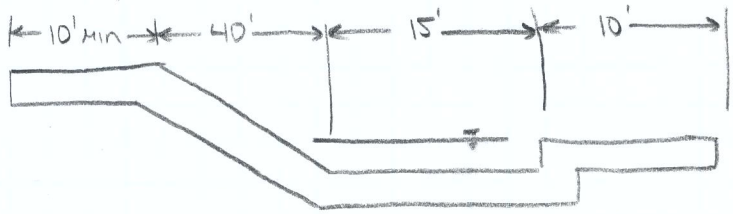
* Approximately 4ft drop (need to verify w/ field survey)
* Use 10% slope

$\frac{4ft}{0.10} = 40ft$ $\qquad Q_{tot} = 161$ cfs

$q = \frac{161 cfs}{10ft} = 16.1 \frac{ft^2}{s}$ $\qquad q_{conc} = 1.25q = 1.25(16.1 \frac{ft^2}{s}) = 20.2 \, ft^2/s$

$D_{30} = \frac{1.95 S^{0.555} q^{2/3}}{g^{1/3}} = \frac{1.95(0.10)^{0.555}(20.2 ft^2/s)^{2/3}}{(32.2 ft/s^2)^{1/3}} = 1.3 ft.$

Thickness $= 2D_{30} = 3ft.$




### McCormick - Riffles

For XS 424 to 163.9

$S_o = 0.012$

$S_f = 0.005$ $\qquad H = (0.012 - 0.005)(260ft) = 1.82ft$

Use (2) 1 ft riffle

$V = 7 \frac{ft}{s}$ $\qquad V_d = 1.6V = 1.6(7 ft/s) = 11.2 \frac{ft}{s}$

$d = 1.5ft$ $\qquad C = 2(1.0)(1.0)(0.375)(1.5) = 1.125$

$D_{30} = (1.125)\left[(0.79)\left(\frac{11.2}{\sqrt{(32.2 \cdot 1.5)}}\right)\right]^{2.5} = 1.99ft \sim 2ft$

Spacing $= \frac{260ft}{2} = 130 ft.$

For XS 163.9 to Confluence

$S_o = 0.025$ $\qquad H = (0.025 - 0.005)(97ft) = 1.94ft$

$S_f = 0.005$ $\qquad$ Use (2) 1ft riffle

Spacing $= \frac{97ft}{2} = 48.5 ft.$

$V = 7 ft/s$ $\qquad V_d = 11.2 \frac{ft}{s}$

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$d = 2ft \qquad C = (2)(0.375)(2ft) = 1.5$

$$D_{30} = (1.5)\left[(0.78)\left(\frac{11.2 ft/s}{\sqrt{32.2 \frac{ft}{s^2} \cdot 2ft}}\right)\right]^{2.5} = 1.85 ft$$

<u>Janes - Riffles</u>

- New Tributary
  - cut side slopes back ... 2:1 slope
  - install armor stone at head of cut
    - ↳ train flow to center of channel
    - ↳ provide small plunge pool at bottom

For XS 607 to Confluence

$S_o = 0.02$

$S_f = 0.006$

$H = (0.02 - 0.006)(415ft) = 5.81 ft$

$\frac{H}{h} = \frac{5.81 ft}{0.5 ft} = 11.62 \rightarrow$ Use (12) 6" structures

$\text{Spacing} = \frac{415 ft}{12} = 34.6 ft$

$V = 5.5 \frac{ft}{s} \qquad V_d = 1.6V = 1.6(5.5 ft/s) = 8.8 \frac{ft}{s}$

$C = 1.125$

$$D_{30} = (1.125)\left[(0.78)\left(\frac{8.8 ft/s}{\sqrt{32.2 \frac{ft}{s^2} \cdot 1.5 ft}}\right)\right]^{2.5} = 1.09 ft$$

