Annex C

Civil Design Annex

Alternative 2 Quantities - DEC 10, 2025

TOTAL CUT AND FILL VOLUMES	CUT	FILL
BREACHES (BCY)	53,500	700
CHANNELS (BCY)	60,840	4,900
DITCH FILLS (BCY)	-	36,450
GRADING FOR TEMPORARY ACCESS ROAD (BCY)	1,000	2,700
LEVEE LOWERINGS (BCY)	95,860	24,320
SMITH ISLAND LOWERINGS (BCY)	14,100	200
VIEWING PLATFORMS (BCY)	500	1,600
MARSH BENCHES (BCY)	-	140,900
TOTAL CUT (BCY)	225,800	-
TOTAL CUT (LCY)	248,380	-
TOTAL CUT (CCY)	223,542	-
TOTAL FILL (BCY)	-	211,770
TOTAL FILL (LCY)	-	232,947
TOTAL FILL (CCY)	-	209,652

VOLUMES	
NET VOLUME (C-F) (BCY)	14,030.00
NET VOLUME (C-F) (LCY)	15,433.00
NET VOLUME (C-F) (CCY)	13,889.70
BALANCE VOLUME (BCY)	-
BALANCE VOLUME (LCY)	-
BALANCE VOLUME (CCY)	-

AREAS	
MARSH BENCH AREA (ACRES)	27.80
TOTAL LEVEE LOWERING AREA (ACRES)	26.18
TOTAL SMITH ISLAND LOWERINGS (ACRES)	1.95
TEMPORARY ACCESS ROAD AREA - ROAD/PATH (ACRES)	0.84
TEMPORARY ACCESS ROAD AREA - SEEDING (ACRES)	0.90
TOTAL TEMPORARY ACCESS ROAD AREA (ACRES)	1.74
VIEWING PLATFORM AREA - GRAVEL (ACRES)	0.43
VIEWING PLATFORM AREA - SEEDING (ACRES)	0.66
TOTAL VIEWING PLATFORM AREA (ACRES)	1.09
TOTAL SEEDING AREA (ACRES) (SEE NOTES BELOW FOR EQUATION)	55.54

Assumed Swell = 10%
Assumed Shrinkage = 10%

Notes:

- These values are conservative.
- The spreadsheet assumes there will be no off-site disposal. This assumption made the Balance Volumes equal 0CY.
- Regarding the Levee Lowering Elevations: The elevations of the levee lowering's for Spencer Island are set at 10.5ft. The trail improvement along Spencer island is typcally elevation16ft. Smith Island Channel Improvement will be lowered to elevation 7ft on the South side, and elev 7ft and elev 10.5ft on the North side.
- The use of the limited bathymetry was applied to some of the ditch fills to increase their volumes. The remaining ditch fills were adjusted based on the largest volume increase of 17%.
- Regarding the Ditch Fills Adjusted Volumes: In the previous version of these calculations, The volume of ditch fills was not increased correctly. This error has been fixed and has resulted in a significant increase in Ditch Fill volume.
- Swell and Shrinkage of volumes is assumed to be 10%. The true values are unknown currently.
- MARSH BENCHS have been modeled within the project site at an elevation of 10.5ft. These MARSH BENCHS are currently large piles of excess material that is stored on site made from the levee lowerings, breaches, and the channel cuts. These MARSH BENCHS are not final design.
- [TOTAL SEEDING AREA (ACRES)] = [MARSH BENCH AREA (ACRES)] + [TOTAL LEVEE LOWERING AREA (ACRES)] + [TEMPORARY ACCESS ROAD AREA - SEEDING (ACRES)] + [VIEWING PLATFORM AREA - SEEDING (ACRES)]
- The No Work Area Environmental Resources Avoidance Zone was added to all the models. This area is along Steamboat Slough from STA 29+00 to 31+20 and is approximately 200ft in diameter and 1acre in area. No work is allowed in this area.
- Viewing Platforms: The South Dike Viewing Platform was projected to the existing surface. No work to the trail occurs in this area. Some of the volume from the Union Slough Viewing Platform are double counted in the Trail Widening. This can be refined later in design.
- The stationing for Union Slough Alternative 8 does not match the stationing for Union Slough Alternatives 2-7. This is due to the additional length required for the trail widening only included in Alternative 8.
- The Channel Fill is due to the modeling of Channel 7 and 7A. If this is ignored, then the net volume increases.
- The drawing package shown in Appendix A does not match the quantities in the tables above. The drawings presented represent Alternative 8 of the site design. The quantities represent a site design with additional features not shown in the drawing package.

Alternative 2 Quantities - DEC 10, 2025

BREACHES	Feature Name	Start STA	to	End STA	ROUNDED VOLUMES (CY) CUT	FILL	ROUNDED Length (ft)	ROUNDED Area (acre)
	SS B STA 01+60	-	to	188.07	4100	0	189	0.36
	SS B STA 07+40	-	to	187.53	2500	0	188	0.24
	SS B STA 11+20	-	to	185.75	2500	0	186	0.24
	SS B STA 15+80	-	to	203.25	2700	0	204	0.26
	SS B STA 19+10	-	to	175.29	2000	0	176	0.21
	SS B STA 26+40	-	to	325.67	6400	0	326	0.51
	SS B STA 32+10	-	to	256.84	3700	0	257	0.35
	SS B STA 36+50	-	to	215.89	3100	0	216	0.29
	SS B STA 46+60	-	to	176.53	1500	0	177	0.18
	SS B STA 49+50	-	to	155.73	1400	0	156	0.17
	SS B STA 52+40	-	to	156.96	1600	0	157	0.18
	SS B STA 55+90	-	to	208.80	2300	0	209	0.25
	SS B STA 59+00	-	to	179.02	1900	0	180	0.21
	SS B STA 62+90	-	to	81.30	600	0	82	0.09
Steamboat Slough Breaches				TOTALS	36300	0	2703	3.54
	US B STA 10+60	-	to	128.52	1900	0	129	0.24
	US B STA 20+30	-	to	114.03	1900	0	115	0.23
	US B STA 29+70	-	to	205.87	1900	0	206	0.22
	US B STA 42+80	-	to	124.15	1100	0	125	0.13
	US B STA 50+80	-	to	427.92	7300	700	428	1.06
Union Slough Breaches				TOTALS	14100	700	1003	1.88
	CD North B STA 2+20	-	to	221.99	900	0	222	0.17
North Cross Dike Breach				TOTALS	900	0	222	0.17
	CD South B STA 16+00	-	to	163.53	1100	0	164	0.21
	CD South B STA 24+00	-	to	145.88	1100	0	146	0.23
South Cross Dike Breach				TOTALS	2200	0	310	0.44
				GRAND TOTALS	53500	700	4238	6.03

	Feature Name	Start STA	to	End STA	ROUNDED VOLUMES (CY) CUT	FILL	ROUNDED Length (ft)	ROUNDED Area (acre)
	CHANNEL 1	-	to	314.83	1000	0	315	0.27
	CHANNEL 2	-	to	173.74	510	0	174	0.16
	CHANNEL 3	-	to	143.73	460	0	144	0.13
	CHANNEL 4	-	to	183.06	520	0	184	0.16
	CHANNEL 5	-	to	218.20	0	0	219	0.13
	CHANNEL 6	-	to	186.82	500	0	187	0.15
	CHANNEL 7	-	to	817.92	2300	4900	187	1.66
	CHANNEL 7A	-	to	3,337.94	30000	0	3338	5.27
	CHANNEL 8	-	to	1,050.15	1200	0	1051	0.52
	CHANNEL 9	-	to	36.33	20	0	37	0.02
	CHANNEL 10	-	to	5,095.30	17200	0	5096	3.68
	CHANNEL 10A	-	to	116.09	220	0	117	0.10
	CHANNEL 10B	-	to	236.52	510	0	237	0.18
	CHANNEL 10C	-	to	339.82	800	0	340	0.30
	CHANNEL 10D	-	to	140.34	0	0	141	0.05
	CHANNEL 11	-	to	167.74	600	0	168	0.16
TIDAL CHANNELS	CHANNEL 12	-	to	1,677.94	5000	0	1678	1.15
				GRAND TOTALS	60840	4900	13613	14.09

Alternative 2 Quantities - DEC 10, 2025

	Feature Name	Start STA	to	End STA	ROUNDED VOLUMES (CY) CUT	FILL	ROUNDED Length (ft)	ROUNDED Area (acre)
	DF1	-	to	500.92	0	1600	501	0.31
	DF2	-	to	212.38	0	640	213	0.17
	DF3	-	to	635.13	0	5200	636	0.52
	DF4	-	to	280.86	0	2000	281	0.23
	DF5	-	to	506.68	0	3100	507	0.36
	DF6	-	to	443.09	0	2400	444	0.39
	DF7	-	to	201.89	0	910	202	0.14
	DF8	-	to	801.99	0	3700	802	0.49
	DF9	-	to	348.64	0	1200	349	0.20
	DF10	-	to	217.02	0	800	218	0.14
	DF11	-	to	138.83	0	100	139	0.08
	DF12	-	to	500.67	0	1900	501	0.29
	DF13	-	to	458.10	0	1600	459	0.28
DITCH FILLS	DF14	-	to	256.21	0	900	257	0.16
	DF15	-	to	393.65	0	2200	394	0.28
	DF16	-	to	311.80	0	2200	312	0.24
The use of the limited bathymetry	DF17	-	to	386.06	0	1100	387	0.22
was applied to some of the ditch fills	DF18	-	to	215.01	0	600	216	0.13
to increase their volumes. The	DF19	-	to	415.49	0	1400	416	0.26
highlighted ditch fills were adjusted	DF20	-	to	455.73	0	1700	456	0.29
based on the largest volume increase	DF21	-	to	92.89	0	300	93	0.07
of 17%.	DF22	-	to	291.66	0	900	292	0.19
				GRAND TOTALS	0	36450	8075	5.44

	Feature Name	Start STA	to	End STA	ROUNDED VOLUMES (CY) CUT	FILL	ROUNDED Length (ft)	ROUNDED Area (acre)
	SD VIEWING PLATFORM Gravel	-	-	-	0	50	-	0.10
	US VIEWING PLATFORM Gravel	-	-	-	0	140	-	0.33
				TOTALS	0	190	-	0.43
	SD VIEWING PLATFORM	-	-	-	0	1300	-	0.27
	US VIEWING PLATFORM	-	-	-	500	300	-	0.39
VIEWING PLATFORMS				TOTALS	500	1600	-	0.66
				GRAND TOTALS	500	1790	-	1.09

	Feature Name	Start STA	to	End STA	ROUNDED VOLUMES (CY) CUT	FILL	ROUNDED Length (ft)	ROUNDED Area (acre)
	MARSH BENCH 1	-	-	-	-	9400	-	2.14
	MARSH BENCH 2	-	-	-	-	16000	-	3.60
	MARSH BENCH 3	-	-	-	-	8600	-	1.87
	MARSH BENCH 4	-	-	-	-	13900	-	2.94
	MARSH BENCH 5	-	-	-	-	21400	-	4.15
	MARSH BENCH 6	-	-	-	-	9500	-	1.75
	MARSH BENCH 7	-	-	-	-	20000	-	3.62
	MARSH BENCH 8	-	-	-	-	1100	-	0.22
	MARSH BENCH 9	-	-	-	-	10100	-	1.60
	MARSH BENCH 10	-	-	-	-	8500	-	1.37
	MARSH BENCH 11	-	-	-	-	16800	-	3.08
	MARSH BENCH 12	-	-	-	-	4500	-	0.88
	BRIDGE 1	-	-	-	-	600	-	0.28
MARSH BENCH / MARSH BENCHS	BRIDGE 2	-	-	-	-	500	-	0.30
		TOTAL FROM TIDAL CHANNELS				35900	-	6.97
		TOTAL FROM UNION SLOUGH				30600	-	5.13
		TOTAL FROM STEAMBOAT				63900	-	13.26
		TOTAL FROM NORTH CROSS DIKE				1100	-	0.21
		TOTAL FROM SOUTH CROSS DIKE				9400	-	2.13
		GRAND TOTALS				140900	-	27.80

