Appendix F: Design Calculations

1. Tidal Datum Evaluation
2. Percent Inundation Evaluation
3. Containment Dike Design
4. Fill Area Design
5. Borrow Area Design
6. Access Dredging Calculations
7. Earthwork Calculations

I. TIDAL DATUM EVALUATION

A. Given:

Control Station	**CRMS2041**
Location	N 29° 46’ 13.97”
	W 92° 9’ 48.3”
5-Year Epoch Used	July 17, 2008-January 17, 2014
Subordinate Station	**TV63-04**
Location	N 29° 43’ 3.6”
	W 92° 13’26”
Observation Period:	April 4, 2013-October 24, 2013 (excluding August 2013)

B. Calculations:

KNOWN VARIABLES	EQUATION	ELEV. FT, NAVD88
MHW_c= 5-Yr Mean High Water at CONTROL STATION	*Measured*	1.86
MLW_c= 5-Yr Mean Low Water at CONTROL STATION	*Measured*	1.15
MTL_c= 5-Yr Mean Tide Level at CONTROL STATION	$(MHW_c+MLW_c)/2$	1.51
Mn_c= 5-Yr Mean Tide Range at CONTROL STATION	MHW_c-MLW_c	0.71
TL_c= Mean Tide Level for the *Observation Period* at CONTROL STATION	$(HW_c+LW_c)/2$	1.78
N_C= Mean Tide Range for the *Observation Period* at CONTROL STATION	HW_c-LW_c	0.72
MHW_s= Mean High Water at SUBORDINATE STATION	*Measured*	0.94
MLW_s= Mean Low Water at SUBORDINATE STATION	*Measured*	0.75
TL_s= Mean Tide Level for the *Observation Period* at SUBORDINATE STATION	$(HW_s+LW_s)/2$	0.84
N_s= Mean Tide Range for the *Observation Period* at SUBORDINATE STATION	HW_s-LW_s	0.19

Subordinate Station Estimations

Mn_s= 5-Yr Mean Tide Range at SUBORDINATE STATION *(el. Ft. NAVD88)*

Eq. $Mn_s= (Mn_c*N_s)/N_c$

Mn_s=**0.19**

MTL_s= 5-Yr mean Tide Level at SUBORDINATE STATION *(el. ft. NAVD88)*

Eq. $MTL_s= TL_s+MTL_c-TL_c$

MTL_s=**0.57**

MHW_s= 5-Yr Mean High Water at SUBORDINATE STATION *(el. Ft. NAVD88)*

Eq. $MHW_s= MTL_s+(Mn_s/2)$

MHW_s= **0.68**

MLW_s= 5-Yr Mean Low Water at SUBORDINATE STATION *(el. Ft. NAVD88)*

Eq. $MLW_s = MTL_s - (Mn_s/2)$

MLW_s= **0.48**

REFERENCE: Tides and Datums, noaa.gov

II. PERCENT INUNDATION EVALUATION

A. Given:

-See TIDAL DATUM EVALUATION

B. Calculations:

Percent Inundated	5-Yr Inundated El. (NAVD88) at CONTROL STATION (I_c)	*Observation Period* Inundated El. (NAVD88) at CONTROL STATION (O_c)	*Observation Period* Inundated El. (NAVD88) at SUBORDINATE STATION (O_s)
10	2.48	2.61	1.39
20	2.14	2.37	1.19
30	1.89	2.16	1.07
40	1.68	1.97	0.97
50	1.48	1.75	0.87
60	1.28	1.55	0.77
65	1.18	1.43	0.68
70	1.07	1.32	0.67
80	0.83	1.08	0.5
90	0.56	0.79	0.22

***All elevations were calculated by taking the percentile (10^{th} percentile, 20^{th} percentile, etc.) of the collected water elevation data that was adjusted to NAVD88.**

I_s= 5-Yr Inundated El. (NAVD88) at SUBORDINATE STATION

Eq. $I_s = I_c + (O_s - O_c)$

Percent Inundated	5-Yr Inundated El. (NAVD88) at SUBORDINATE STATION (I_s)
10	**1.26**
20	**0.96**
30	**0.80**
40	**0.68**
50	**0.60**
60	**0.50**
65	**0.43**
70	**0.42**
80	**0.25**
90	**-0.01**