$\approx 1.1 ft$

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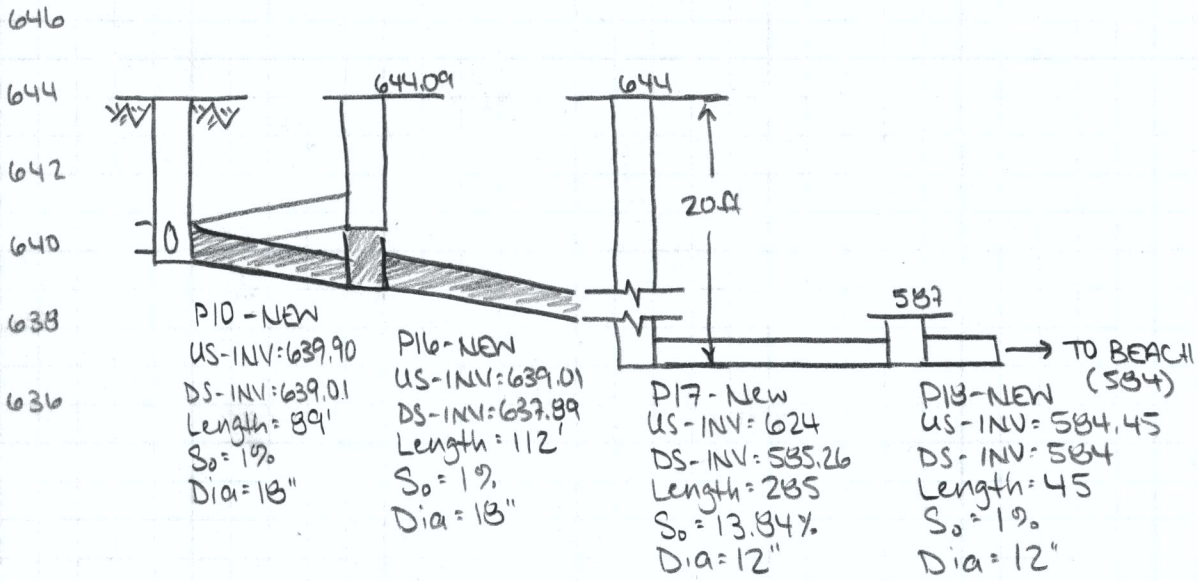
## Option #1: Intercept Sewer & Redirect

* Intercept sewer & push pipe down bluff face
  - ↳ Catch at J4
  - ↳ Replace P10 w/ 18" line (versus 12") & reverse slope
  - ↳ Drop J5 to intersect P10-NEW
  - ↳ Push pipe down bluff face




* Use J16-NEW to align pipe w/ existing ROW
* Drop 20ft at J16 to reduce pipe slope & velocity
* Push pipe to J17-NEW
  - ↳ need to avoid property line of house on beach
  - ↳ need to avoid damage to property
  - ↳ intercept pushed pipe at this structure
  - ↳ allow 1ft. difference so we don't blast the outlet pipe from the structure
* Run pipe to outlet on beach at existing riprap revetment
* Resultant Discharges:

| Ravine Outlet | Beach Outlet |
|---|---|
| $Q_{max}$ = 0.56 cfs | $Q_{max}$ = 2.95 cfs |
| $V_{max}$ = 4.4 ft/s | $V_{max}$ = 4.51 ft/s |

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Provide Stone Aprons After Outlets

Ravine Outlet

$S_o \sim \frac{2ft}{23.9ft} \sim 8.4\%$ $\quad q = \frac{0.56\ cfs}{1.5ft} = 0.373\ \frac{ft^2}{s} \Rightarrow q_c = 1.25q = 0.47\ \frac{ft^2}{s}$

$$D_{30} = \frac{1.95 S_o^{0.555} q^{2/3}}{g^{1/3}} = \frac{1.95(0.084)^{0.555}(0.47\ \frac{ft^2}{s})^{2/3}}{(32.2\ \frac{ft}{s^2})^{1/3}} = 1.2\ ft.$$

* Provide armor along first 6D of length → 9ft.

Beach Outlet

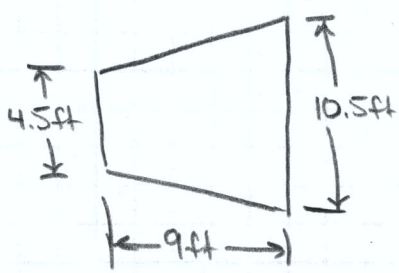
$Q_d = 1.2Q = 3.54\ cfs$

$V_d = 1.2V = 5.4\ ft/s$

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{2.65-1}\left(\frac{5.4\ \frac{ft}{s}^2}{2 \cdot 32.2\ \frac{ft}{s^2}}\right) = 1.5ft.$$

$$D_{50} = 0.02D\left(\frac{Q}{D^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right)$$

$$= 0.02(1ft)\left(\frac{3.54\ cfs}{(1ft)^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right) = 0.2ft$$



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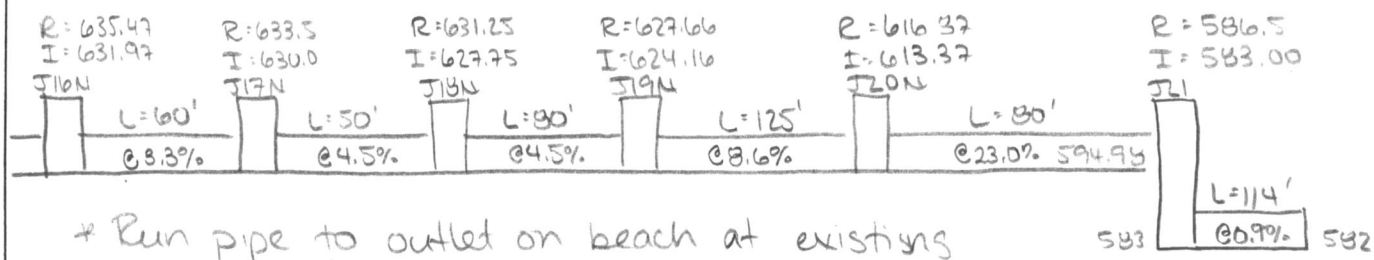
## Option #2: In-Ravine Pipe

* Replace existing outfall w/ structure & run in-ravine pipe to mouth. Install plunge pool at the outlet
  - ↳ Catch at OUT I
  - ↳ Replace w/ structure (INV = 631.97 / RIM = 633.97)
  - ↳ Replace pipes in following sequence.




