Development of Stage-Discharge Ratings for Site 4830 – South Boulder Creek at Sans Souci

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Prepared for:
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1.0 CERTIFICATION

I, Richard Spotts, state that the information presented in this report entitled, "Development of Stage-Discharge Ratings for Site 4830 – South Boulder Creek at Sans Souci," prepared for The Urban Drainage and Flood Control District, Denver, Colorado was prepared by me or by persons under my supervision and is correct to the best of my knowledge and information.

_____

Richard Spotts, P.E.
Registration No. 26155

2.0 INTRODUCTION

Water and Earth Technologies, Inc. (WET) was contracted by The Urban Drainage and Flood Control District (UDFCD) to develop a hydraulic rating at Site 4830, South Boulder Creek at Sans Souci. This station, located upstream of Route 93 is already instrumented to measure river stage.

Stage information for this site is telemetered in real time to local base stations that assess the flooding potential during large runoff events. In addition to stage, discharge information is valuable for decision-making. Stage-discharge rating relationships (ratings) are used to convert the stage, represented as a water depth in feet above a reference elevation monitored by a pressure transducer (PT) in the stream to values of discharge in cubic feet per second (cfs). The discharge rating developed in this report is based on precise measurement of the river channel and physical structures controlling flow and mathematical approximation of the hydraulics at this site.

This report includes the following sections:

- an introduction,
- a discussion of field survey methods,
- a discussion of office procedures for data reduction and analysis,
- a description of each site and a discussion and presentation of survey data and model results (including model output, a stage-discharge rating table and a plot of the rating curve, and recommendations relevant to the results),
- a compilation of references, and
- cross section field survey notes.

3.0 FIELD SURVEY METHODS

A theoretical step-backwater technique using the U.S. Army Corps of Engineers HEC-RAS computer model (USACOE 2002) was used to develop the stage-discharge ratings. The modeling typically requires data for five cross sections at a site. Typically, the cross section in which stage is observed is bracketed by one or more cross sections both upstream and downstream. Cross sections were surveyed from left to right looking downstream. Cross sections were numbered from downstream to upstream. Bench marks and end points of each cross section were marked as appropriate. A mapping grade GPS unit was used to determine the latitude and longitude of monument bench marks at each site, the stage measurement sensor housing (with the cap removed) and each cross-section end point so that cross sections and bench marks can be easily located in the future. Additionally, the coordinates were used to establish cross-section orientation in the HEC-RAS model. A self-leveling level, tape and survey rod were used to measure each point in the cross section and to relate streambed and water-surface cross section elevations to the bench mark elevation.

Variations in channel roughness (Manning's n value) were determined for each cross section. The main channel and overbank areas within each cross section were subdivided into n-value break points (locations where n-values change), and n-values specific to each subdivision were estimated. A current meter flow measurement was made and was referenced to the water-surface elevation in the gaged cross section. Section velocity measurements and discharge determinations were made using the midsection method. This information was used to determine the Manning's n-value associated with the measured stage, low-flow discharge, and gradient of

the water surface between cross sections. The information was used to check the calibration of the HEC-RAS model run associated with the measured discharge.

Photos of the site and each surveyed cross section were taken. Cross-section location selection, spacing, and orientation; surveying techniques; roughness parameter selection (Manning's n values); current meter/velocity measurement techniques; and photographic and methods documentation followed standard protocols (Arcement and Schneider 1990; Barnes 1987; Benson and Dalrymple 1984; Dalrymple and Benson 1984; Harrelson et. al. 1994; Schulz 1974; U.S Army COE 2002; U.S. Geological Survey 1977).

4.0 DATA REDUCTION, MODELING AND ANALYSIS

As previously mentioned, the U.S. Army COE HEC-RAS computer model was used to analyze the field data and develop the stage-discharge rating relationships. HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The steady flow water-surface profile component of the modeling system was used to calculate water surface profiles and elevations for a wide range in flows, from very low flow to flood flows, or flow that would occur at the highest stage contained within the channel and surveyed overbank. The basic computational procedure is based on the solution of a one-dimensional energy equation describing gradually varied uniform flow through the channel. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head).

WET's HEC-RAS modeling input applied the initial assumption that the downstream modeling boundary condition was controlled by normal depth as defined by measured channel conditions and slope. At higher flows however, other cross sections may control the flow. These controlling locations and conditions are additional valuable output from the HEC–RAS model. Output values from the HEC-RAS model include the predicted water surface elevations at each cross section for a range of known discharges. The water surface predictions at the pressure transducer cross section were used to develop the stage-discharge rating for the site.

Where possible, the current rating defined by UDFCD was compared to the HEC-RAS modeling results based on the WET channel survey.

5.0 RATING DEVELOPMENT

A general site investigation was performed by WET staff on January 10, 2006. The site was surveyed by WET staff on January 26, 2006. River cross sections were surveyed to describe the channel and used as input data to the HEC-RAS hydraulic model in order to develop a stage–discharge relationship at the PT cross section.

Site 4830, South Boulder Creek at Sans Souci is located on City of Boulder Open Space property just northwest of the intersections of Route 93 and Route 170, South of Boulder, CO (circled in red in Figure 1).