Alternative 2 Quantities - DEC 10, 2025								
					ROUNDED VOLUMES (CY)		ROUNDED Length (ft)	ROUNDED Area (acre)
LEVEE LOWERINGS / DIKE LOWERINGS	Feature Name	Start STA	to	End STA	CUT	FILL		
	SS STA 02+40 TO 06+80	240.00	to	680.00	4500	450	440	0.97
	SS STA 07+80 TO 10+80	780.00	to	1,080.00	2600	250	300	0.61
	SS STA 11+60 TO 15+20	1,160.00	to	1,520.00	3200	430	360	0.89
	SS STA 16+20 TO 18+60	1,620.00	to	1,860.00	1600	300	240	0.51
	SS STA 19+50 TO 26+10	1,950.00	to	2,610.00	7500	1100	660	1.90
	SS STA 27+20 TO 29+00	2,720.00	to	2,900.00	6700	410	180	1.28
	SS STA 31+20 TO 31+70	3,120.00	to	3,170.00	600	50	50	0.21
	SS STA 32+50 TO 36+00	3,250.00	to	3,600.00	2200	500	350	0.98
	SS STA 36+90 TO 41+60	3,690.00	to	4,160.00	5000	700	470	1.24
South Steambout Slough				TOTALS	33900	4190	3050	8.59
	SS STA 43+40 TO 46+30	4,340.00	to	4,630.00	0	360	290	0.19
	SS STA 46+90 TO 49+20	4,690.00	to	4,920.00	0	260	230	0.16
	SS STA 49+80 TO 52+00	4,980.00	to	5,200.00	0	300	220	0.16
	SS STA 52+70 TO 54+80	5,270.00	to	5,480.00	700	400	210	0.34
	SS STA 56+30 TO 58+60	5,630.00	to	5,860.00	0	200	230	0.16
	SS STA 59+50 TO 61+70	5,950.00	to	6,170.00	900	400	220	0.38
	SS STA 61+70 TO 62+60	6,170.00	to	6,260.00	0	200	90	0.07
	SS STA 63+30 TO 65+50	6,330.00	to	6,550.00	140	2800	220	0.48
North Steambout Slough				TOTALS	1740	4920	1710	1.94
	ND STA 00+00 TO 00+50	-	to	50.00	210	50	50	0.17
	ND STA 00+50 TO 01+90	50.00	to	190.00	140	110	140	0.21
	ND STA 2+40 TO 2+60	240.00	to	260.00	0	20	20	0.03
	ND STA 26+0 TO 3+00	260.00	to	300.00	0	30	40	0.05
	ND STA 3+00 TO 4+40	300.00	to	440.00	50	80	140	0.13
North Cross Dike				TOTALS	400	290	390	0.59
	SD STA 11+20 TO 15+30	1,120.00	to	1,530.00	3200	260	410	0.99
	SD STA 16+80 TO 24+04	1,680.00	to	2,404.00	7100	0	724	1.28
South Cross Dike				TOTALS	10300	260	1134	2.27
	US ACCESS STA 00+00 TO 18+30	-	to	1,830.00	1000	2700	1830	1.74
Union Slough Trail				TOTALS	1000	2700	1830	1.74
	US STA 21+00 TO 29+00	2,100.00	to	2,900.00	9600	2900	800	2.30
	US STA 30+40 TO 31+60	3,040.00	to	3,160.00	280	500	120	0.22
	US STA 31+60 TO 32+80	3,160.00	to	3,280.00	40	260	120	0.17
	US STA 32+80 TO 40+40	3,280.00	to	4,040.00	11900	3100	760	2.70
	US STA 41+40 TO 52+00	4,140.00	to	5,200.00	23200	5700	1060	4.19
	US STA 53+00 TO 58+20	5,300.00	to	5,820.00	4500	2200	520	1.47
Union Slough				TOTALS	49520	14660	3380	11.05
	SM IS SOUTH STA 00+65 TO 5+88	70.00	to	588.00	10900	0	518	1.37
	SM IS NORTH STA 00+65 TO 5+89	749.00	to	949.00	3200	200	200	0.58
Smith Island				TOTALS	14100	200	718	1.95
				GRAND TOTALS	110960	27220	12212	28.13

BREACH VOLUME ESTIMATES - NOV 17, 2025

	MODEL VALUES							
	BREACH TEMPLATE DIMENSIONS				NEATLINE	Planar	ROUNDED	
NAME	BOTTOM WIDTH	SIDE SLOPE	LANDWARD ELEV	WATERWARD ELEV	Length	Area	VOLUMES (CY)	
	FT	FT	FT	FT	FT	ACRES	**CUT**	FILL
SS B STA -01+20	10	3	-1.19	-7.00	146	0.22	**1,100**	-
SS B STA 01+60	5	2	-2.00	-4.00	189	0.36	**4,100**	-
SS B STA 07+40	5	2	-2.00	-4.00	188	0.24	**2,500**	-
SS B STA 11+20	5	2	-2.00	-4.00	186	0.23	**2,500**	-
SS B STA 15+80	5	2	-2.00	-4.00	204	0.26	**2,700**	-
SS B STA 19+10	5	2	-2.00	-4.00	176	0.20	**2,000**	-
SS B STA 26+40	5	2	-2.00	-4.00	326	0.50	**6,400**	-
SS B STA 32+10	5	2	-2.00	-4.00	257	0.34	**3,700**	-
SS B STA 36+50	5	2	-2.00	-4.00	216	0.29	**3,100**	-
SS B STA 46+60	5	2	-2.00	-4.00	177	0.18	**1,500**	-
SS B STA 49+50	5	2	-2.00	-4.00	156	0.17	**1,400**	-
SS B STA 52+40	5	2	-2.00	-4.00	157	0.18	**1,600**	-
SS B STA 55+90	5	2	-2.00	-4.00	209	0.24	**2,300**	-
SS B STA 59+00	5	2	-2.00	-4.00	180	0.20	**1,900**	-
SS B STA 62+90	5	2	-2.00	-4.00	82	0.09	**600**	-
US B STA 10+60	30	3	1.50	0.00	129	0.24	**1,900**	-
US B STA 20+00	10	4	2.00	0.00	115	0.22	**1,900**	-
US B STA 31+00	5	4	3.00	0.00	206	0.22	**1,900**	-
US B STA 42+80	5	4	3.00	3.00	125	0.13	**1,100**	-
US B STA 50+80	50	5	1.00	-4.00	428	1.06	**7,300**	700
CD North B STA 2+20	5	2	3.00	3.00	222	0.16	**900**	-
CD South B STA 16+00	25	4	0.88	-1.32	164	0.21	**1,100**	-

BREACH VOLUME ESTIMATES - NOV 17, 2025

					END AREA VOLUME						
	ASSUMED TRAPAZOID DIMENSIONS				ELEVATION AT -4FT (TYP) WATERWARD						
	APPROX	NEATLINE	APPROX TOP WIDTH		APPROX HEIGHT					SCALING	**ADJUSTED**
NAME	BOTTOM WIDTH	Length	LANDWARD	WATERWARD	LANDWARD HEIGHT	WATERWARD HEIGHT	LANDWARD AREA	WATERWARD AREA	VOLUME	FACTOR	**VOLUME**
	FT	FT	FT	FT	FT	FT	SQFT	SQFT	CF		
SS B STA -01+20	10	146	70	110	15.00	17.00	600.00	1,020.00	4,380.00	0.25	**1,100.00**
SS B STA 01+60	5	189	100	100	12.00	14.00	630.00	735.00	4,777.50	0.86	**4,100.00**
SS B STA 07+40	5	188	65	55	12.00	14.00	420.00	420.00	2,924.44	0.85	**2,500.00**
SS B STA 11+20	5	186	60	60	12.00	14.00	390.00	455.00	2,910.56	0.86	**2,500.00**
SS B STA 15+80	5	204	60	60	12.00	14.00	390.00	455.00	3,192.22	0.85	**2,700.00**
SS B STA 19+10	5	176	58	63	12.00	14.00	378.00	476.00	2,783.41	0.72	**2,000.00**
SS B STA 26+40	5	326	60	71	12.00	14.00	390.00	532.00	5,566.15	1.15	**6,400.00**
SS B STA 32+10	5	257	55	58	12.00	14.00	360.00	441.00	3,812.17	0.97	**3,700.00**
SS B STA 36+50	5	216	58	62	12.00	14.00	378.00	469.00	3,388.00	0.91	**3,100.00**
SS B STA 46+60	5	177	52	53	12.00	14.00	342.00	406.00	2,451.78	0.61	**1,500.00**
SS B STA 49+50	5	156	53	53	12.00	14.00	348.00	406.00	2,178.22	0.64	**1,400.00**
SS B STA 52+40	5	157	57	57	12.00	14.00	372.00	434.00	2,343.37	0.68	**1,600.00**
SS B STA 55+90	5	209	57	57	12.00	14.00	372.00	434.00	3,119.52	0.74	**2,300.00**
SS B STA 59+00	5	180	55	62	12.00	14.00	360.00	469.00	2,763.33	0.69	**1,900.00**
SS B STA 62+90	5	82	47	55	12.00	14.00	312.00	420.00	1,111.56	0.54	**600.00**
US B STA 10+60	30	129	90	90	8.00	10.00	480.00	600.00	2,580.00	0.74	**1,900.00**
US B STA 20+00	10	115	80	80	8.00	10.00	360.00	450.00	1,725.00	1.10	**1,900.00**
US B STA 31+00	5	206	50	45	8.00	10.00	220.00	250.00	1,792.96	1.06	**1,900.00**
US B STA 42+80	5	125	40	35	5.00	7.00	112.50	140.00	584.49	1.88	**1,100.00**
US B STA 50+80	50	428	140	110	12.00	14.00	1140.00	1,120.00	17,912.59	0.41	**7,300.00**
CD North B STA 2+20	5	222	37	34	5.00	7.00	105.00	136.50	992.83	0.91	**900.00**
CD South B STA 16+00	25	164	110	93	9.32	11.32	629.10	667.88	3,938.98	0.28	**1,100.00**

BREACH VOLUME ESTIMATES - NOV 17, 2025

	END AREA VOLUME					
	ELEVATION AT -2FT (TYP) WATERWARD					
	APPROX HEIGHT					**ADJUSTED**
NAME	LANDWARD HEIGHT	WATERWARD HEIGHT	LANDWARD AREA	WATERWARD AREA	VOLUME	**VOLUME**
	FT	FT	SQFT	SQFT	CF	**CF**
SS B STA -01+20	13.00	15.00	520.00	900.00	3,839.26	**964.20**
SS B STA 01+60	10.00	12.00	525.00	630.00	4,042.50	**3,469.23**
SS B STA 07+40	10.00	12.00	350.00	360.00	2,471.85	**2,113.10**
SS B STA 11+20	10.00	12.00	325.00	390.00	2,462.78	**2,115.38**
SS B STA 15+80	10.00	12.00	325.00	390.00	2,701.11	**2,284.62**
SS B STA 19+10	10.00	12.00	315.00	408.00	2,356.44	**1,693.21**
SS B STA 26+40	10.00	12.00	325.00	456.00	4,714.93	**5,421.26**
SS B STA 32+10	10.00	12.00	300.00	378.00	3,226.78	**3,131.84**
SS B STA 36+50	10.00	12.00	315.00	402.00	2,868.00	**2,624.20**
SS B STA 46+60	10.00	12.00	285.00	348.00	2,074.83	**1,269.39**
SS B STA 49+50	10.00	12.00	290.00	348.00	1,843.11	**1,184.62**
SS B STA 52+40	10.00	12.00	310.00	372.00	1,982.85	**1,353.85**
SS B STA 55+90	10.00	12.00	310.00	372.00	2,639.59	**1,946.15**
SS B STA 59+00	10.00	12.00	300.00	402.00	2,340.00	**1,608.93**
SS B STA 62+90	10.00	12.00	260.00	360.00	941.48	**508.20**
US B STA 10+60	6.00	8.00	360.00	480.00	2,006.67	**1,477.78**
US B STA 20+00	6.00	8.00	270.00	360.00	1,341.67	**1,477.78**
US B STA 31+00	6.00	8.00	165.00	200.00	1,392.41	**1,475.53**
US B STA 42+80	3.00	5.00	67.50	100.00	387.73	**729.70**
US B STA 50+80	10.00	12.00	950.00	960.00	15,138.52	**6,169.47**
CD North B STA 2+20	3.00	5.00	63.00	97.50	659.83	**598.14**
CD South B STA 16+00	7.32	9.32	494.10	549.88	3,170.61	**885.42**