* Run pipe to outlet on beach at existing riprap revetment
* Remove & replace stones to make gap
* Need to install blanket to dissipate wave energy.

### Resultant Discharge

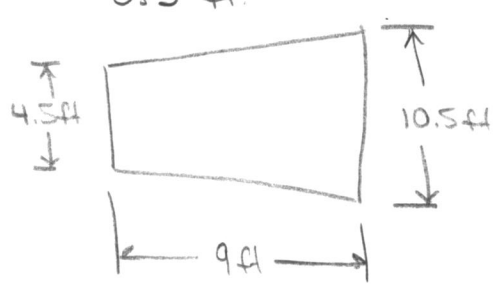
$Q = 5.2$ cfs $\quad Q_d = 6.3$ cfs

$V = 4.7$ ft/s $\quad V_d = 5.64$ ft/s

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{2.65-1}\left(\frac{5.64\,\frac{ft}{s}^2}{2\cdot 32.2\,\frac{ft}{s^2}}\right) = 0.2\text{ ft.}$$

$$D_{50} = 0.02D\left(\frac{Q}{D^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right) = 0.02\,(1.5\text{ft})\left(\frac{6.3\text{ cfs}}{1.5\text{ft}^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right)$$

$$= 0.5\text{ ft.}$$



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## Option #3: Riprap / Riffles

$Q_{max} = 5.2$ cfs

$V_{max} = 6.2$ ft/s $\qquad V_d = 1.2V = 7.4$ ft/s

$$D_{30} = (0.225)\left[(0.78)\left(\frac{7.4\,ft/s}{\sqrt{(32.2\,ft/s^2)(0.3\,ft)}}\right)\right]^{2.5} = 1.06\text{ ft}$$

$S_o \approx \frac{50'}{542} = 0.092 \qquad S_f = 0.02$ (assume)

$H = (0.092 - 0.02)(542) = 39.16$

$\frac{H}{h} = \frac{39.16}{0.5} = 78.32 \rightarrow$ need (79) 6" structures

Spacing $= \frac{542\text{ ft}}{79\text{ ft}} = 6.9$ ft.

---

If use 12" structures,

$\frac{H}{h} = \frac{39.16\text{ ft}}{1\text{ ft}} = 39.16 \rightarrow$ need (40) 12" structures

Spacing $= \frac{542\text{ ft}}{40} = 13.6$ ft.

Note:

For given configuration, the riffles will overlap!

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# Option #1: Single Wet-Bottom Detention Pond

## North Sewer Line

* Break into sewer line at PS1 near gap in trees
  ↳ Approx. invert = 647.57
  ↳ Set Rim elev = street
* Install sewer line at 1% slope until it clears the tree line
  ↳ 24" diameter
  ↳ Approx. 130 ft. long
* Route to detention storage

## East Sewer Line

* Leave alone

## South Sewer Line

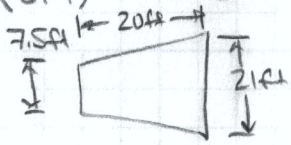
* Consider in-street storage
  ↳ Not realistic. Not enough depth to develop head necessary to only use storage space available w/in the ROW
* Consider rerouting flow through existing cul-de-sac lines
  ↳ Replace P85, P83, P84, P19
  ↳ Replace J39, J46, J47
  ↳ Push pipe down slope
  ↳ A lot of modifications for very little benefit!
→ * Consider intercepting outfall at outlet & bypass the ravine
  ↳ Add intercept structure @ 75 feet from J40
  ↳ Push pipe down bluff
  ↳ $Q_{max} = 20.63$ cfs  $Q_d = 1.2Q = 24.76$ cfs
  $V_{max} = 18.63$ cfs  $V_d = 1.2V = 22.4$ ft/s
  ↳ Size apron for Outlet

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) = \frac{0.692}{2.65-1}\left(\frac{22.4\,\frac{ft}{s}^2}{2\cdot 32.2\,\frac{ft}{s^2}}\right) = 3.3\text{ ft.}$$

$$D_{50} = 0.02D\left(\frac{Q}{D^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right) = 0.02(2.5\text{ ft})\left(\frac{24.8\text{ cfs}}{2.5^{2.5}}\right)^{4/3}\left(\frac{1}{0.4}\right)$$

$$= 0.43\text{ ft}$$

Thickness = 4.8 ft.