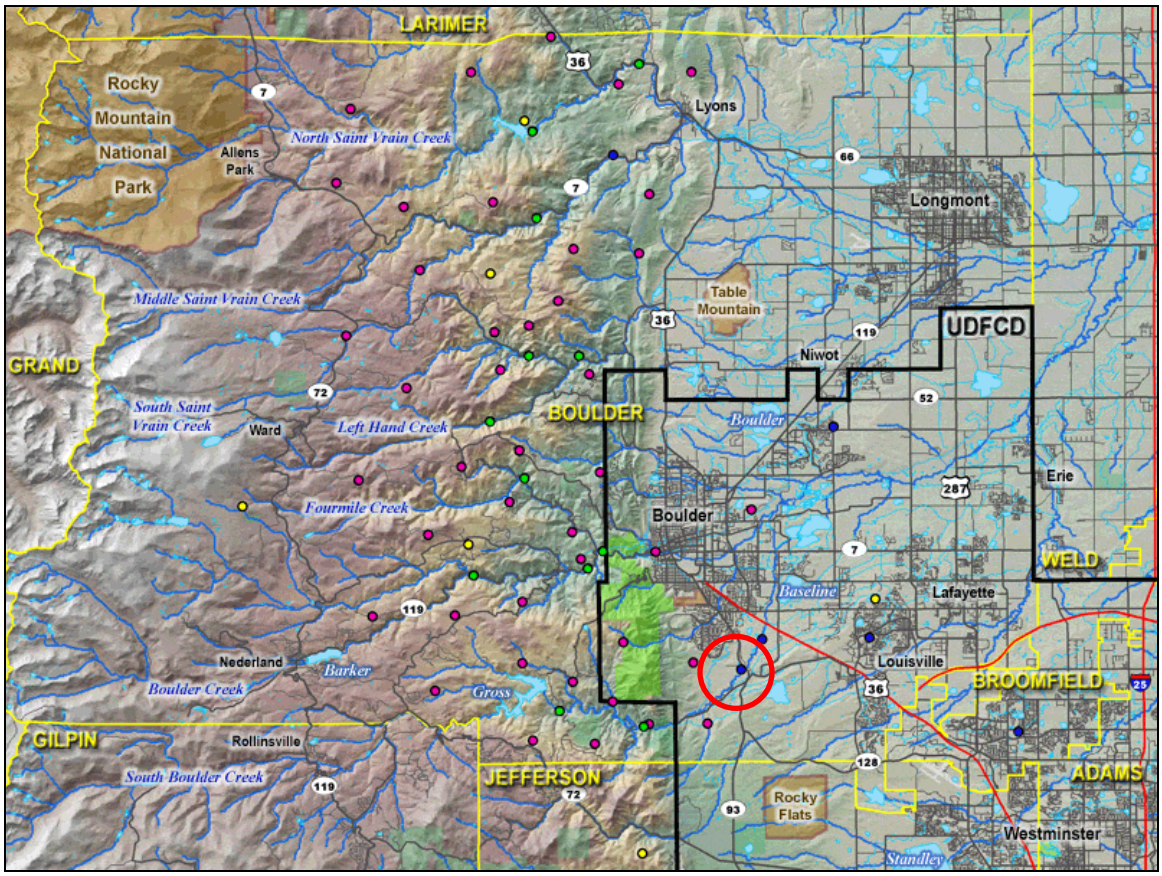

Figure 1. Site 4830 Location Map.

Figure 2. South Boulder Creek at Site 4830 Looking Upstream from the Gaged Cross Section.

5.1 Site 4830 Channel Survey

On January 26, 2006 WET surveyed five channel cross sections to define the geometry of the river channel and overbank areas at this site. An aerial photo with approximate locations of cross sections and landmarks is presented in Figure 3. Photos of each cross section are presented in Figure 4 - Figure 8. Additional photos of the overbank topography upstream of the PT are presented in Figure 9. A monument was placed near the standpipe as an additional vertical control point for the survey. This monument is shown in Figure 10.

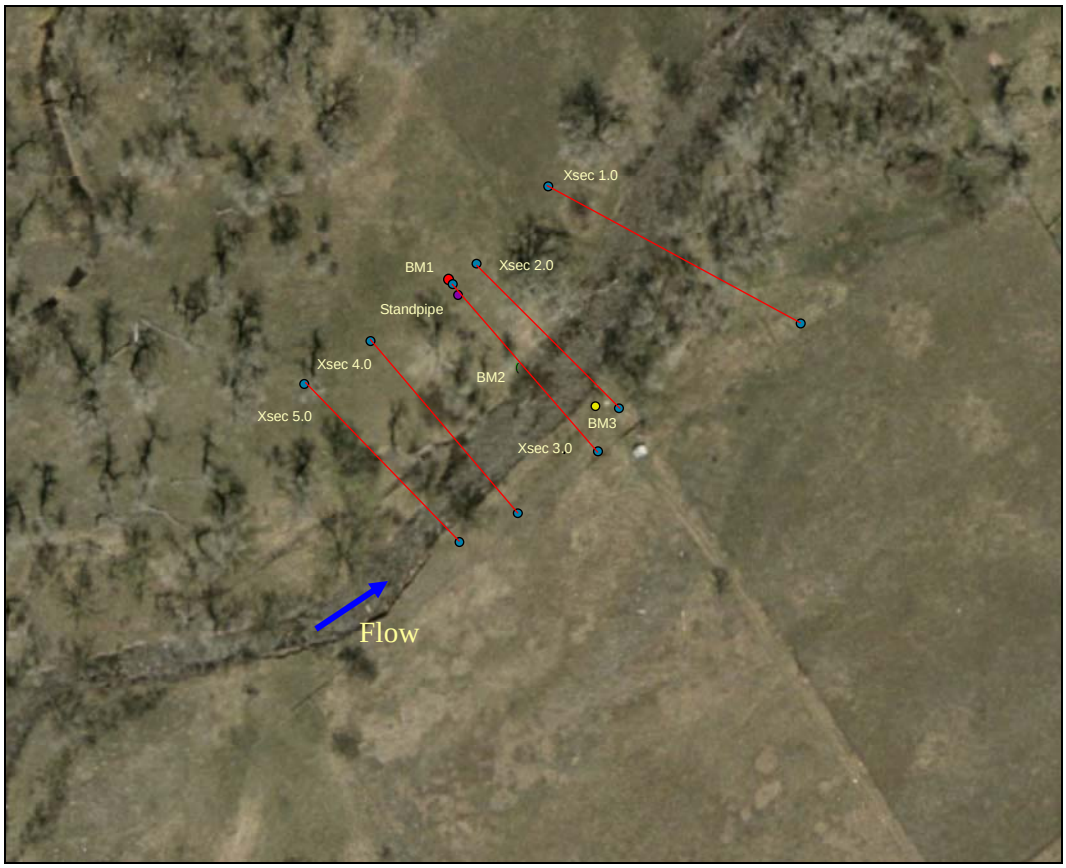

Figure 3. Site 4830 Cross Section and Landmark Locations.