BREACH VOLUME ESTIMATES - NOV 17, 2025

	END AREA VOLUME					
	ELEVATION AT 0FT (TYP) WATERWARD					
	APPROX HEIGHT					**ADJUSTED**
NAME	LANDWARD HEIGHT	WATERWARD HEIGHT	LANDWARD AREA	WATERWARD AREA	VOLUME	**VOLUME**
	FT	FT	SQFT	SQFT	CF	**CF**
SS B STA -01+20	11.00	13.00	440.00	780.00	3,298.52	**828.40**
SS B STA 01+60	8.00	10.00	420.00	525.00	3,307.50	**2,838.46**
SS B STA 07+40	8.00	10.00	280.00	300.00	2,019.26	**1,726.19**
SS B STA 11+20	8.00	10.00	260.00	325.00	2,015.00	**1,730.77**
SS B STA 15+80	8.00	10.00	260.00	325.00	2,210.00	**1,869.23**
SS B STA 19+10	8.00	10.00	252.00	340.00	1,929.48	**1,386.42**
SS B STA 26+40	8.00	10.00	260.00	380.00	3,863.70	**4,442.52**
SS B STA 32+10	8.00	10.00	240.00	315.00	2,641.39	**2,563.67**
SS B STA 36+50	8.00	10.00	252.00	335.00	2,348.00	**2,148.41**
SS B STA 46+60	8.00	10.00	228.00	290.00	1,697.89	**1,038.77**
SS B STA 49+50	8.00	10.00	232.00	290.00	1,508.00	**969.23**
SS B STA 52+40	8.00	10.00	248.00	310.00	1,622.33	**1,107.69**
SS B STA 55+90	8.00	10.00	248.00	310.00	2,159.67	**1,592.31**
SS B STA 59+00	8.00	10.00	240.00	335.00	1,916.67	**1,317.85**
SS B STA 62+90	8.00	10.00	208.00	300.00	771.41	**416.39**
US B STA 10+60	4.00	6.00	240.00	360.00	1,433.33	**1,055.56**
US B STA 20+00	4.00	6.00	180.00	270.00	958.33	**1,055.56**
US B STA 31+00	4.00	6.00	110.00	150.00	991.85	**1,051.06**
US B STA 42+80	1.00	3.00	22.50	60.00	190.97	**359.41**
US B STA 50+80	8.00	10.00	760.00	800.00	12,364.44	**5,038.94**
CD North B STA 2+20	1.00	3.00	21.00	58.50	326.83	**296.27**
CD South B STA 16+00	5.32	7.32	359.10	431.88	2,402.24	**670.85**

Subject: Spencer Island Ecosystem Restoration Project Lidar Base Map QC, Earthwork Volume Adjustment Factors and Value Engineering Opportunities

BLUF: This memorandum summarizes an analysis of the underlying data being used in hydraulic and terrain modeling to support the Spencer Island Ecosystem Restoration project feasibility level design effort. In September 2025 the NFS acquired design phase survey data of the levees where vegetation artifacts are most apparent in the lidar data (acquired by Snohomish County in 2019). Comparison of surveyed elevations to lidar elevations in the same locations indicates that there is a systematic bias in the terrain data being used in the hydraulic modeling and earthwork modeling (elevations being used now for levees are about 2.2 feet higher than actual elevations). This bias is common in vegetated areas and will be formally corrected in the next phase of the project, Design and Implementation, by inclusion of the ground survey data in the hydraulic models and terrain models. Because this bias results in over-conservative earthwork volume calculations, we recommend calculating a bias correction factor and applying it the CAD estimated earthwork volumes for levee cut for the final draft of the feasibility study. This memorandum provides recommended adjustment factors and a rough order of magnitude estimate of potential savings ($1.6m).

Background

Review of lidar point cloud data along the levees used to create the raster terrain files and ultimately CAD DTM at Spencer Island shows that it is sparse and heavily influenced by vegetation (triangulation artifacts are present in the bare earth DEM where the lidar data was clipped and interpolated to remove vegetation). The effect of these artifacts is most likely a bias to the high side when compared with actual ground elevations. This results in conservative (over) estimates of earthwork that affect all alternatives similarly.

Due to the knowledge that this issue affected all alternatives proportionately (resulting in conservative cost estimates) and given the difficulty of acquiring ground survey across the entire island due to access limitations and heavy vegetation, this survey work was scheduled for the design phase, where it would be acquired and used to update quantities.

Unexpected schedule delays have resulted in the NFS collecting this data and USACE receiving it prior to completion of feasibility. Due to scope and schedule limitations is not prudent to delay completion of feasibility by months to fully update the underlying civil design with the new survey data. The new survey data shows that the levee crests are consistently lower which would result in less cut quantities and cost savings for the project but not result in significant scope/design change. The added technical work to fully refine cut quantities would delay completion of feasibility unnecessarily, and it is not essential to complete feasibility-level design (35% design maturity). Since the underlying planning decision (alternative comparison and selection) is not affected by this bias, the focus of this analysis is to determine if the bias is significant enough to warrant scaling earthwork estimates in feasibility phase so that feasibility phase costs estimates are more accurate and representative of on-the-ground conditions.

Data & Analysis

More than 980 individual points were surveyed around the perimeter of Spencer Island at the request of USACE. The ground survey data originated in an AutoCAD file provided by the surveyors that was imported in the same coordinate system as the Lidar (Figure 1). ArcGIS pro was used to extract Lidar Z values at all ground survey points. The surveyed z values were subtracted from the lidar values to compute bias (Figure 2). Zones were created in GIS around the survey footprint. The zones delineate areas below the final degraded levee elevations and areas above. These are referred to as “marsh” and “levee” respectively. The marsh and levee zones were then subdivided by project dike segment. This was done to see if there are any obvious trends in areas where levee removal is going to be conducted and areas where channels and marsh benches will be constructed. A spatial join was then used to tag the surveyed points to the dikes and marsh/levee zones for investigation of spatial and elevations trends in bias.

Figure 3 compares the differences between surveyed elevations and lidar elevations at the same locations for all data. Figure 4 through Figure 8 shows the deviation of the lidar elevations from the surveyed elevations by dike segment (for marsh and levee points). Table 1 and Table 2 summarize the data shown in Figures 4 through 8. Table 3 provides a summary of the statistics for the lidar error by levee points and marsh points.

Representative cross sections through Union Slough and Steamboat Slough dikes that illustrate the issues posed by the use of the lidar survey data in the DTM used to compute earthwork quantities are shown in Figure 9 and Figure 10.

Results

More than 2/3 (724 of 983, 74%) of surveyed points are lower than the elevations used to create the digital terrain model used in CAD to compute quantities. This trend is present in both the marsh points (314/529, 59%) and 90% of the points on the levee (410/454, 90%) are lower than the lidar elevation, which indicates that the most common condition is an upward bias in the lidar due to artifacts (vegetation). Inspection of Figure 4 through Figure 8 shows that this error increases with ground elevation. This is attributed to the brackish marsh environment that limits woody shrub and tree growth below elevation 10.

The average bias of all survey points is -0.94 feet (meaning the surveyed ground elevation is lower than the lidar). For marsh points it is +0.2 feet (with a mode of -0.2 feet). For levee/dike points it is -2.2 feet (average and mode). There is substantial variability within the site. Higher elevation dikes have greater error, as the higher elevation favors bushier plant growth. Error for Union Slough dike (average elev. of 12.2 feet) is -2.4 feet, the Steamboat Slough south levee (average elev. of 10.9 feet) is -2.5 feet, North Cross dike (avg. ground elev. 9.7 ft) is -1.1 feet, South Cross Dike (average

10.4 feet) is -1.1 feet, with the lowest dike segment (Steamboat Slough north, 9.6 feet) having the lowest error (-1.0 ft).

In the marsh areas adjacent to the levees there is more variability and less of a trend. The Union Slough dike marsh elevations are lower than the lidar elevations by 0.3 feet. At the South Cross Dike lidar elevations in the marsh are higher by 0.6 feet than the surveyed elevations, and at the North Cross Dike marsh elevations are higher by about 0.9 feet than the surveyed elevations. Marsh lidar elevations are lower than surveyed elevations by 0.2 feet along the Steamboat Slough south dike, and 1.2 feet along the Steamboat Slough north dike.

Discussion

Points surveyed on levees are consistently lower than the elevations used to create the digital terrain model used in CAD to compute quantities. Because more than 100,000 cubic yards of levee cut are anticipated over an area of 28 acres, this represents an equivalent cut height of 2.5 feet. Thus, this average elevation bias (-0.94 feet, for all survey/lidar points) represents a substantial portion (nearly 40%) of the equivalent site average cut height, justifying reducing the quantity of cut in the feasibility level cost estimates so that the scope and budget are closer to what they will be in PED.

As shown in Figure 3 and Figure 9 the bias in the data increases near the crest of the levees and decreases toward the levee toe and marsh. The bias is also less in lower elevation dikes (South and North Cross dikes). This is attributed to higher elevations promoting growth of dense riparian vegetation. Vegetation growth is at its maximum in summer when the lidar was reportedly acquired. Elevation errors (surveys lower than lidar) could also be due to settling of levees over time, or erosion from overtopping. Regardless of the error source the issue is widespread.

There are several areas outside the dike embankment prisms within the tidal marsh where the surveyed elevations are higher than the lidar DTM. The cause for this is assumed to be deposition of sediment and woody material in lower lying areas since the lidar was acquired in 2019. It could also be due to lateral spreading of the dikes due to settlement, deposition of eroded material, and dense vegetative mat growth.

As shown in Figure 9 and Figure 10, the levees along Union Slough and Steamboat Slough could be far less substantial than the lidar suggests. Thus, the footprint of levee lowering could decrease in addition to the overall cut volume. The target levee lowering elevation and marsh bench elevation of 10.5 feet exceeds the average dike/ground elevation for the northern portion of the Steamboat Slough dike and North Cross dike. This implies that the levee lowering work in these locations could be negligible, and potentially descoped from the project in PED.

While the error in the lidar based DTM has a significant impact on project earthwork quantities (and costs), it has other important influences on the project that will be refined in PED. The hydraulic modeling conducted for this study has showed that the

Snohomish River in the vicinity of Spencer Island is sensitive to the elevation of levees. Since this analysis shows that the underlying lidar data is biased high this bias affects the models by both exaggerating the influence of existing levees and the effects of removing them. These biases will be corrected in PED with the result expected to be a reduction in modeled offsite induced flooding. These refinements are not necessary to complete feasibility level design and are appropriate for the PED phase. The working assumptions in feasibility remain conservative for potential offsite induced flooding.