## Detention Pond Design

* Max depth = 6 ft.
* Allow small area for Hutchinson flow to filter into pond
* Only 65% storage-volume used in 100-year event
* Provide (2) beehive grates as overflow.
* Provide 6" primary outlet.

| Elev | Area (ft²) |
|---|---|
| 644 | 60,000 |
| 646 | 80,000 |
| 647 | 120,000 |
| 650 | 300,000 |

US INV = 642.36  $S_o \sim 1\%$
DS INV = 637.61  Dia = 30"
Length = 475 ft.

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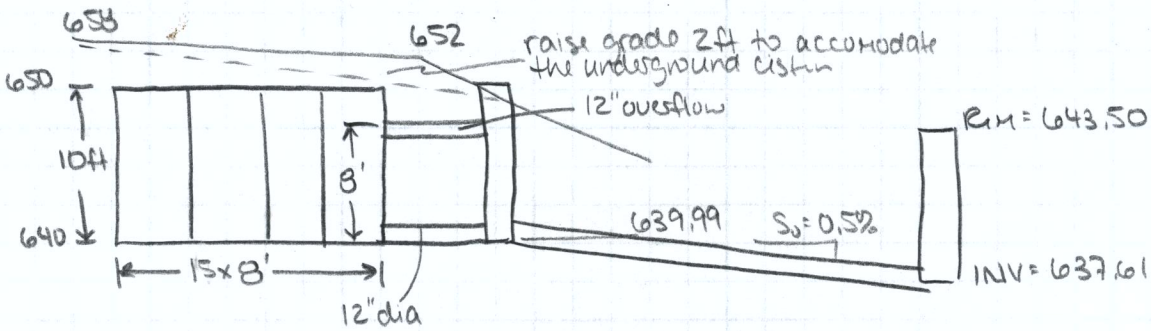
## Option #2: Underground Cistern

* Use same sewer intersection methods as suggested for Option #1

### Detention Pond Cross-Section




* Need to provide 960,000 ft³ of storage.
  → Need (15) 8'×10' box culverts 750' long
  → Uses 96% of storage for 100-year 24-hour event
  → $Q_{peak}$ = 5.9 cfs
* Can relocate based on golf course.

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## Plunge Pool at Head of Ravine

$Q_{max} = 4.63\ cfs \rightarrow Q_d = 1.2Q = 5.6\ cfs$
$t = 2\ hrs\ (4.3\text{-}4.6\ cfs)$

### Estimated Scour Hole Dimensions

$h = 2.1\ ft$
$W = 6.67\ ft$
$L = 8.15\ ft$
$L_{max} = 3.3\ ft$

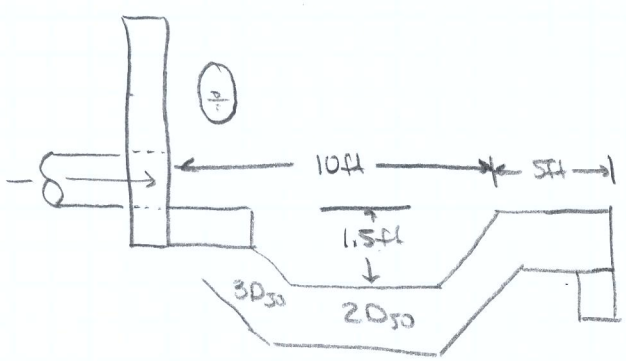
### Estimate $D_{50}$

$$\frac{h_s}{Y_e} = 0.86\left(\frac{D_{50}}{Y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gY_e}}\right) - C_o$$

Use $h_s = 1.5\ ft$, $Y_e = 0.7\ ft$, $D_{50} = 0.5\ ft$

$\frac{D_{50}}{Y_e} > 0.1$? OK! $\quad \frac{h_s}{D_{50}} \geq 2$? OK!

$L_s = 10h_s = 10\ ft$
$L_A = 5h_s = 5\ ft.$




### Check velocity at end of apron

$$\frac{Q^2}{g} = \frac{A_c^3}{T_c} = \frac{[Y_c(W_B + 2Y_c)]^3}{W_B + 4Y_c}$$

$$\frac{(4.63\ ft^3/s)^2}{32.2\ ft/s} = \frac{[Y_c(5ft + 2Y_c)]^3}{5ft + 4Y_c}$$

Solving for $Y_c$, $Y_c = 0.29\ ft$

$A_c = Y_c(W_B + 2Y_c) = 1.59\ ft^2$

$V = \frac{Q}{A} = \frac{4.63\ ft^3/s}{1.59\ ft^2} = 2.92\ ft/s$ okay!