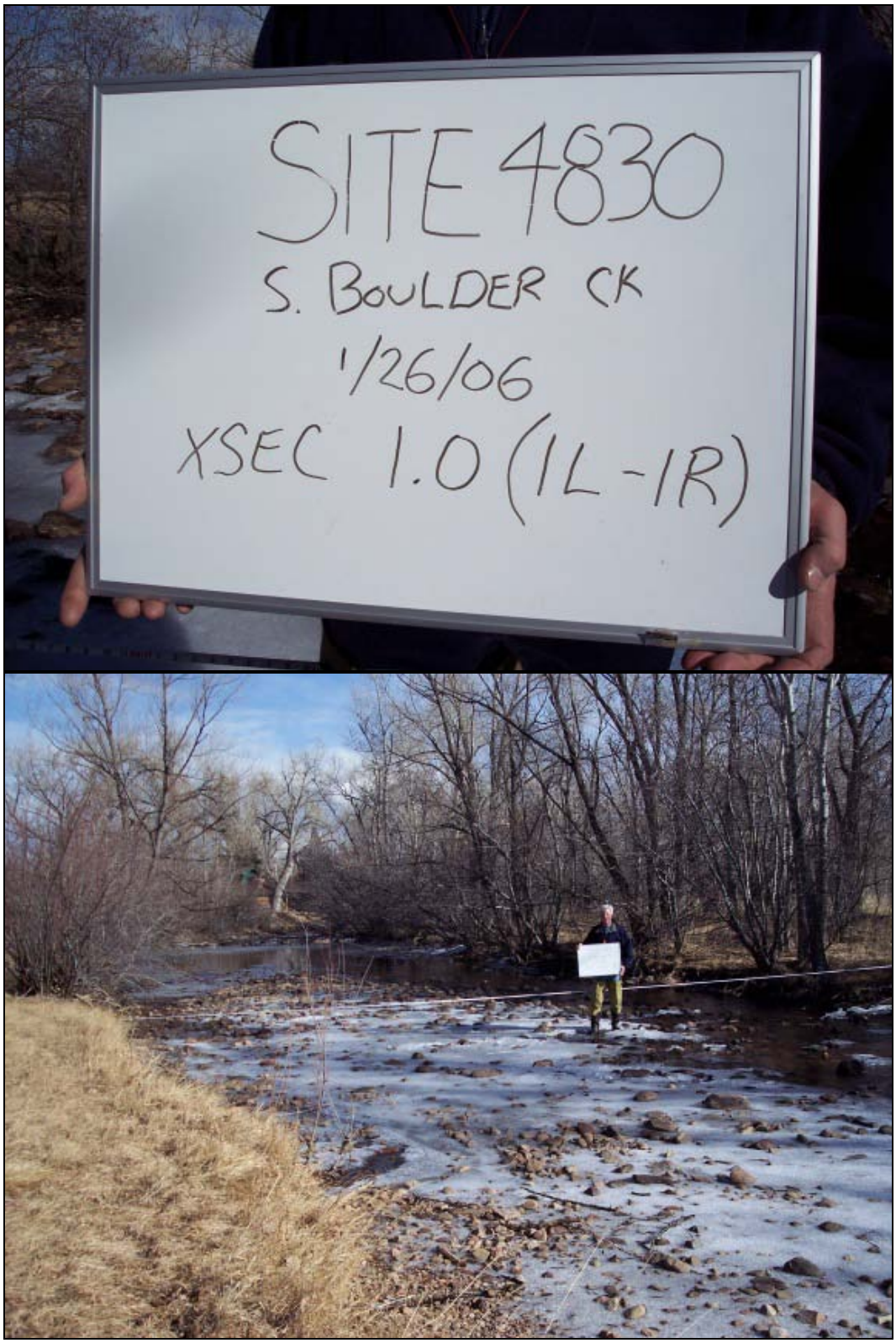

Figure 4. Site 4830 Cross-Section 1.0 Looking Downstream.