Bias correction of earthwork quantities and ROM cost savings
To bias correct the earthwork volumes without updating the underlying DTM and all of the grading plans, the following process is used: The CAD footprint for levee excavation to elevation 10.5 is assumed to remain as designed. The equivalent cut height for each levee segment is then estimated by dividing the total cut volume computed in the Lidar based DTM by the planar cut area shown in CAD (Table 4). To bias correct the cut, the design cut elevation is subtracted from the average surveyed elevation within the dike footprint. This equivalent cut height is then multiplied by the CAD estimated footprint to estimate the “true” bias corrected cut volume. The difference between the CAD computed cut volume and bias corrected cut volume is the expected reduction in earthwork that will be realized once the survey points are converted into an existing conditions DTM in PED. Because every cubic yard of cut that is removed from the scope also eliminates a cubic yard of onsite marsh bench construction, the effects of scope reduction are doubled.

As shown in Table 4, the effects of including the PED phase survey data could decrease the excavation and onsite fill scope by nearly 50,000 cubic yards from 110,000 cy for levee degrade work, with the tallest levees have the greatest potential savings. Cut areas would experience far lower within the Union Slough levee lowering area, the equivalent average cut height will decrease from 4.3 feet to 1.7 feet, reducing estimated earthwork (both cut and fill) by 15,920 cy (32%).

Within the southern portion of the Steamboat Slough levee lowering area the equivalent average cut height will decrease from 2.6 feet to 0.4 feet, reducing estimated earthwork (both cut and fill) by 27,800 cy (82%). The large reduction in this segment is due to the lack of a maintained trail, which has allowed the levee to become heavily overgrown with blackberries. Figure 11 which compares surveyed elevations to lidar elevations shows the Steamboat Slough dike is far less substantial than the lidar indicates. Given the large reduction in scope that will result from use of the new survey data, PED phase confirmatory surveys should be conducted validate the NFS data and to fill small data gaps.

The South Cross dike has much less vegetation but is still has about a 1-ft bias that when used to correct the lidar estimated volume will result in a decrease in estimated cut/fill of 1,600 cy (16%). The NFS did not survey the Smith Island dikes where mitigation is proposed, however conditions here (maintained trail) are similar to the

South Cross dike, so the same vertical error was applied resulting in a decrease in estimated cut/fill of 2,400 cy (17%) from lidar based estimates.

There are nearly 14 acres of channel construction work. Even though the elevation bias in marshy areas is small (-0.2 feet), including this correction factor could result in small but non-negligible decreases in scope (roughly 4,500 cy) of cut and fill work.

Levee breach earthwork was computed separately from levee degrade work. The cut volume for breaches includes both the marsh and levee. Error for ground elevations at breaches uses the average error for all survey points (-0.94 ft) to adjust the equivalent cut heights for all breaches. The sum of breach cut/excavation/onsite fill is 53,500 cy without adjustment, which decreases 9,000 cy (17%) to 44,500 once the elevation bias is factored in.

The error in the North Cross Dike and North Steamboat Slough dike survey data (~1 ft) exceeds the equivalent cut height of 0.6 ft and 0.4 ft respectively, indicating that the need for grading work here is likely much less than the lidar data suggest. Due to the limited scope in these areas earthwork savings were not estimated.

Table 6 provides current total project cost-based unit pricing for channel cut, levee cut, breach cut, and onsite disposal. These unit prices are combined and multiplied by the decrease in earthwork to estimate savings that will result from utilization of the ground survey (Table 7). From inspection, use of corrected elevation data could potentially result in $1.6 m in project cost savings due to reduced scope. The error corrections along Union Slough and the southern portion of Steamboat Slough dikes represent 83% of the total savings. Savings are much less along the South Cross dike, north Steamboat Slough, Smith Island, and are minimal at the North Cross dike.

Value Engineering Opportunities to reduce costs further

Channel cut and levee breach areas are located within the tidal marsh and are not likely to be as affected by systemic elevation bias since marsh vegetation is less dense. The feasibility design breach elevation was set to the lowest tide elevation to ensure that the island was always connected to the adjacent sloughs. This elevation is lower than the water elevations experienced in the sloughs and will ensure that the island remains connected. Given that the average breach elevation on the island is higher than -4 the design elevation could be increased in height, reducing need for channel and breach cut work. In PED the team will further refine these elevations, so they are optimized for local conditions and total cost. Since this design change would apply to any of the selected or unselected alternatives, the effect on benefits would be negligible from the plan formulation standpoint (meaning any reduction would scale uniformly).

If further cost savings are desired in these areas, the existing cut elevation for breaches can be increased from -4 feet NAVD 88 to -2 or 0 feet. Table 5 provides estimates for the reduced cut associated with these revised configurations. Using current unit price data from the current TPCS the savings associated with these configurations would range from $216k to $436k (Table 7).

Conclusions

In summary, 70% of all points, and 90% of surveyed points on dikes are lower than the elevations used in the lidar based DTM at the same locations. The error (-0.2 feet) is small in marsh areas but is significant (-2.2 feet) on dikes. CAD based cut volume estimates include systemic bias in leveed areas, resulting in over-estimation of earthwork, and impacts to the project budget. By scaling the computed earthwork with a bias correction factor developed from ground survey data, this will result in significant reduction in total excavation work for this project reducing the total project cost from current estimates.

Recommendations

It is recommended to refine feasibility project cost estimates by applying a bias correction factor to CAD computed earthwork volumes (see Table 4). This would result in a global reduction in levee cut/onsite fill of 43%, levee breach cut/fill of 19%, and channel cut/fill of 8%. If further cost savings are desired, the bottom elevations of the breaches can be increased (see Table 5), provided the typical sections shown in the 35% plans are adjusted accordingly. The length and number of channels and breaches should remain unaltered to avoid having to update the 35% grading plans.