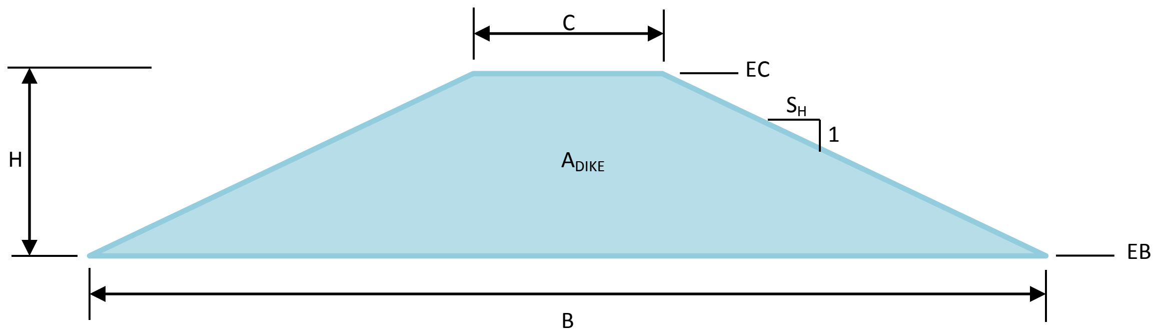
REFERENCE: Snedden and Swenson, 2012

III. CONTAINMENT DIKE DESIGN

A. Given:

1. Crown Width: 5.0 ft
2. Side Slope: 4(H):1(V)
3. Freeboard: 1.0 ft. above target marsh elevation
4. Containment Dike Crown Elevation: +3.0 ft. NAVD88 for marsh creation cells 1 &2; +3.5 ft. NAVD88 for marsh creation cell 3
5. Survey Data: XYZ points from profiles run along proposed containment dike locations

B. Methodology:



Where: H= Dike height
B= Base width
C= Crown width
EB= Base Elevation
EC= Crown Elevation
A_{A-B}= Cross-sectional area of dike between points A & B
L_{A-B}= Length between points A & B
S_H= Side Slope

1. Base Elevation: The base elevation between two points was determined by taking the average of the Z values between the two points of interest along the survey profiles.

2. Dike Height: The height of the dike is computed by subtracting the base elevation from the crown elevation (+3.0 ft. NAVD88 in MC 1 &2; +3.5 ft. NAVD88 in MC 3) as shown in the following formula:

$$H=EC-EB$$

3. Base Width: The base width is governed by the dike height, the crown width, and the horizontal component of the side slope, S_H (4.0 throughout the project area) and is computed using the following formula:

$$B= 2(S_H H)+C$$

4. Cross-Sectional Area: The cross-sectional area of each containment dike differs from site to site and is governed by the base elevation (given in the survey data), dike height, and base width at the proposed location. Once these variables are determined, the area can be calculated by treating the dike section as a trapezoid as shown in the formula below:

$$A_{DIKE}= ½ [H(C+B)]$$

5. Containment Dike Length: Calculated between each XYZ point along each profile

$$L_{A\text{-}B}= [(x_b\text{-}x_a)^2+(y_b\text{-}y_a)^2]^{1/2}$$

6. Containment Dike Volume: The volume of material required to construct each containment dike portion is computed by multiplying each dike area by its corresponding length.

$$V_{A\text{-}B}= A_{A\text{-}B}*L_{A\text{-}B}$$

Example Calculations:

Given:

Survey Points			Dike Design Parameters
Point A:	X_a= 2682419.6	Easting	Crown Width: C= 5.0 ft
	Y_a= 508690.7	Northing	Crown Elevation: EC= 4.0 ft
	Z_a= -0.21	ft. NAVD88	Side Slope: S_H= 4.0
Point B:	X_b= 2682440.2	Easting	
	Y_b= 508706.72	Northing	
	Z_b= -0.34	ft. NAVD88	

Cross-Sectional Design:

Base Elevation:	$E_{A\text{-}Bbase}$=	$(Z_B+Z_A)/2$=	0.275	ft. NAVD88
Dike Height:	H=	$EC\text{-}E_{A\text{-}Bbase}$=	4.28	ft. NAVD88
Base Width	B=	$2(S_HH)+C$=	39.24	ft
Cross-Sectional Area:	$A_{A\text{-}B}$=	½ [H(C+B)]=	94.5	ft

Volume Calculations:

Segment Length:	$L_{A\text{-}B}$=	$[(x_b\text{-}x_a)^2+(y_b\text{-}y_a)^2]^{1/2}$=	26.11	ft
Dike Volume:	$V_{A\text{-}B}$=	$(A_{A\text{-}B}*L_{A\text{-}B})/27$=	91.4	yd^3

This calculation was performed using an Excel Spreadsheet resulting in the following totals for the containment dike for each Marsh Creation cell. Containment dike lengths and volumes were also calculated in CAD and shown in the table below along with the percent error.