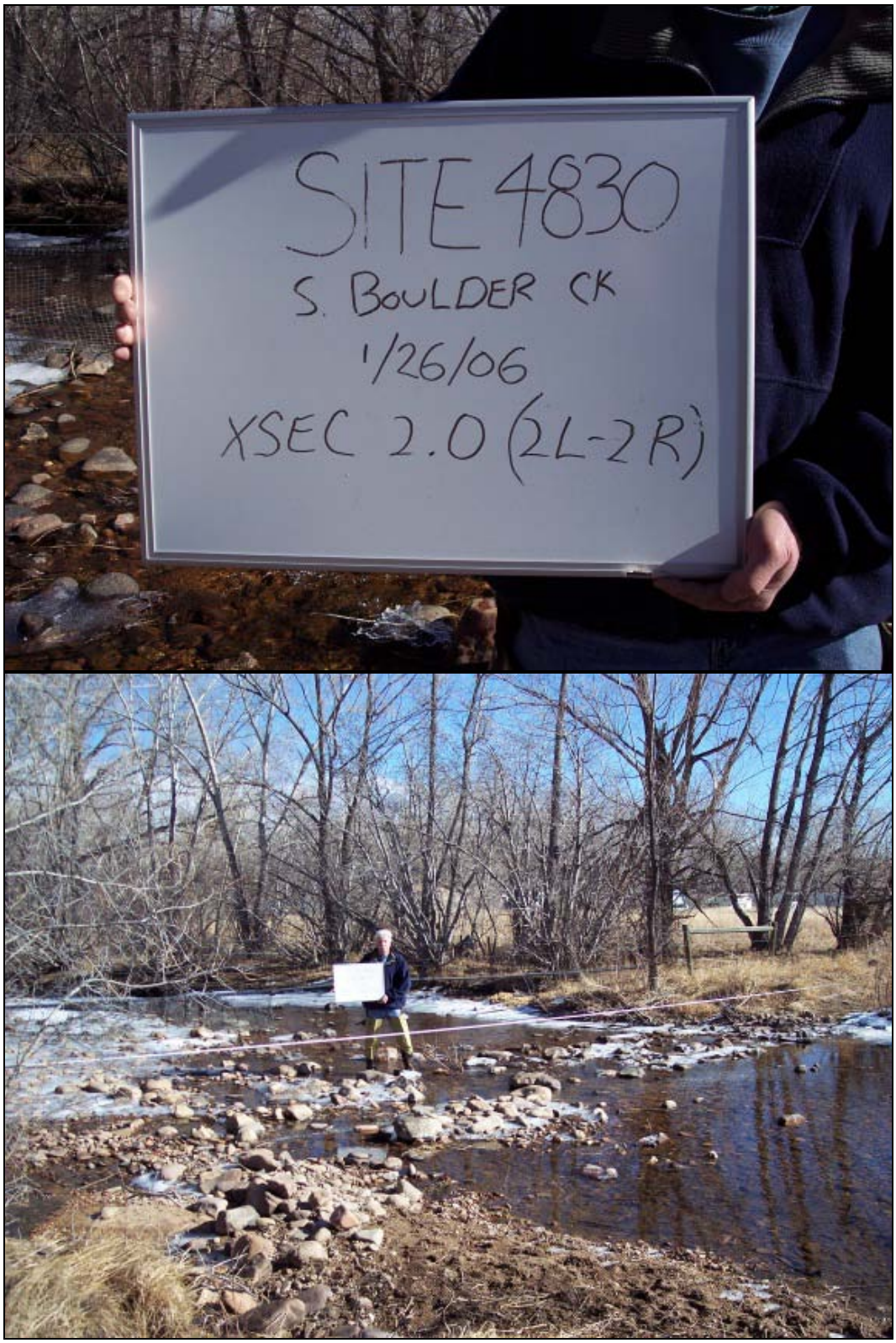

Figure 5. Site 4830 Cross-Section 2.0 Looking Downstream.

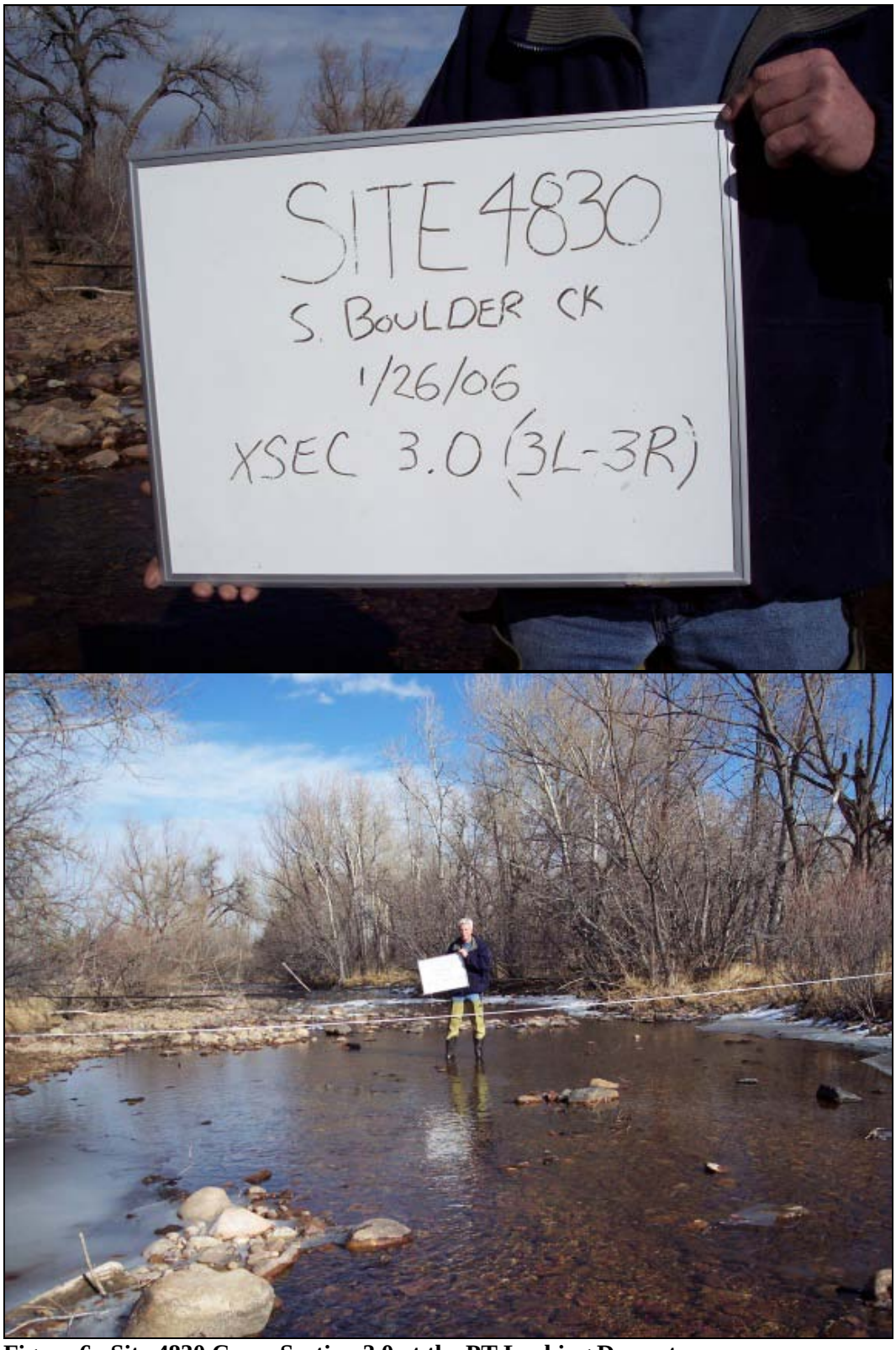

Figure 6. Site 4830 Cross-Section 3.0 at the PT Looking Downstream.