Zachary P. Corum, PE
Sr., Hydraulic Engineer
Spencer Island ERP Technical Lead

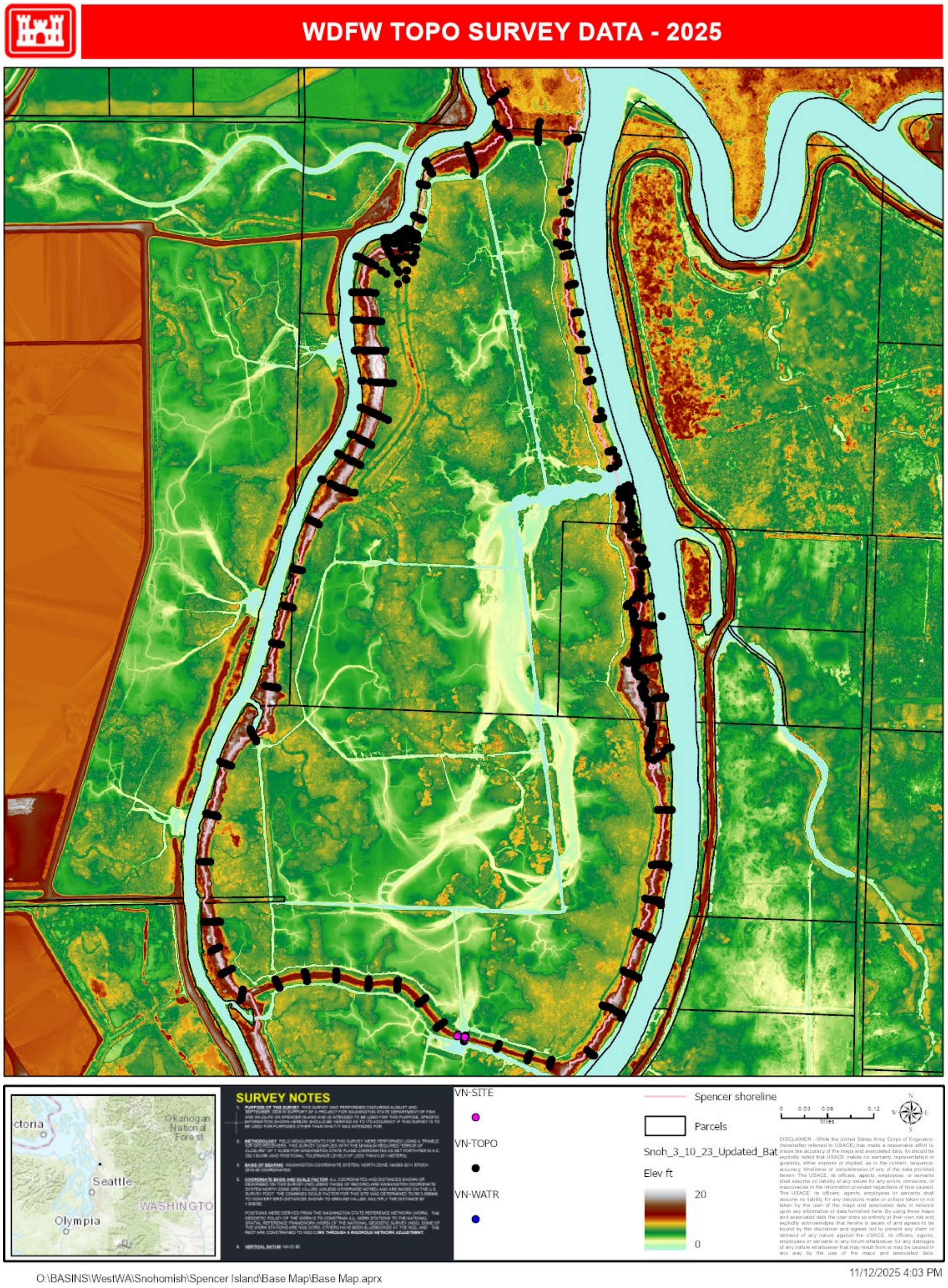


Figure 1. Spencer Island survey data and 2019 lidar data

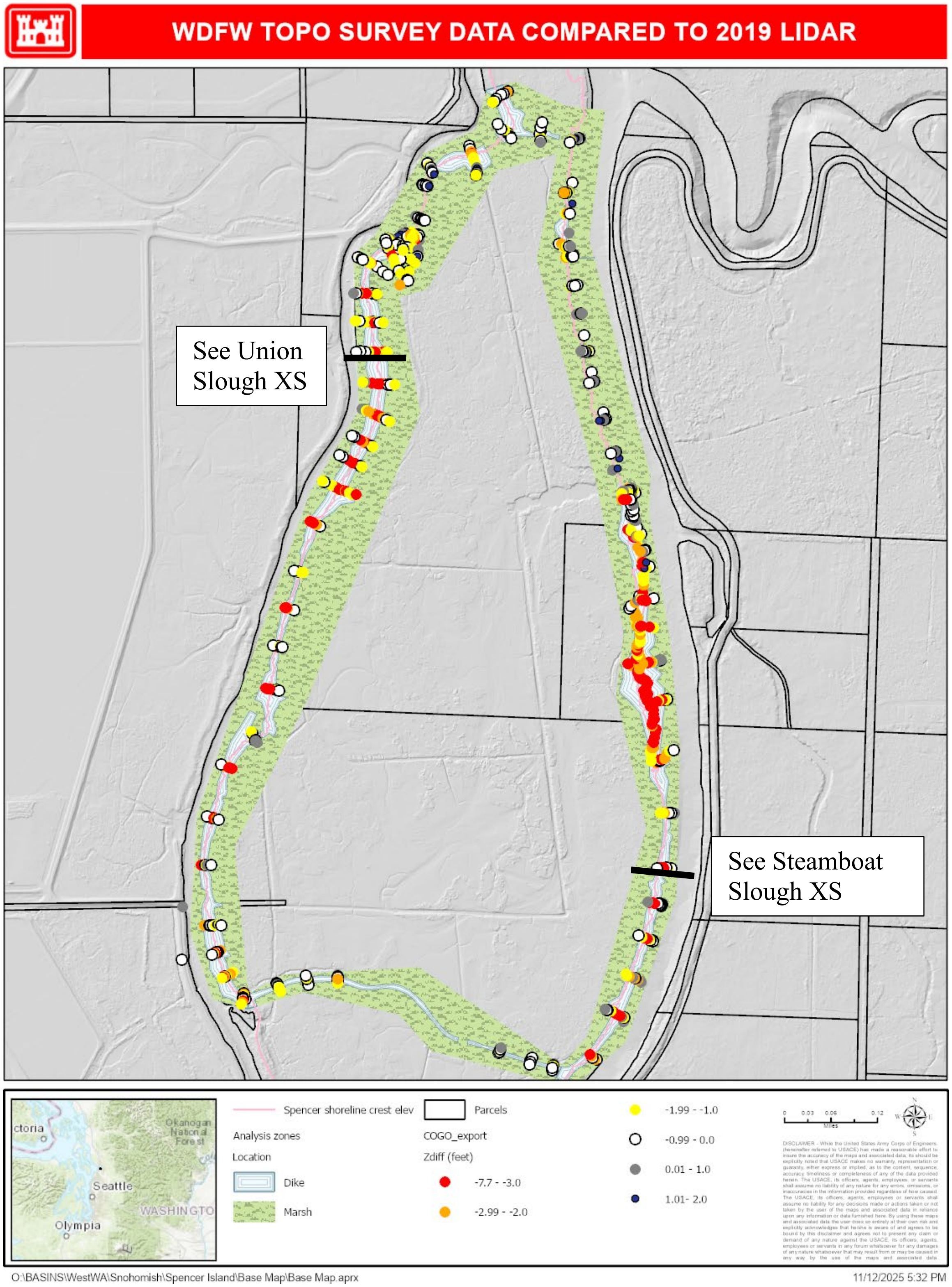


Figure 2. Spencer Island survey data compared with 2019 lidar data

Table 1. Summary of lidar error by dike segment in marsh areas

Location – marsh areas		**levee exterior survey points**			**levee exterior lidar points**			**Error**
Dike segment	number survey points	min elev, ft	max elev, ft	avg elev, ft	min elev, ft	max elev, ft	avg elev, ft	Avg. survey minus lidar elev, (dz, ft)
Union Slough	200	1.34	13.045	6.45	1.88	10.26	6.75	-0.3
South Cross	32	6.46	9.91	7.79	6.79	10.01	8.36	-0.57
Steamboat Slough South	174	1.23	14.529	6.61	-5.1	12.44	6.42	0.19
Steamboat Slough North	113	1.64	14.608	8.25	0.94	10.07	7.07	1.18
North Cross	10	3.7	8.83	7.1	3.28	10.27	7.98	-0.88
	Weighted Avg	1.7	13.6	7.0	-0.3	10.9	6.8	0.2

Table 2. Summary of lidar error by dike segment in levee fill areas

Location - levee lowering areas		**levee interior survey points**			**levee interior lidar points**			**Error**
Dike segment	number survey points	min elev, ft	max elev, ft	avg elev, ft	min elev, ft	max elev, ft	avg elev, ft	Survey minus lidar elev, (dz, ft)
Union Slough	204	7.78	18.71	12.18	9.36	20.28	14.55	-2.37
South Cross	41	8.081	11.77	10.37	9.01	13.55	11.44	-1.07
Steamboat Slough South	181	6.67	14.99	10.94	7.87	18.29	13.4	-2.46
Steamboat Slough North	13	7.93	12.93	9.58	9.88	11.62	10.6	-1.02
North Cross	15	8.66	10.9	9.69	9.68	11.7	10.81	-1.12
	Weighted Avg	7.4	16.2	11.4	8.8	18.3	13.6	-2.2

Table 3. Lidar error statistics, all data

Levee error (dz)		**Marsh error (dz)**	
#	454	#	529
% < 0	90%	% < 0	59%
% > 0	10%	% > 0	41%
Mean (ft)	-2.2	Mean (ft)	0.2
Mode (ft)	**-2.2**	**Mode (ft)**	**-0.2**
Max (ft)	4.14	Max (ft)	6.33
Min (ft)	-7.66	Min (ft)	-3.17

Table 4. Earthwork quantities based on lidar and ground survey corrected

Levee cut	Lidar based earthwork volume (Vo, cy)	CAD Footprint Area (A, ac)	Avg Ht Cut (Ho = Vo/A, ft)	Survey Corrected Avg Cut Ht = Hc	Survey Corrected Vol (Vc= A*Hc, cy)	**Rounded Corrected vol (Vrc, cy)**	Avg Elev Error (Ho - Hc, ft)	Volume difference (Vd = Vrc - Vo, cy)	% Difference (%D)
Union Slough	50520	12.76	4.3	1.7	34585	**34600**	2.7	15920	-32%
South Cross	10300	2.26	2.8	2.4	8641	**8700**	0.5	1600	-16%
Steamboat Slough South	33900	8.54	2.6	0.4	6062	**6100**	2.2	27800	-82%
Steamboat Slough North	1740	1.91	0.6	0.0	1740	**1740**	0.6	0	0%
North Cross	400	0.57	0.4	0.0	400	**400**	0.4	0	0%
Smith Island Flowage	14100	1.94	4.6	3.7	11674	**11700**	0.9	2400	-17%
total	110960	27.97	2.5		63103	**63200**	1.2	47760	-43%
Levee breaches									
Union Slough	14100	1.86	4.7	3.8	11279	**11300**	0.9	2800	-20%
South Cross	1100	0.21	3.2	2.3	782	**800**	0.9	300	-27%
Steamboat Slough	37400	3.71	6.2	5.3	31774	**31800**	0.9	5600	-15%
North Cross	900	0.16	3.5	2.5	657	**700**	0.9	200	-22%
total	53500	5.94	5.6	4.6	44492	**44500**	0.9	9000	-17%
Channel Cut									
All	55940	14.09	2.5	2.3	51394	**51400**	0.2	4540	-8%

Table 5. Potential de-scope options A and B at Spencer Island, increase bottom elevation of levee breaches

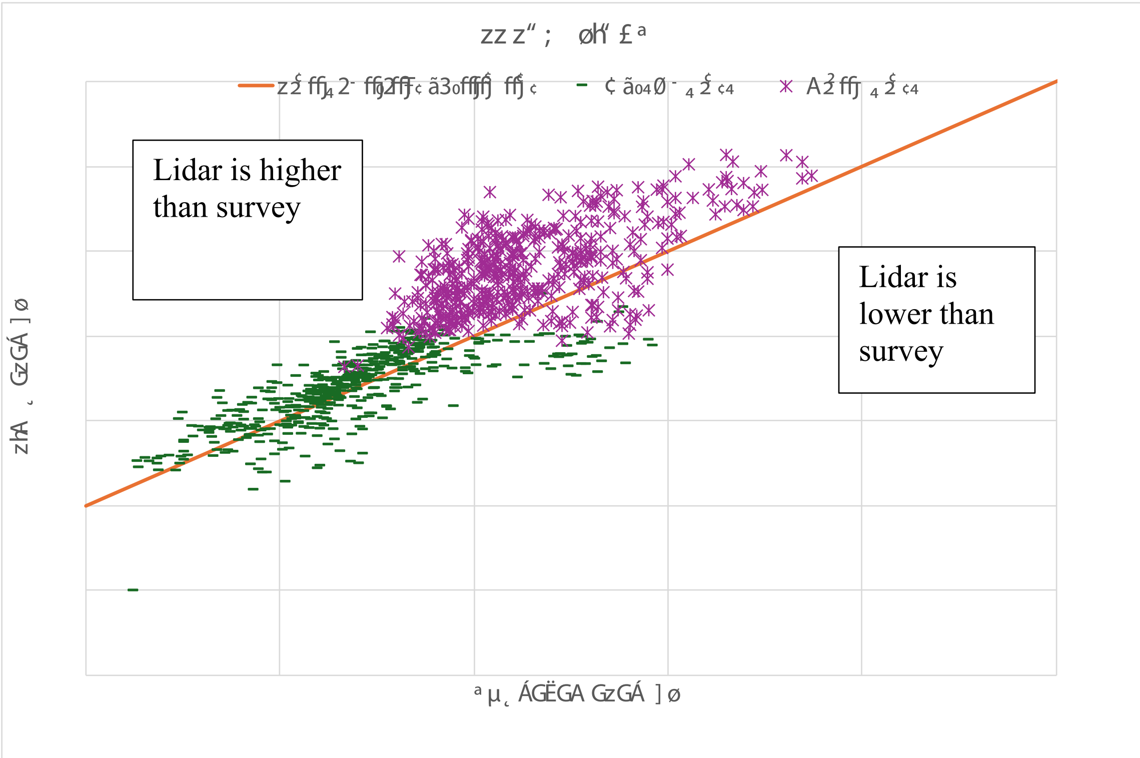
Location	Design Levee Breaches (-4 ft invert) (cy)	Option A Breach Cut Volume (-2 ft invert) (cy)	Option A Scope Reduction (cy)	Option B Breach Cut Volume (0 ft invert) (cy)	Option B Scope Reduction (cy)
Union Slough	14100	11400	2700	8600	5500
South Cross	1100	1100	0	1100	0
Steamboat Slough	37400	31700	5700	26000	11400
North Cross	900	900	0	900	0
total	53500	45100	8400	36600	16900

Table 6. Unit prices for estimating savings provided by Cost Engineer. Levee lowering unit price is added to marsh bench unit price to estimate savings

WBS Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared:			14-Nov-25	Program Year (Budget EC):			2026					
		Estimate Price Level:			1-Oct-25	Effective Price Level Date:			1 -Oct-25					
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	RISK BASED CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	ESC (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	B	C	D	E	F	G	H	I	J	P	L	M	N	O
06	Levee Lowerings	$11	$3	30.0%	$15	0.0%	$11	$3	$15	2028Q3	6.6 %	$12	$4	$16
06	Breaches	$11	$3	30.0%	$14	0.0%	$11	$3	$14	2028Q3	6.6 %	$12	$4	$15
06	Marsh Benches	$7	$2	30.0%	$10	0.0%	$7	$2	$10	2028Q3	6.6 %	$8	$2	$10
06	Channel Cut	$18	$5	30.0%	$23	0.0%	$18	$5	$23	2028Q3	6.6 %	$19	$6	$25

Table 7. Potential cost savings

Location	Lidar DTM bias correction	Option A scope reduction	Option B scope reduction
Union Slough Dike + Breach	$ 484,277.60	$ 69,687.00	$ 141,955.00
South Cross dike + Breach	$ 49,151.00	$ -	$ -
Steamboat Slough Dike + Breach	$ 864,000.00	$ 147,117.00	$ 294,234.00
North Cross Dike + Breach	$ 5,162.00	$ -	$ -
Smith Island Dike	$ 62,112.00	$ -	$ -
Channel Cut	$ 158,900.00	$ -	$ -
total	$ 1,623,602.60	$ 216,804.00	$ 436,189.00