	Volume (CY)			Length (LF)		
	Calculated	CAD	Error (%)	Calculated	CAD	Error (%)
MC Area #1	6,666.30	7,244.00	8	5,671.94	6,099.00	7
MC Area #2	8,800.08	9,226.00	5	9,643.81	10,131.00	5
MC Area #3	57,868.28	62,614.00	8	27,635.56	25,912.00	7

IV. FILL AREA DESIGN

A. Given:

1. Cross-Sectional Survey Data of Marsh Fill Sites: XYZ data for each fill area cross section.
2. Volume Calculation Fill Elevations:
   i. +2.0 ft. NAVD88 for MC 1&2
   ii. +2.5 ft. NAVD88 for MC 3
3. Containment Dike Parameters:
   iii. Elevation= 1.0 ft. above target marsh creation elevation;
   iv. Side Slope= 4(H):1(V)
   v. Crown Width= 5.0 ft
   vi. Cut:Fill for Containment Dike Material: 1.3

B. Methodology:

1. Area Calculations: The cross-sectional area of each marsh fill transect was calculated using the XYZ data mentioned above. Due to the large number of points involved with each TV-63 cross-section, the following simplified example is used to show the method of calculating cross-sectional areas:

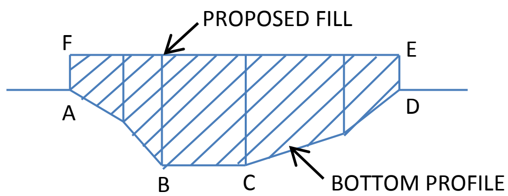


Figure 1

The area of this section can be obtained by incrementally computing the areas of each of the trapezoids ABCDEF shown in Figure 1. By treating the section as a traverse, fundamental survey methods can be utilized to calculate this area. These areas are calculated using the given data from the survey datasets with each point having a corresponding XYZ value. The incremental area calculations are carried out using the following formula:

$$A_i = \frac{1}{2} [D_i(Z_{i+1} - Z_{i-1})]$$

Where: A_i=incremental area

D_i=cumulative distance from beginning of transect to point i
Z_{i+1}=elevation of previous point
Z_{i-1}=elevation of next point

The cumulative distance is computed by continuously summing the distance between each point, which is calculated with the distance formula:

$L_i= [(X_2-X_1)^2+(Y_2-Y_1)^2+(Z_2-Z_1)^2]^{1/2}$

Where: X=easting
Y=northing
Z=elevation

And

$D_i=\sum L_i$

The total area of the cross sections can be then obtained by summing each incremental area. Because these computations are so labor intensive, a spreadsheet was used for these area calculations.

2. Distance Between Cross Sections: Before the volume of the fill sites can be calculated, the distance between cross sections must be obtained. These distances represent the plan view area that each cross section will represent and were computed from the surveyor's CAD drawing.

3. Volume Calculations: The volume calculations for each cross section are computed by taking the product of the cross-sectional area and its corresponding distance. The incremental volumes are then added together to get the total volume of the fill site. This is accomplished using the simple formulas shown below:

$V_{xs}= (A_{xs})(d)$

Where: V_{xs}=Cross-sectional volume
A_{xs}=Cross-sectional area
D=Distance between cross-sections

$V_{tot}=\sum V_{xs}$

These calculations were performed in Excel as well as in CAD. The table below details the results of both calculations.