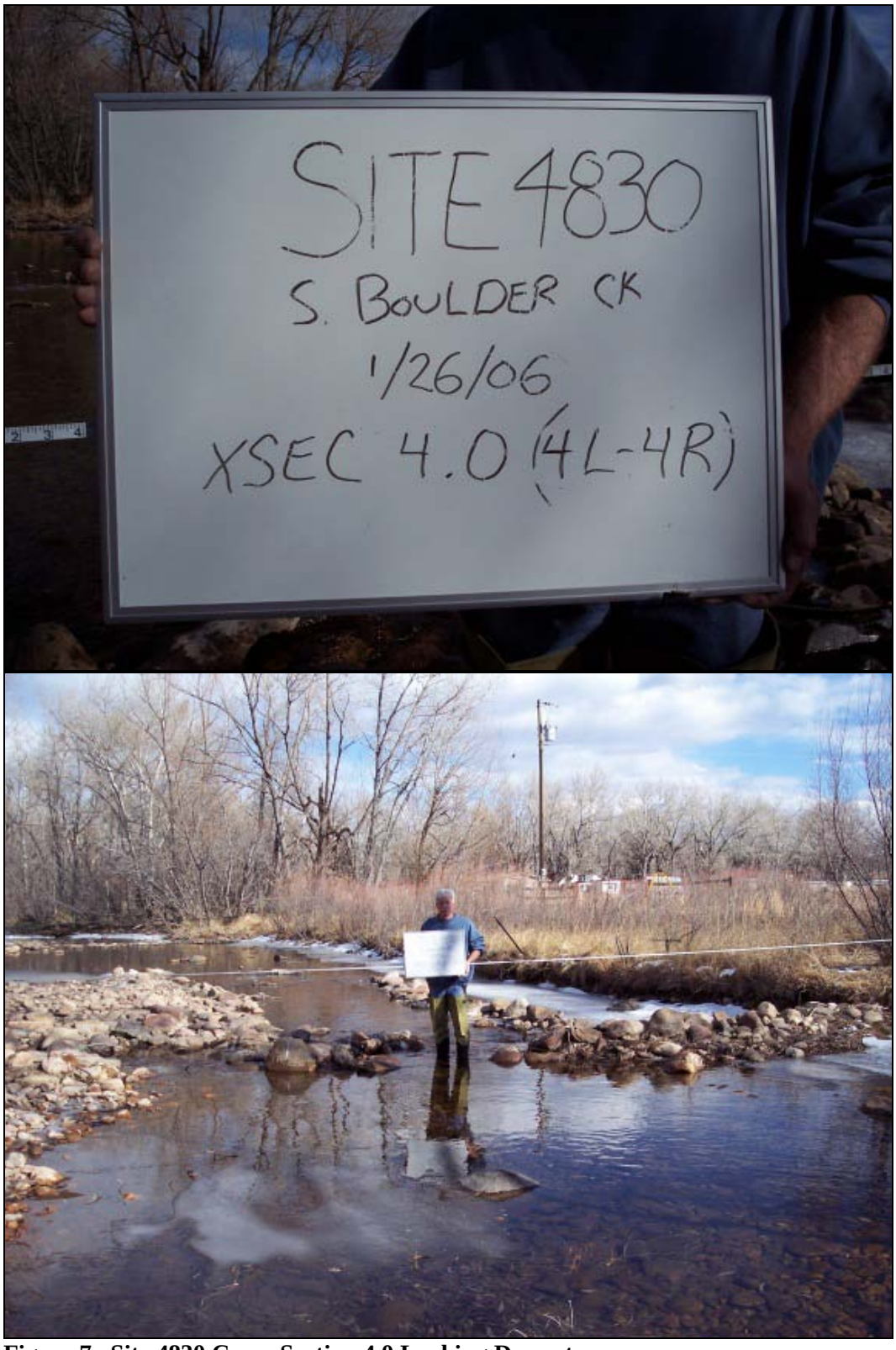

Figure 7. Site 4830 Cross-Section 4.0 Looking Downstream.