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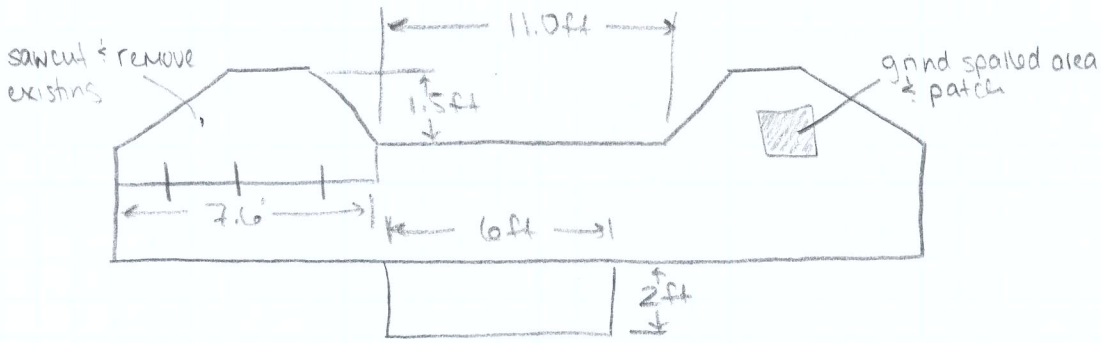
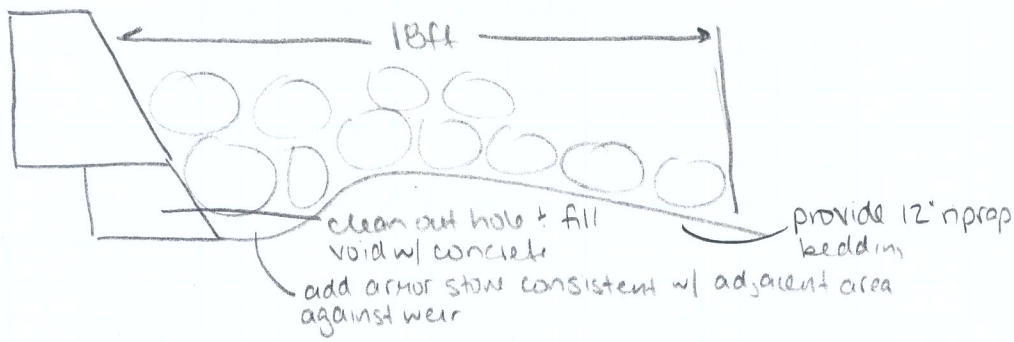
# Check Dam Modification

## If Repair




## If Remove

$$S_o = \frac{599.48 - 581.06}{223.515} = 0.0824$$ ← slope if dam removed. elevations from field survey

$$S_f = \frac{625.96 - 619.35}{762.47 - 556.01} = 0.032$$ ← slope btwn XS's in RAS w/ same Q but acceptable V

$$H = (0.0824 - 0.032)(223.52\,ft) = 11.27\,ft.$$

$$\frac{H}{h} = \frac{11.27\,ft}{1\,ft} = 11.27 \rightarrow \text{use (12) 12" structures}$$

$$\text{Spacing} = \frac{223.5\,ft}{12} = 18.6\,ft$$

Estimate stone size:

$$V_d = 1.6V = 1.6(6.3\,ft/s) = 10\,ft/s$$

$$D_{30} = (2)(0.375)(1)(1)(1.0\,ft)\left[(0.78)\left(\frac{10.0\,ft/s}{\sqrt{32.2\,ft/s^2 \cdot 1\,ft}}\right)\right]^{2.5}$$

$$= 1.7\,ft$$

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## Option #3: Detention Basin, No Rerouted Pipe

Note: Same design as Option #1, but no rerouted pipe from tributary. Need to check size for armoring of the tributary.

### If Riprap as is

* Size based on velocity

$V = 13\,ft/s \qquad V_d = 1.2V = 15.6\,ft/s$

$$D_{30} = (2)(0.375)(1)(1)(0.4\,ft)\left[(0.78)\left(\frac{15.6\,ft/s}{\sqrt{32.2\,ft/s^2 \cdot 0.4}}\right)\right]^{2.5} = 6.4\,ft$$

* Size for flow

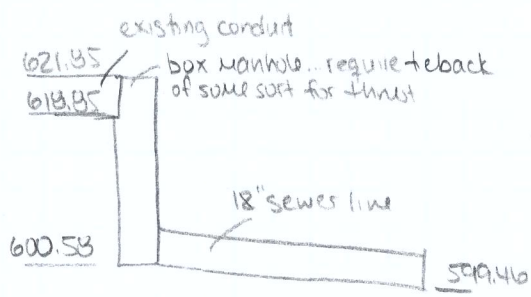
$$q = \frac{30\,cfs}{6\,ft} = 5\,\frac{ft^2}{s} \longrightarrow q_c = 1.25q = 6.25\,\frac{ft^2}{s}$$