Lidar is higher than survey
Lidar is lower than survey

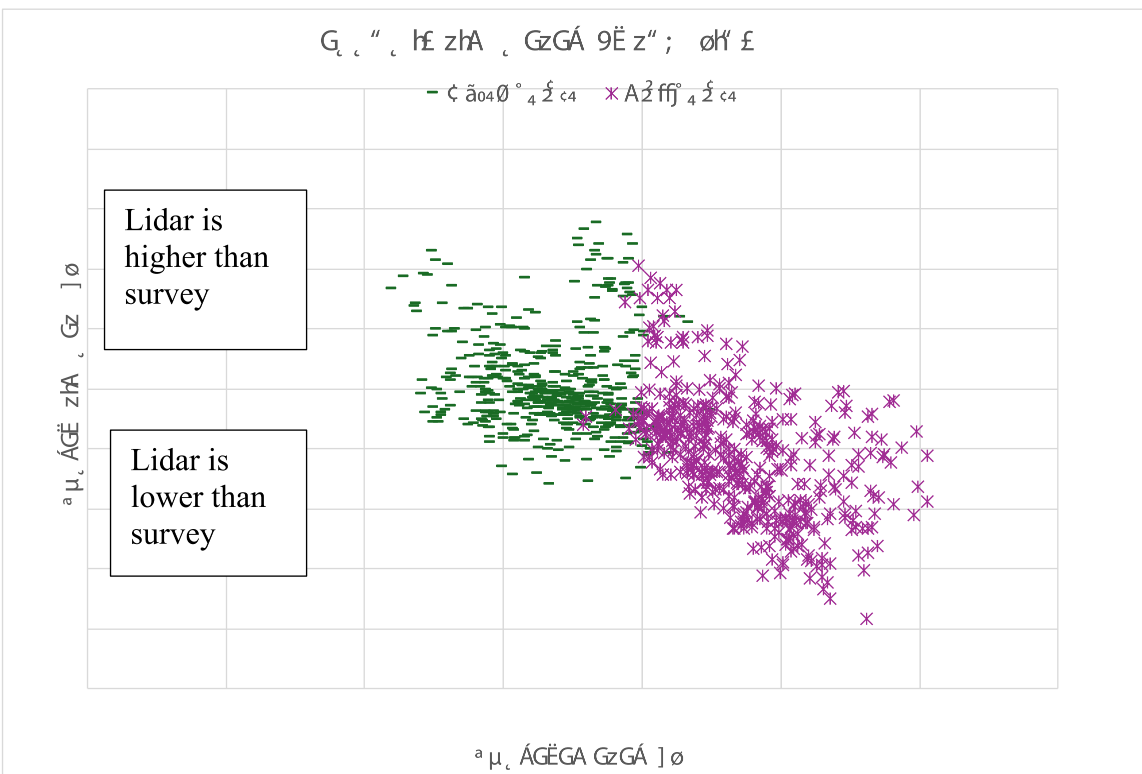
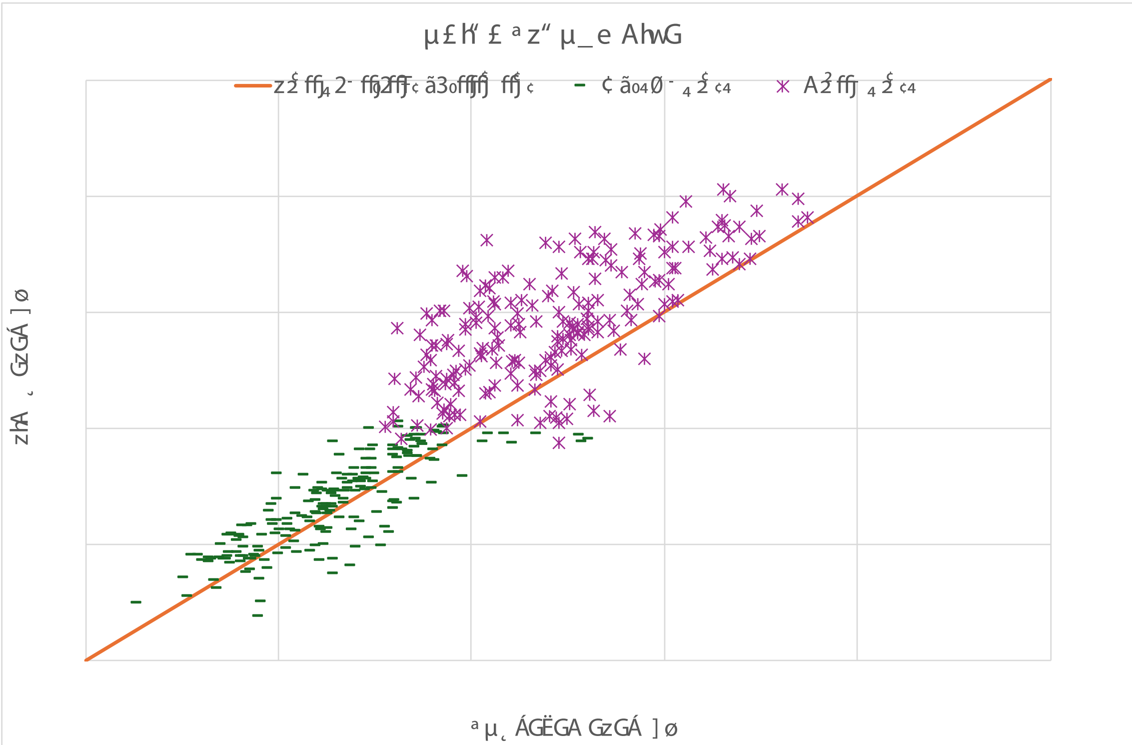

Lidar is higher than survey
Lidar is lower than survey

Figure 3. All survey data points along dikes and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)



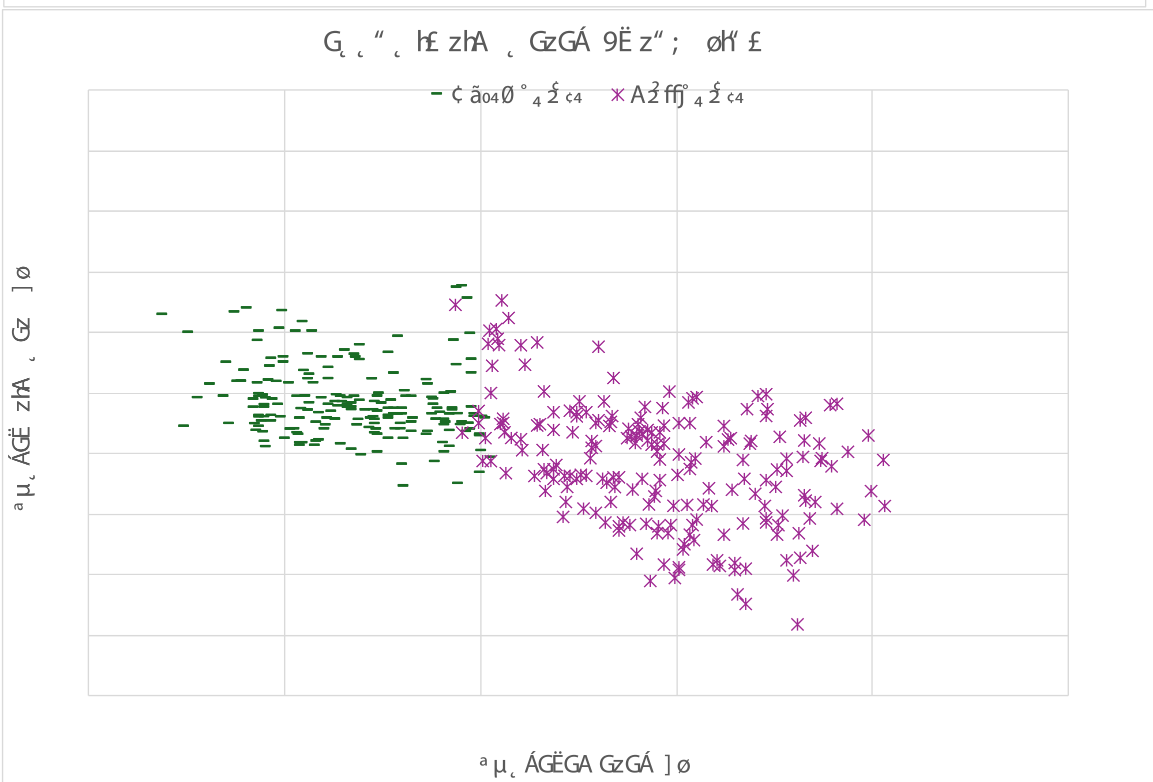


Figure 4. All survey data points along Union Slough dike and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)

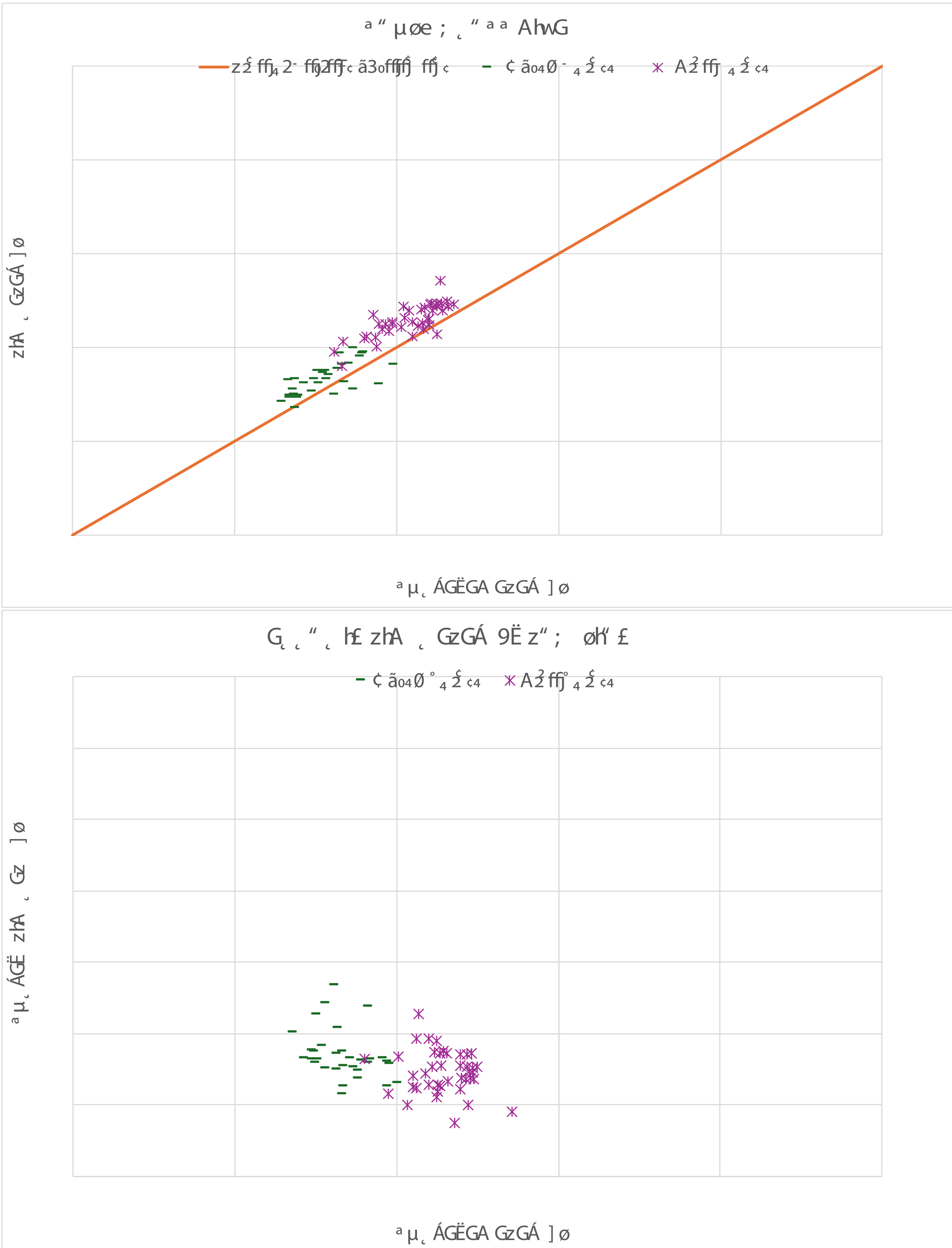


Figure 5. All survey data points along South Cross dike and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)