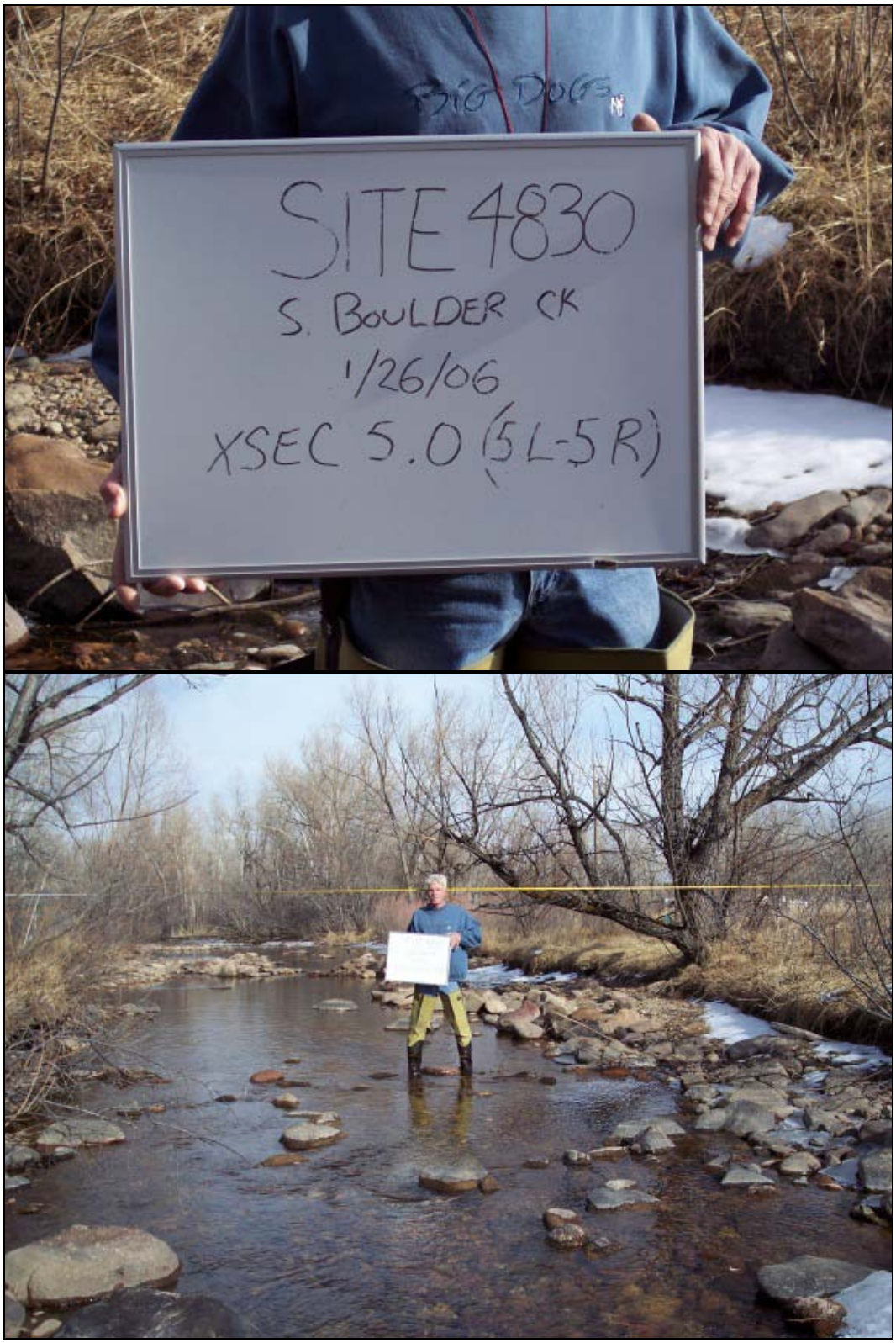

Figure 8. Site 4830 Cross-Section 5.0 Looking Downstream.

Figure 9. Views of the Side Channel on the Left Bank of Site 4830 Cross-Section 5.0 Looking Upstream.

Figure 10. Site 4830 Location of the WET-Installed Survey Monument near the Standpipe at the End Point of Cross-Section 3.0.

The reduced survey field notes for the five channel cross sections are presented in Figure 11 and Figure 12.

Benchmarks

	HI (ft amsl)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	5472.13	5.10	5467.03	BM1 - WET installed cap near standpipe, elevation GPS (corrected)
		6.28	5465.85	BM2 - top of PT pipe with cap removed
		6.21	5465.92	BM3 - top of concrete vault bottom (not on lid) on River right

Figure 11. Site 4830 Bench Mark Survey Notes.

Cross Section 1.0
downstream

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	0.0	6.10	5466.03	Pin 1L
	8.0	7.36	5464.77	
	15.4	7.74	5464.39	
	22.0	7.48	5464.65	
	27.8	7.66	5464.47	
	32.0	8.12	5464.01	
	46.5	8.17	5463.96	TOB
	47.0	9.25	5462.88	
	50.0	9.66	5462.47	LEW
	53.5	9.65	5462.48	
	61.0	9.75	5462.38	
	69.0	9.90	5462.23	
	72.0	9.46	5462.67	
	74.5	10.20	5461.93	
	77.0	9.80	5462.33	
	81.5	10.05	5462.08	
	84.0	9.70	5462.43	
	89.5	10.05	5462.08	REW
	92.0	8.65	5463.48	TOB
	101.0	8.10	5464.03	
	104.5	8.12	5464.01	
	119.0	7.32	5464.81	
	128.0	7.10	5465.03	
	143.0	7.10	5465.03	
	155.0	8.10	5464.03	
	179.5	7.50	5464.63	
	188.0	7.64	5464.49	
	207.5	6.50	5465.63	Pin 1R

Cross Section 2.0
PT d/s control

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	0.0	5.22	5466.91	Pin 2L
	5.0	5.40	5466.73	
	11.5	6.74	5465.39	
	32.0	6.18	5465.95	
	41.0	6.85	5465.28	
	62.3	7.01	5465.12	
	62.5	8.34	5463.79	TOB
	64.2	8.54	5463.59	LEW
	70.4	8.22	5463.91	
	74.8	7.75	5464.38	
	76.5	8.41	5463.72	
	82.5	8.41	5463.72	
	84.0	8.05	5464.08	
	86.0	8.75	5463.38	
	90.5	8.34	5463.79	
	94.0	8.79	5463.34	
	97.0	8.25	5463.88	
	99.8	8.53	5463.60	
	102.2	8.69	5463.44	
	105.2	8.24	5463.89	
	108.4	8.05	5464.08	REW
	112.0	7.62	5464.51	
	115.0	6.65	5465.48	TOB
	125.5	6.35	5465.78	
	130.0	6.41	5465.72	
	136.0	5.89	5466.24	
	146.8	5.39	5466.74	Pin 2R

Cross Section 3.0
at PT

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	0.0	5.10	5467.03	Pin 3L
	1.0	5.04	5467.09	Standpipe
	11.5	5.38	5466.75	
	17.0	6.23	5465.90	
	29.5	6.07	5466.06	
	33.7	6.38	5465.75	
	47.0	6.35	5465.78	
	58.0	6.78	5465.35	
	64.8	6.48	5465.65	
	67.8	6.65	5465.48	TOB
	69.0	7.76	5464.37	left edge of channel
	74.0	7.79	5464.34	
	78.7	8.15	5463.98	LEW
	82.0	8.31	5463.82	middle of intake pipe
	84.8	8.35	5463.78	end of intake pipe
	87.8	8.60	5463.53	
	93.6	8.52	5463.61	
	96.0	8.47	5463.66	
	101.8	8.37	5463.76	
	106.6	8.68	5463.45	
	110.7	8.60	5463.53	
	115.4	8.03	5464.10	REW
	118.0	6.54	5465.59	TOB
	126.5	6.76	5465.37	
	136.0	5.84	5466.29	
	147.7	5.32	5466.81	Pin 3R