	Volume (CY)		
Marsh Creation Area	**Calculated**	**CAD**	**Error (%)**
1	82,691.52	75,870.16	9
2	327,226.00	306,168.24	7
3	1,451,692.30	1,373,449.32	6

The total volume (including containment dike volume) needed based on this evaluation is presented in the table below:

Marsh Creation Area	Volume (cy)	Cut:Fill	Volume*Cut:Fill (cy)
1	85,288	1.5	127,932
2	318,163	1.5	477,244
3	1,373,450	1.5	2,060,175
Total	**1,776,901**		**2,665,352**

V. BORROW SITE DESIGN

A. Given:

1. Necessary Fill Volume for Marsh Creation (V_f): 1,776,901 cy

2. Cut to Fill Ratio: 1.5

3. Elevation of Max Cut Depth: -15 ft. NAVD88

4. Cross-Sectional Survey Data of Borrow Sites: XYZ data for each fill borrow site cross-section.

B. Methodology:

5. Required Borrow Volume, V_1: The borrow volume needed to fill the marsh creation/nourishment sites to the target elevation was computed by taking the product of the Necessary Fill Volume and the Cut:Fill Ratio:

$$V_1=V_f*C:F=(1,776,901)*(1.5)=2,665,352 \text{ cy}$$

6. Available Volume in Permitted Borrow Site: To ensure the permitted borrow site contains enough material to fill the marsh creation/nourishment sites to the target fill the marsh creation/nourishment sites to the target fill elevations (a volume greater than (or equal to) the Required Fill Volume), the volume of the Permitted Borrow Site was calculated. The cross-sectional area of each borrow site transect was computed with a similar method ads the fill are cross-sectional areas using the XYZ survey data for the borrow sites (see Section IV "Area Calculations"). Once each cross-sectional area was computed, the volume was calculated using the formulas below:

$$V_{xs}=A_{xs}*d$$

where:
V_{xs}= Cross-sectional Volume
A_{xs}= Cross-sectional Area
D= Distance between Cross-sections

$$V_{borrow}=\sum V_{xs}$$

This volume was then compared to the Necessary Fill Volume to ensure that the Permitted Borrow site contains a sufficient quantity of borrow material.

Borrow Area (Cut Depth -15')

Transect	Area (ft^2)	Distance	Average End Area
14	17939.259		
15	18426.144	250	4545675.369
16	18953.069	250	4672401.612
1	19523.312	250	4809547.631
2	20109.699	250	4954126.394
3	20524.464	250	5079270.369
4	21098.613	250	5202884.588
5	21832.732	250	5366418.144
6	22302.469	250	5516900.113
7	22751.442	250	5631738.875
8	23332.784	250	5760528.256
9	23932.663	250	5908180.85
10	24485.63	250	6052286.638
11	25066.661	250	6194036.406
12	25600.12	250	6333347.644
13	26150.022	250	6468767.769

Total Volume (ft^3)	82496110.66
Total Volume (yd^3)	**3,055,411.51**
CAD Volume (yd^3)	**3,154,001.21**
% Difference (yd^3)	**3**

VI. ACCESS CHANNEL DESIGN

A. <u>Given</u>:

1. Necessary Draft for Construction Equipment: d_e= 9.0 ft.

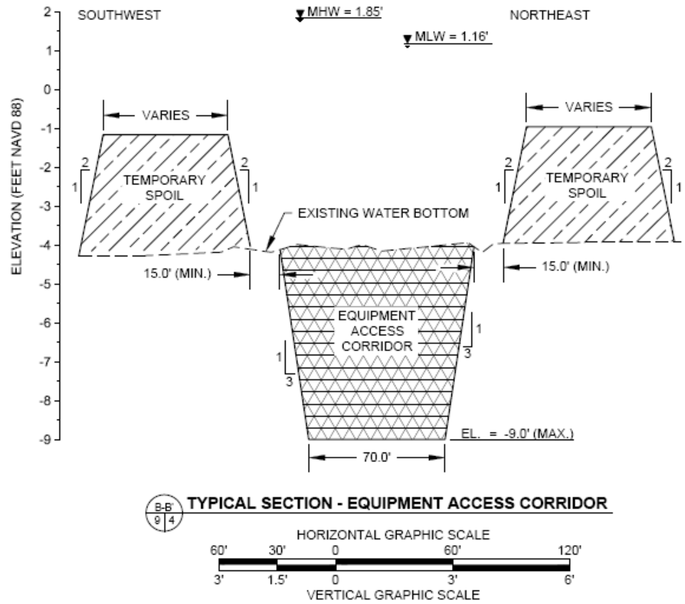
2. Side Slopes: S_{ac}= 3(H):1(V)

3. Minimum Bottom Width: $B_{AC\text{-}BOTTOM}$= 70 ft.

4. Elevation of Max Cut Depth: -9.0 ft. NAVD88

5. Cross-Sectional Survey Data of Access Route: XYZ data for the transects taken along centerline of TV-12 out into Little Vermilion Bay to Borrow Area; orientation dictated by existing oil and gas infrastructure

B. Methodology:



6. Cross-Sectional Area: $A_{CHANNEL}$= Area between the existing water bottom elevation to the Elevation of Max Cut Depth. This value was calculated by applying the above dimensions to the survey transects in AutoCAD.