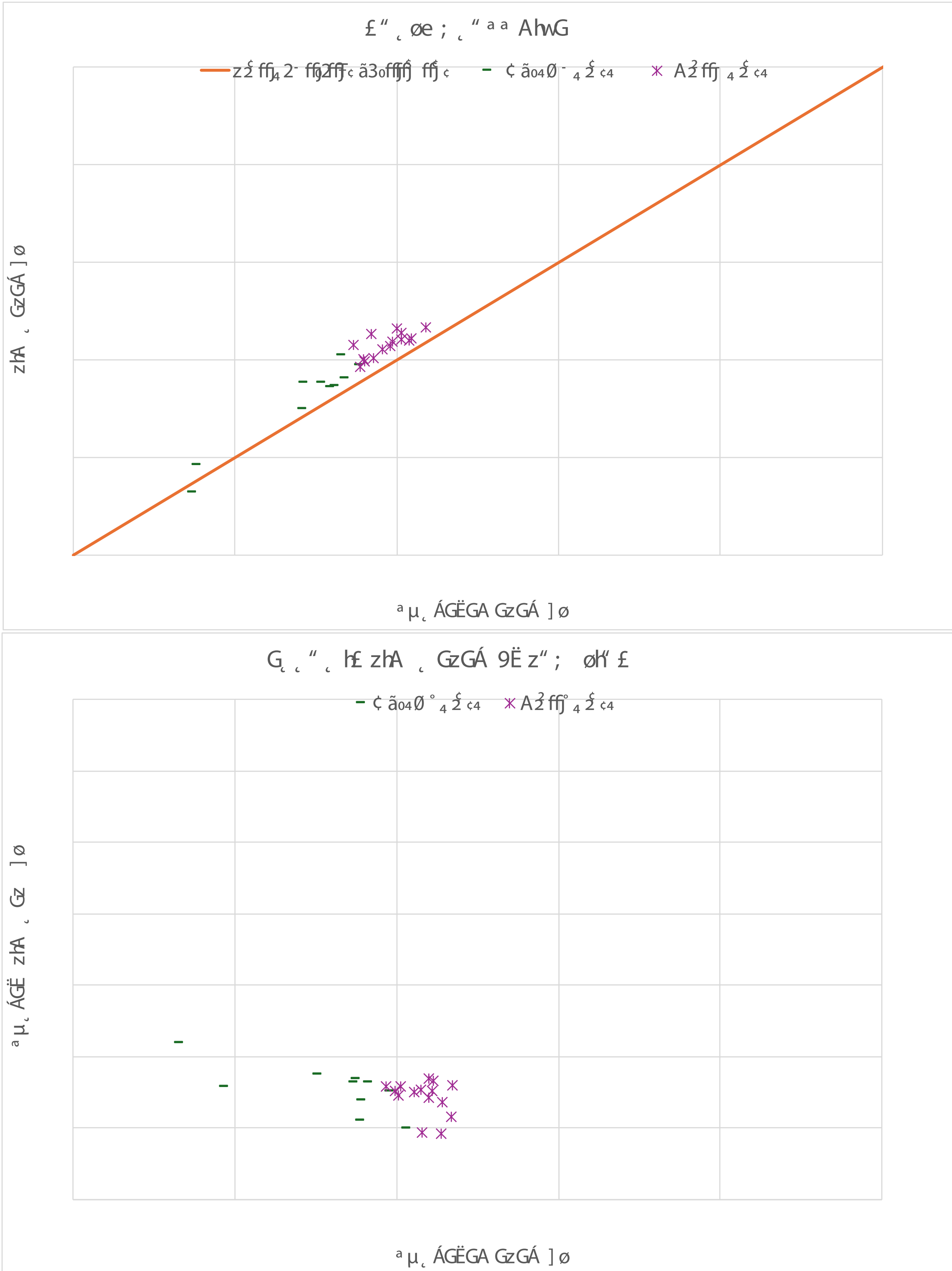


Figure 6. All survey data points along North Cross dike and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)

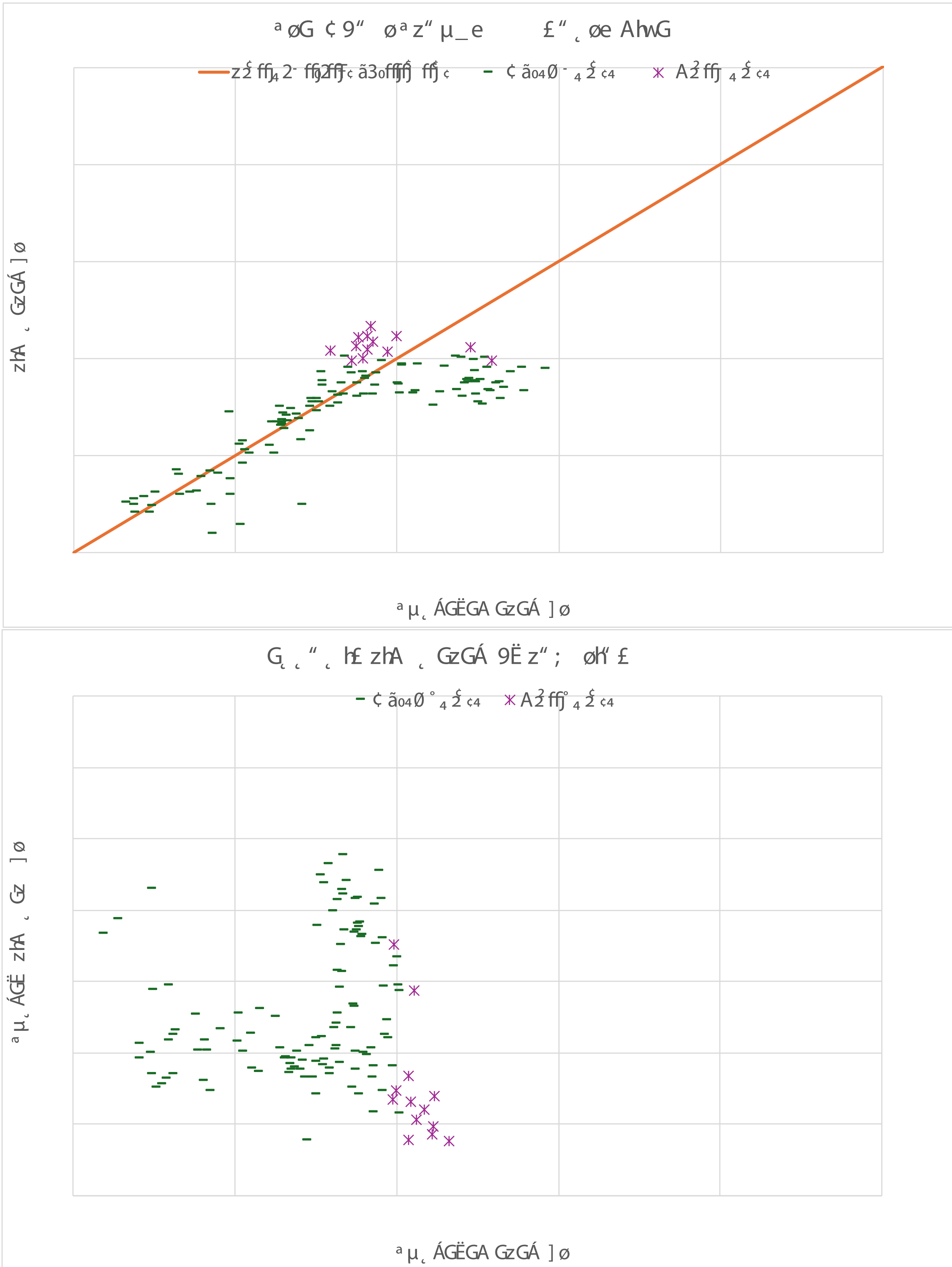


Figure 7. All survey data points along north portion of Steamboat Slough dike and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)

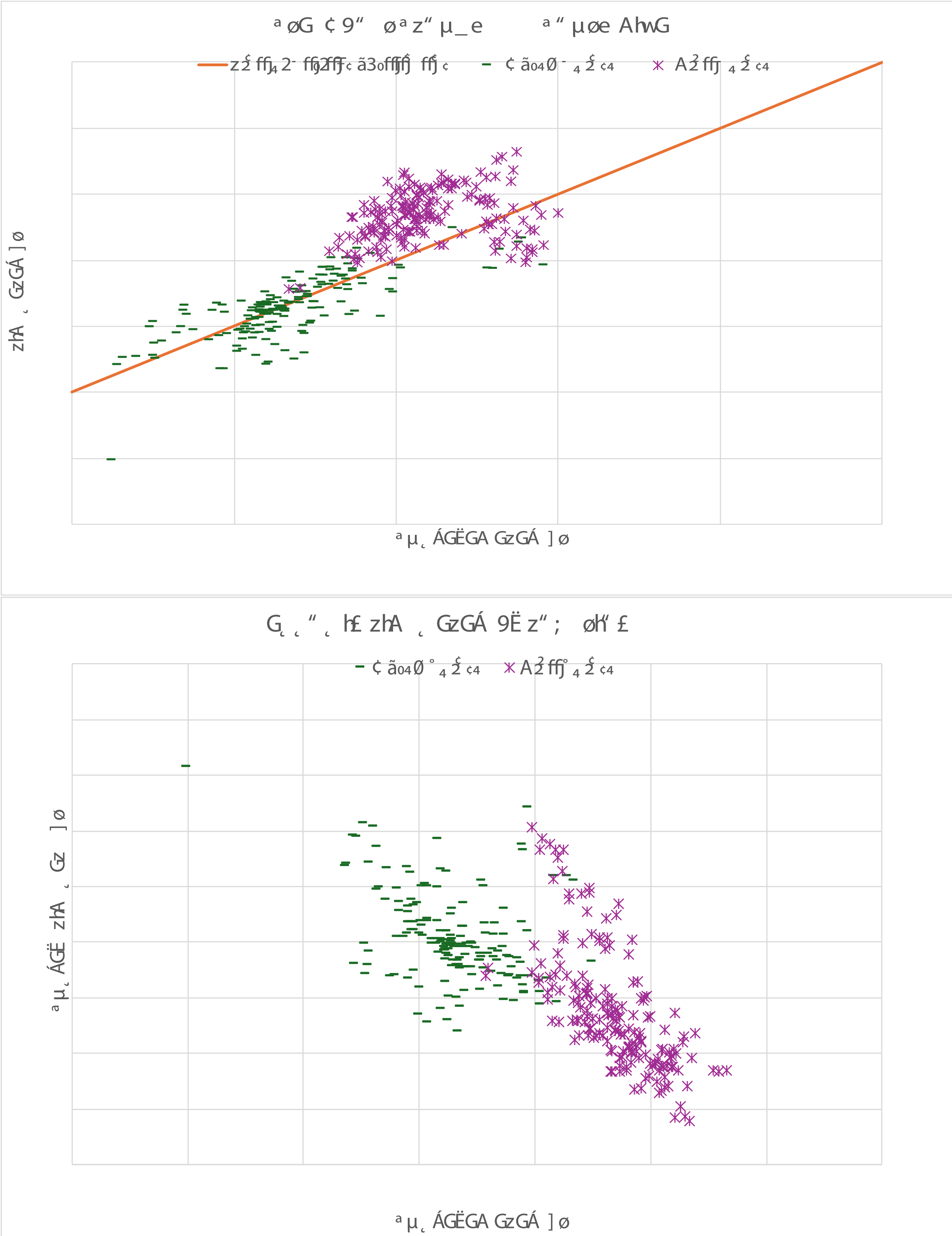


Figure 8. All survey data points along south portion of Steamboat Slough dike and adjacent marsh compared to lidar (above) and error in lidar used in civil design DTM being used to compute earthwork volumes (below)