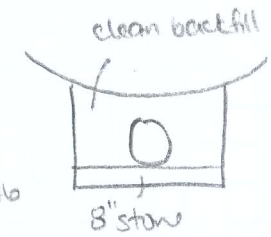
$$D_{30} = \frac{1.95\,S^{0.555}\,q^{2/3}}{g^{1/3}} = \frac{1.95(0.161)^{0.555}(6.25\,ft^2/s)^{2/3}}{(32.2\,ft/s^2)^{1/3}} = 0.754\,ft$$

* Would need to provide plunge pool at base of chute

### If Drop Tributary Bed

$Q = 23\,cfs$
$Q_d = 1.2Q = 27.6\,cfs$
$H = 618.85 - 599.48 = 19.4\,ft$
$dist = 110.134\,ft$
$S_o = 16.1\%$
$S_f = 1\%$
$H_{req} = 1.1\,ft.$




* Box structure needs to accomodate 3' diameter pipe at top
* Will it need teback to resist momentum?
* Drop to 600.58
* Run 18" dia. pipe
* Daylight pipe prior to confluence
* Provide plunge pool at outlet

$D = 1.5\,ft \qquad R_h = 0.75\,ft \qquad d_{max} = 1.5\,ft$

$A = \frac{\pi D^2}{4} = 1.77\,ft^2 \rightarrow Y_e = \left(\frac{A}{2}\right)^{1/2} = 0.94\,ft$

$h_s = 1\,ft$

$L_s = 10h_s = 10\,ft$

$L_{s,min} = 3W_o = 4.5\,ft$

$L_B = 15h_s = 15\,ft$

$L_{B,min} = 4\,ft$

$W_B = W_o + 2(L_B/3) = 1.5\,ft + 2(4/3) = 4.2\,ft$

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From HEC-14, Eqn. 10.1-10.3

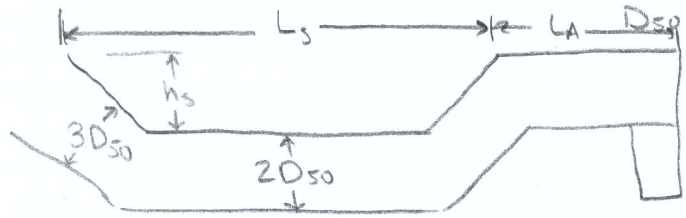
$$\frac{h_s}{Y_e} = 0.86\left(\frac{D_{50}}{Y_e}\right)^{-0.55}\left(\frac{V_0}{\sqrt{gY_e}}\right) - C_0$$

where $h_s = 1ft$, $Y_e = 0.94ft$, $V_0 = 14ft/s$, $g = 32.2 ft/s^2$, $C_0 \approx 2$

use $D_{50} = 0.5ft$, $h_s = 1.03ft$

$\frac{D_{50}}{Y_e} = 0.532 > 0.1$ OK!

$\frac{h_s}{D_{50}} = 2.06 > 2$ OK!




Check velocity at end of apron,

$$\frac{Q^2}{g} = \frac{A_c^3}{T_c} = \frac{[Y_c(W_B+2Y_c)]^3}{W_B+4Y_c} \Rightarrow \frac{(23\frac{ft^3}{s})^2}{32.2\frac{ft}{s^2}} = \frac{[Y_c(4.2ft+2Y_c)]^3}{4.2ft+4Y_c}$$

Solving for $Y_c$, $Y_c = 0.85ft$

$A_c = Y_c(W_B+2Y_c) = 5.02ft^2$

$$V = \frac{Q}{A} = \frac{23\frac{ft^3}{s}}{5.02ft^2} = 4.62\frac{ft}{s}$$

* Limited by width, so consider either routing all the way to the beach or armoring downstream channel.

## Option # 4: In-Ravine Pipe - Rerouted at Tributary

* Use proposed design provided by local sponsors for this measure.
* Tie outfall from properties to the north into in-ravine pipe.
* Terminate pipe at confluence

From HEC-14, Scour Hole Dimension, Equation 5.2

$$A = \frac{\pi D^2}{4} = \frac{\pi (3ft^2)}{4} = 7.07ft^2 \Rightarrow Y_e = \left(\frac{A}{2}\right)^{1/2} = \left(\frac{7.07ft^2}{2}\right)^{1/2} = 1.88ft$$

$h_s = 3ft \quad L = 30ft$

Estimate $D_{50}$

$$\frac{h_s}{Y_e} = 0.86\left(\frac{D_{50}}{Y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gY_e}}\right) - C_o$$

where, $h_s = 3ft$
$Y_e = 1.88ft$
$V_o = 17ft/s \quad V_d = 1.6V_o = 27\frac{ft}{s}$
$g = 32.2ft/s^2$
$C_o \approx 2$