7. Dredge Volume V_{AC}: The volume needed to be removed so as to allow the minimum draft.

$$V_{A-B}= A_{A-B}*L_{A-B}$$

Where: L_{A-B}= is the approximate distance between the survey transect midpoints along the waterway.

$$V_{AC}=\sum V_{A-B}$$

The location of the proposed Access Channel can be found on Sheet 3 in **Appendix E**: Preliminary Design Drawings.

The calculations were performed in Excel and in AutoCAD, and the results are shown in the table below.

	Volume (CY)		
	Calculated	CAD	Error (%)
Access Channel	233,574	216,909	8

VII. EARTHWORK CALCULATIONS

A. Given:

1. Size of Pipe: 4 ft

2. Length of Pipe: See table below. ((2) indicates 2 pipes)

ID	Length (ft)
1	20
2	75
3	65
4	50
5	75
6 (2)	50
7	65
8	60
9	70
10 (2)	70
11 (2)	50
12 (2)	120
Total	**1060**

3. Invert Elevation of Pipe: -2.0 ft. NAVD88

4. Slope of Pipe: 0

5. Side Slope of Backfill: 3(H):1(V)

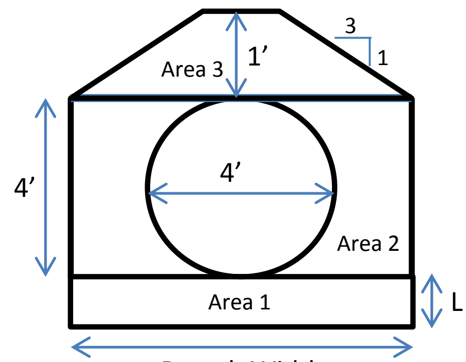
6. Width of Breach (where applicable):

ID	Width (ft)
1	10
2	10
3	20
4	20
5	20
7	25

7. Top of Backfill Elevation: +3.0 ft. NAVD88

8. Existing Bottom Elevation: XYZ data from transects taken at water control structure locations

B. Methodology:



1. Area of Area 1:

A_1=Breach Width*L

Where: L= distance between existing ground to invert elevation of pipe

2. Area of Area 2:

A_2= Breach Width*4-(π*2^2)

3. Area of Area 3:

A_3= ½ (Breach Width+ (2(Slope*1) +Breach width))*1

These calculations were computed in Excel and the results are shown in the tables below.

			Area 1		
ID	**Height (ft)**	**Width (ft)**	**Area (ft^2)**	**Length (ft)**	**Volume (cy)**
1	1.5	10	15	20	11
2	0	10	0	75	0
3	1.5	20	30	65	72
4	2	20	40	50	74
5	0.5	20	10	75	28
7	2	25	50	65	120
Total					**306**

				Area 2			
ID	**Height (ft)**	**Width (ft)**	**Area (ft^2)**	**Area of Pipe (ft^2)**	**Net Area (ft^2)**	**Length (ft)**	**Volume (cy)**
1	4	10	40	13	27	20	20
2	4	10	40	13	27	75	76
3	4	20	80	13	67	65	162
4	4	20	80	13	67	50	125
5	4	20	80	13	67	75	187
7	4	25	100	13	87	65	210
Total							**782**

Area 3							
ID	Height (ft)	Bottom Width(ft)	Side Slope	Top Width (ft)	Area (ft^2)	Length (ft)	Volume (cy)
1	1	10	3	4	7	20	5
2	1	10	3	4	7	75	19
3	1	20	3	14	17	65	41
4	1	20	3	14	17	50	31
5	1	20	3	14	17	75	47
7	1	25	3	19	22	65	53
Total							**197**

	Volume (cy)
Area 1	306
Area 2	782
Area 3	197
Total	**1284**