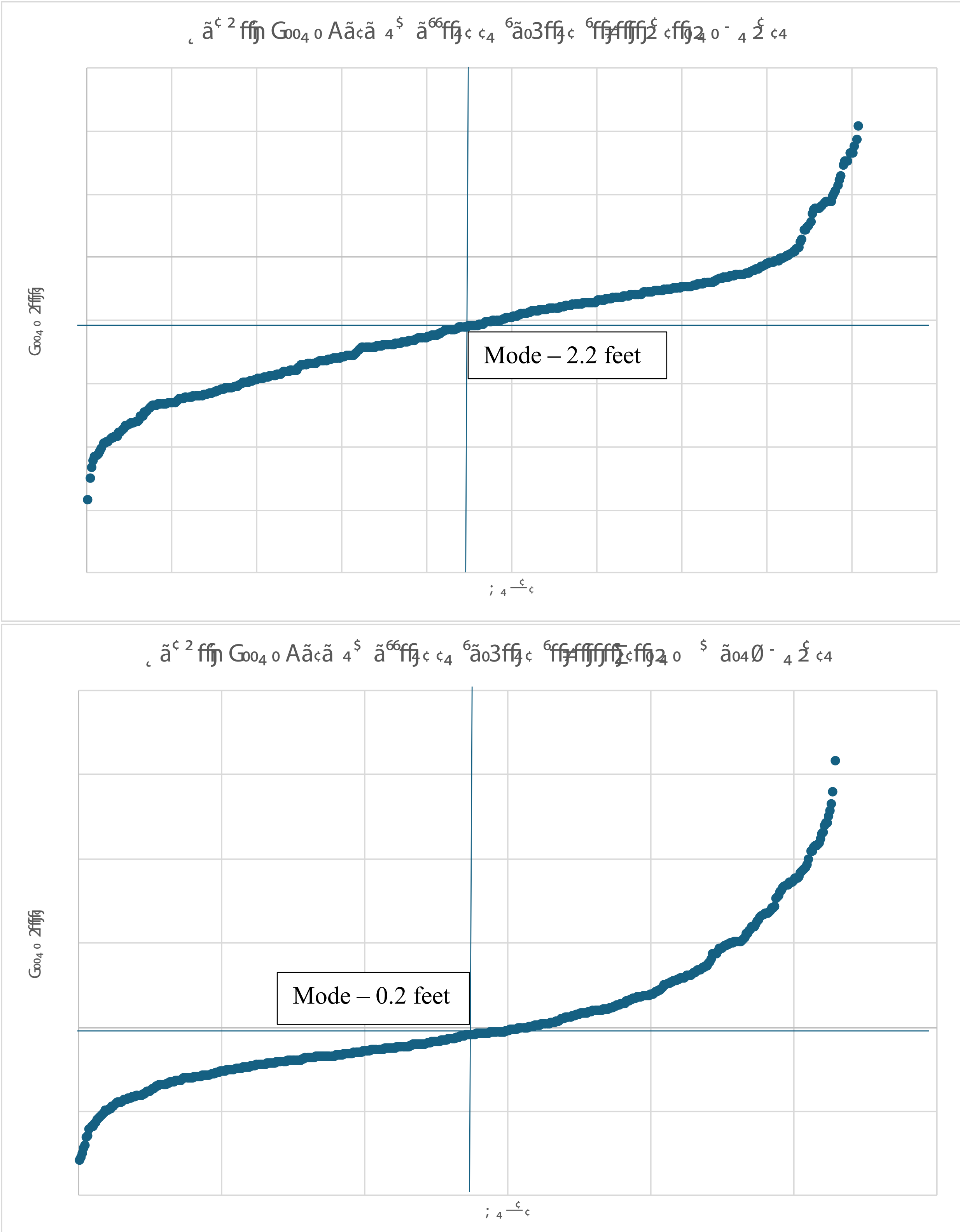


Figure 9. Ranked levee interior and exterior points lidar error showing mid-point error

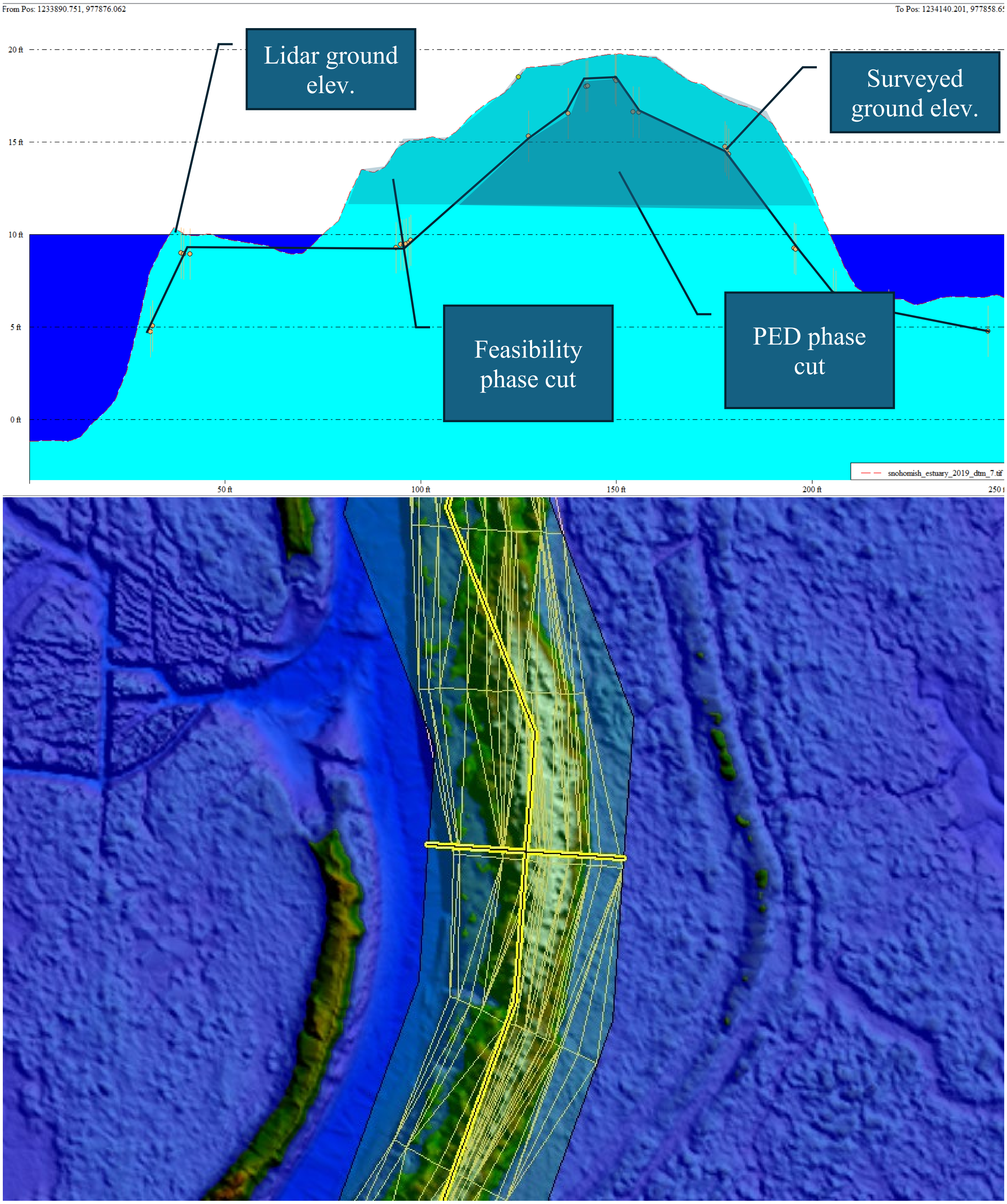


Figure 10. Union Slough representative cross section

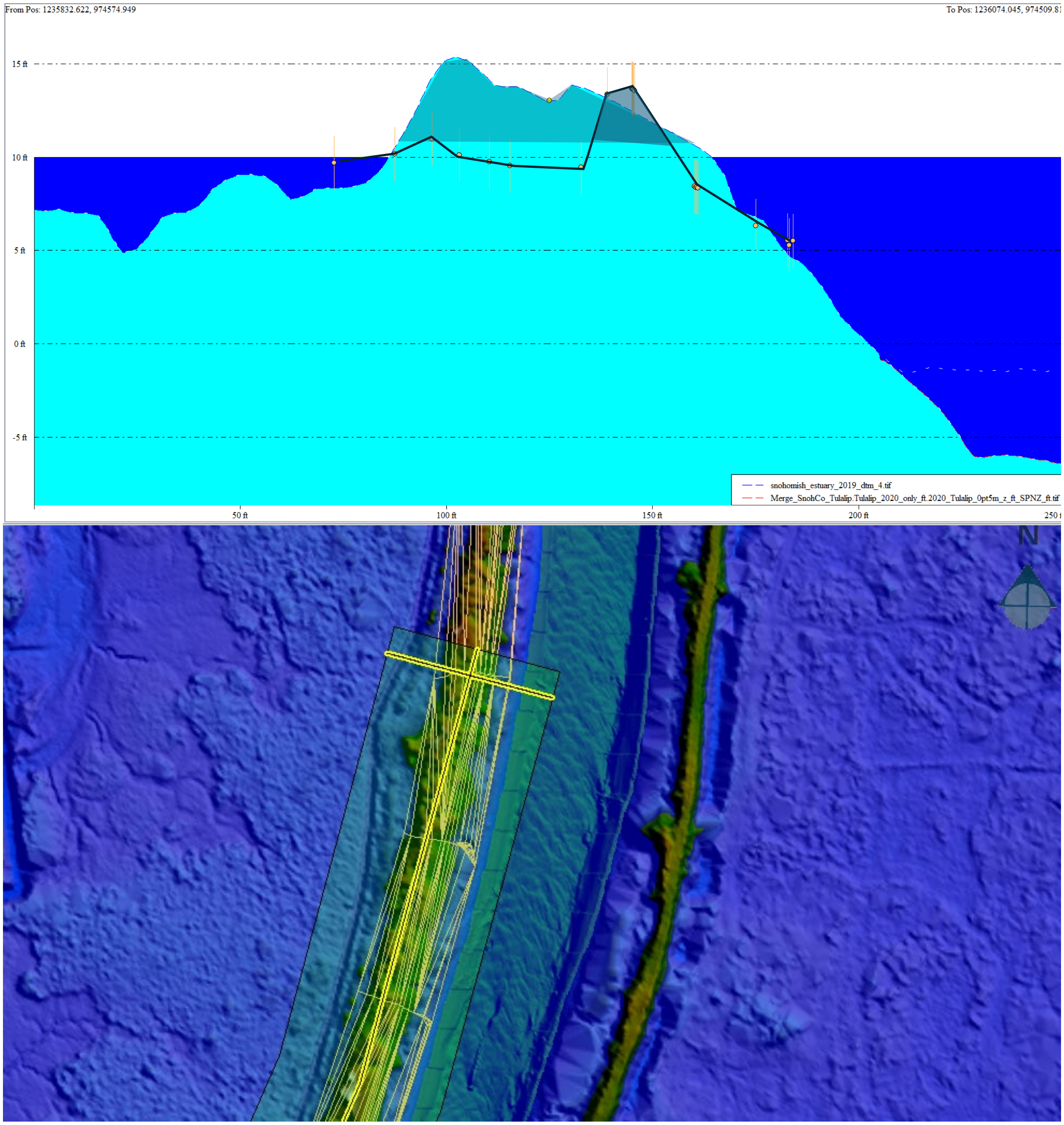


Figure 11. Steamboat Slough representative cross section