Use $D_{50} = 1.35ft$
$h_s = 2.97ft$

$$\frac{D_{50}}{Y_e} = 0.718 > 0.1 \text{ OK!} \qquad \frac{h_s}{D_{50}} = 2.2 > 2 \text{ OK!}$$

### Riffle Design (Assuming Check Dam Removed)

$S_o = 0.0824$ (see p.5)

$$S_f = \frac{625.96 - 619.35}{762.47 - 556.01} = 0.032$$

$H = (0.0824 - 0.032)(223.52ft) = 11.27ft$

$\frac{H}{h} = \frac{11.27}{1ft} = 11.27 \rightarrow$ Use (12) 12" structures

$$\text{Spacing} = \frac{223.52ft}{12} = 18.6ft$$

Estimate stone size:

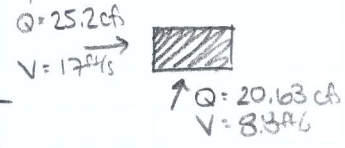
$V_d = 1.6V = 1.6(6.3ft/s) = 10ft/s$

$$D_{30} = 2(0.375)(1)(1)(1.0ft)\left[0.78\left(\frac{10ft/s}{\sqrt{32.2 \cdot 1.0}}\right)\right]^{2.5} = 1.7ft$$

$\approx 1.7ft$

## Option #5: In-Ravine Pipe - Flow Through Tributary

* Use proposed design provided by local sponsors for this measure
* Tie outfall from properties to the north to in-ravine pipe
* Terminate pipe at confluence... provide plunge pools in both reaches.




From HEC-14, Scour Hole Dimension, Equation 5.2

$$A = \frac{\pi D^2}{4} = \frac{\pi (3ft)^2}{4} = 7.07 ft^2 \Rightarrow Y_e = \left(\frac{A}{2}\right)^{1/2} = \left(\frac{7.07 ft}{2}\right)^{1/2} = 1.88 ft$$

$h_s = 3 ft$ $L = 25.6 ft$ (Main)
$h_s = 2.75 ft$ $L = 23.4 ft$ (Tributary)

$$\frac{h_s}{Y_e} = 0.86 \left(\frac{D_{50}}{Y_e}\right)^{-0.55} \left(\frac{V_o}{\sqrt{gY_e}}\right) - C_o$$

where, $h_s = 3 ft$ $Y_e = 1.88 ft$ $V_o = 17 \frac{ft}{s}$ $V_d = 1.6 V_o = 1.6(17 \frac{ft}{s}) = 27 ft/s$
$g = 32.2 \frac{ft}{s^2}$ $C_o \approx 2$

Use $D_{50} = 1.35 ft$
$h_s = 2.97 ft$

$\frac{D_{50}}{Y_e} = 0.718 > 0.1$ ✓ $\frac{h_s}{D_{50}} = 2.2 > 2$ ✓

## Downstream Riffle Design, Assumes Dam Removal

$S_o = 0.0824$
$S_f = 0.02$

$H = (0.0824 - 0.02)(223.52 ft) = 13.94 ft$

$\frac{H}{h} = \frac{13.94 ft}{1.2 ft} = 11.6 \rightarrow$ use (12) 1.2 ft structures

Spacing $= \frac{223.52 ft}{12} = 18.6 ft$

Estimate Stone Size:

$V_d = 1.6V = 1.6(5 \frac{ft}{s}) = 8.0 \frac{ft}{s}$

$$D_{30} \approx 2(0.375)(1)(1)(0.50 ft)\left[(0.78)\left(\frac{8.0 \frac{ft}{s}}{\sqrt{32.2 \frac{ft}{s^2} \cdot 0.50}}\right)\right]^{2.5} = 1.13 ft$$

$\approx 1.25 ft$

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## Option #6: Single Detention Basin - Outlet to Ravine Head

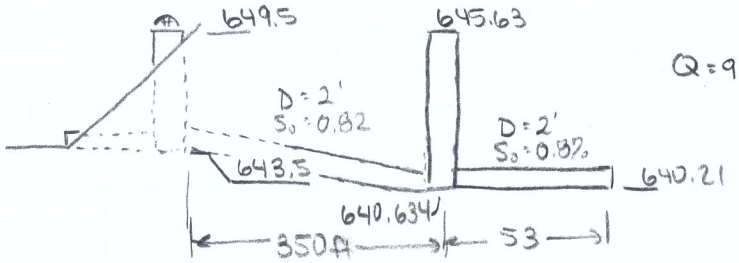
### North Sewer Line
* Use same alteration as option #1