Cross Section 4.0
below confluence of side channel

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	0.0	4.10	5468.03	Pin 4L
	21.0	4.70	5467.43	
	42.0	4.88	5467.25	
	80.5	5.86	5466.27	TOB
	84.3	7.47	5464.66	edge of channel
	88.3	7.65	5464.48	
	96.0	7.46	5464.67	
	101.2	7.96	5464.17	
	103.7	8.36	5463.77	
	105.5	7.71	5464.42	top of control
	109.5	7.91	5464.22	top of control
	109.7	8.63	5463.50	center channel
	111.0	8.75	5463.38	center channel
	112.5	7.76	5464.37	top of control
	114.2	8.20	5463.93	top of control
	116.7	6.84	5465.29	
	122.0	7.36	5464.77	
	127.8	7.03	5465.10	edge of channel
	129.0	5.96	5466.17	TOB
	132.0	5.72	5466.41	
	136.2	6.03	5466.10	
	142.0	5.58	5466.55	
	148.0	4.14	5467.99	
	151.3	4.14	5467.99	
	156.6	3.93	5468.20	Pin 4R

Cross Section 5.0
upstream

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	0.0	3.30	5468.83	Pin 5L
	17.0	3.30	5468.83	
	35.0	3.55	5468.58	
	61.0	4.58	5467.55	
	66.0	6.25	5465.88	in side channel
	78.0	5.80	5466.33	out of side channel
	80.5	6.35	5465.78	in side channel
	89.0	7.18	5464.95	in side channel
	93.0	6.96	5465.17	in side channel
	94.4	5.65	5466.48	at large tree
	108.5	5.07	5467.06	TOB
	113.5	5.46	5466.67	
	114.5	8.05	5464.08	LEW
	116.3	7.88	5464.25	
	116.7	8.70	5463.43	
	120.5	8.59	5463.54	
	124.4	8.50	5463.63	
	125.4	7.90	5464.23	
	127.0	7.82	5464.31	
	127.5	8.32	5463.81	
	129.8	8.45	5463.68	
	132.2	7.94	5464.19	REW
	138.5	6.14	5465.99	edge of channel
	139.5	5.64	5466.49	TOB
	143.5	4.68	5467.45	
	150.0	2.90	5469.23	
	152.0	2.90	5469.23	
	158.0	2.90	5469.23	
	163.6	2.76	5469.37	Pin 5R

Figure 12. Site 4830 Reduced Cross Section Survey Notes.

5.2 Site 4830 HEC-RAS Modeling

The five surveyed cross sections were input to the HEC-RAS modeling software (Figure 13).

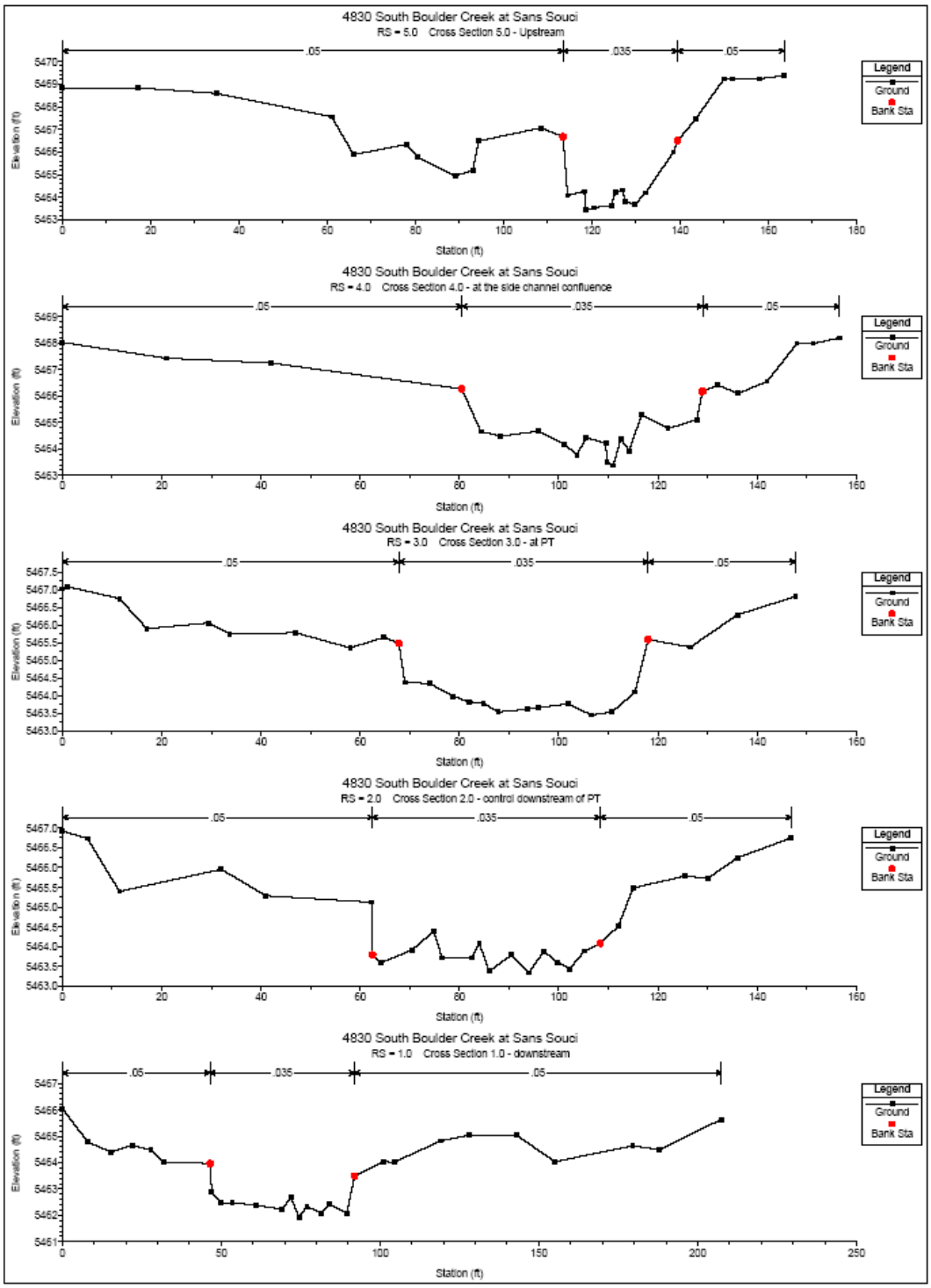

Figure 13. Site 4830 Graphical Description of Surveyed Cross Sections.