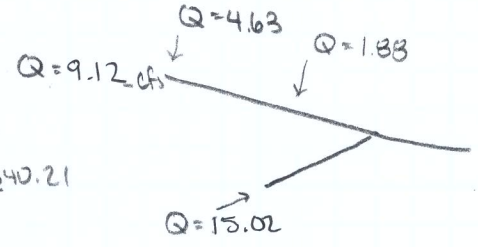
### East Sewer Line
* Leave alone

### South Sewer Line
* Use same alteration as option #1
* Assume no pushed pipe at tributary

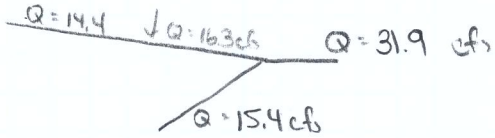
### Detention Pond Design
* Maximum depth = 6ft
* Assume Hutchinson Ravine routed to basin
* Provide two (2) beehive grates as overflow
* Provide 12" primary outlet
* Only 98% storage volume used in 100yr 24hr event

| Elev | Area ($ft^2$) |
|---|---|
| 644 | 69,000 |
| 646 | 80,000 |
| 647 | 120,000 |
| 650 | 310,000 |




Run the outflow hydrographs from SWMM into HEC-HMS model. Use peak flows from HEC-HMS as input to SWMM models.




### Plunge Pool at Head of Ravine
$Q_{max}$ = 14.4 cfs.
t = 4.5 hrs

### Estimate Scour Hole Depth
h = 2.4ft
W = 19.11 ft.
L = 30.98ft
$L_{max}$ = 12.4ft

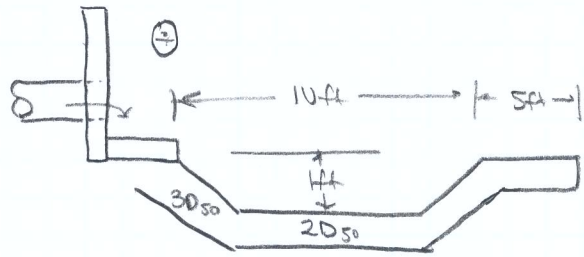
Estimate $D_{50}$

$$\frac{h_s}{Y_c} = 0.86\left(\frac{D_{50}}{Y_c}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gY_c}}\right) - C_o$$

Use $h_s = 1\,ft$, $D_{50} = 0.5\,ft$

$\frac{D_{50}}{Y_c} = 0.98 > 0.1$ Okay ✓ $\qquad \frac{h_s}{D_{50}} = 2 \geq 2$ Okay ✓

$L_S = 10h_s = 10\,ft$
$L_B = 1.5h_s = 15\,ft$
$L_A = 5h_s = 5\,ft$
use $W_B = 5\,ft$




Check velocity at end of apron

$$\frac{Q^2}{g} = \frac{A_c^3}{T_c} = \frac{[Y_c(W_B + 2Y_c)]^3}{W_B + 4Y_c}$$

$$\frac{(14.44\,cfs)^2}{(32.2\,ft/s^2)} = \frac{[Y_c(5ft + 2Y_c)]^3}{5ft + 4Y_c}$$ Solving for $Y_c$, $Y_c = 0.59\,ft$

$A_c = Y_c(W_B + 2Y_c) = 3.65\,ft^2$

$V = \frac{Q}{A} = \frac{14.4\,cfs}{3.65\,ft^2} = 3.98\,\frac{ft}{s}$

Riffles Downstream of Plunge Pool

From HEC-RAS model, use $S_f = 0.03$
$S_o \approx 0.04$

$H = (0.04 - 0.03)(650\,ft) = 6.5\,ft$

Use (13) 6" riffles spaced every 50 ft.

Estimate stone size:
$V_d = 1.6V = 1.6(4\,ft/s) = 6.4\,ft/s$

$$D_{50} = (2)(0.375)(1)(1)(0.77\,ft)\left[(0.75)\left(\frac{6.4\,ft/s}{\sqrt{(32.2\,ft/s^2)(0.77\,ft)}}\right)\right]^{2.5} = 0.6\,ft$$

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## Riffles Along Dropped Reach

* Different routing used than shown in sheet 4, so redo calculations.

$S_o = 0.083$

$S_f = 0.024$

$H = (0.083 - 0.024)(223.5\,ft) = 13.2\,ft.$

$\frac{H}{h} = \frac{13.2\,ft}{1.5\,ft} = 8.8\,ft \rightarrow$ use 9 structures 1.5 ft. high.

$\text{Spacing} = \frac{223.5\,ft}{9} = 24.8\,ft$

Estimate stone size:

$V_d = 1.6V = 1.6(4.0\,ft/s) = 6.4\,ft/s$

$$D_{30} = (2)(0.375)(1)(1)(1.2\,ft)\left[(0.78)\left(\frac{6.4\,ft/s}{\sqrt{32.2\,\frac{ft}{s^2}\cdot 1.2\,ft}}\right)\right]^{2.5}$$

$= 0.52\,ft \rightarrow$ use $D_{30} = 0.75\,ft$

As before, protect last riffle from undermining by placing check dam as toe/scour protection.