Manning's n value for the main channel sections was set to 0.035. Overbank sections were set to 0.5.

Downstream normal depth control was assumed as the modeling boundary condition, with the downstream channel bed slope assumed to be the channel slope of the surveyed reach of 0.0058 ft/ft. A range of flow conditions was simulated. The maximum flow simulated was the highest discharge where the model-predicted water surface elevation was contained completely within the surveyed cross sections. The predicted water surface at this point, 1,200 cfs, is presented in Figure 14.

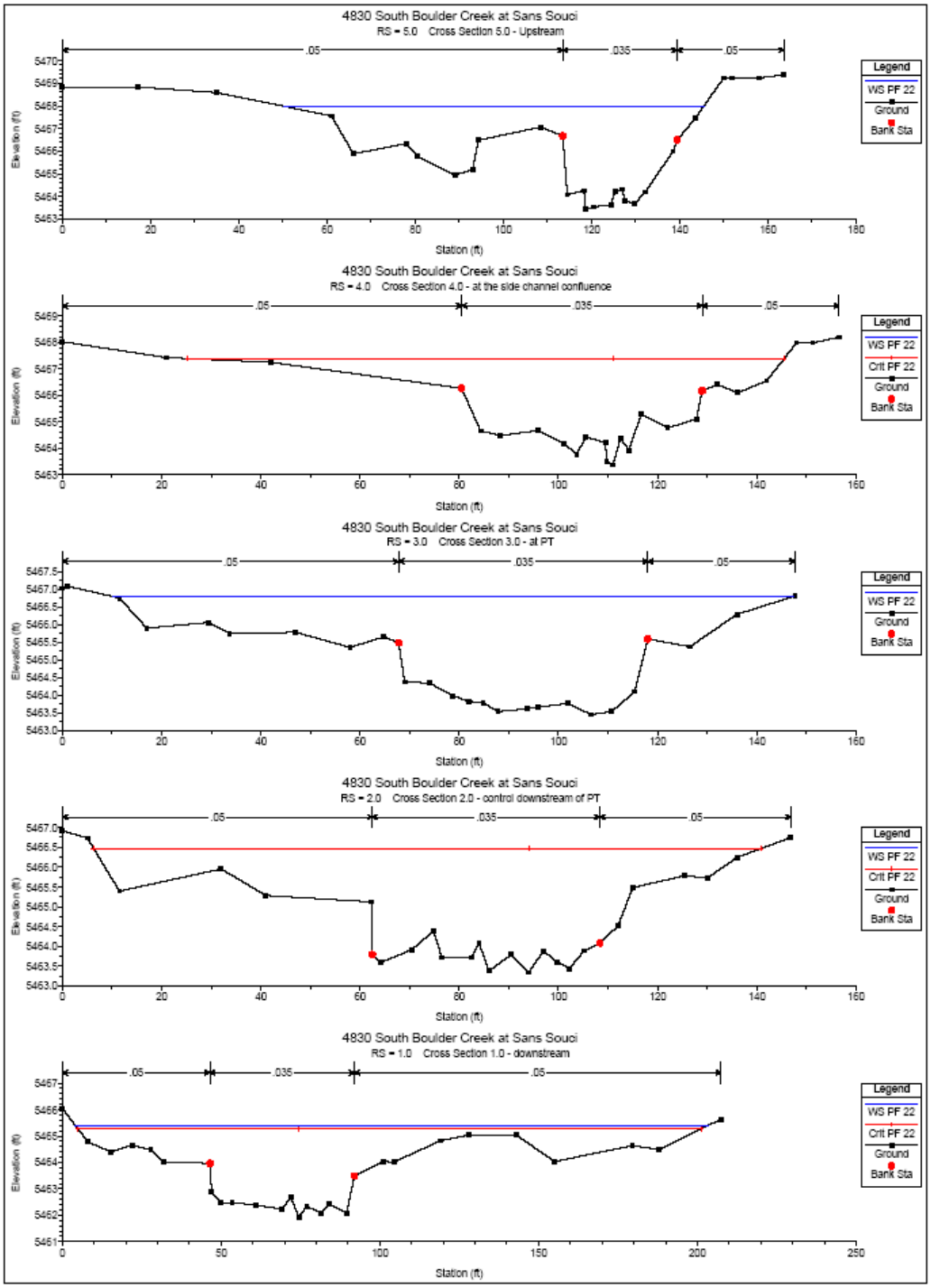

Figure 14. Site 4830 HEC-RAS Water Surface Elevations at Maximum Flow at Cross Section 3.0.

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
4830	5.0	PF 1	0.10	5463.43	5463.66		5463.66	0.000324	0.17	0.60	5.66	0.09
4830	5.0	PF 2	1.00	5463.43	5463.95		5463.95	0.000327	0.33	3.02	10.16	0.11
4830	5.0	PF 3	5.00	5463.43	5464.33		5464.34	0.000664	0.61	8.15	18.27	0.16
4830	5.0	PF 4	10.00	5463.43	5464.54		5464.55	0.000752	0.82	12.15	19.10	0.18
4830	5.0	PF 5	50.00	5463.43	5465.17		5465.23	0.002049	2.00	25.53	27.67	0.33
4830	5.0	PF 6	100.00	5463.43	5465.54		5465.67	0.003245	2.91	37.02	33.45	0.43
4830	5.0	PF 8	200.00	5463.43	5466.00		5466.25	0.005172	4.20	53.69	42.41	0.56
4830	5.0	PF 10	300.00	5463.43	5466.32		5466.69	0.006383	5.10	69.61	54.75	0.63
4830	5.0	PF 12	400.00	5463.43	5466.60		5467.06	0.007287	5.83	85.04	59.67	0.68
4830	5.0	PF 14	500.00	5463.43	5466.85		5467.39	0.007520	6.35	101.44	69.98	0.70
4830	5.0	PF 16	600.00	5463.43	5467.09		5467.68	0.007496	6.74	119.83	79.63	0.71
4830	5.0	PF 17	700.00	5463.43	5467.35		5467.93	0.006851	6.83	140.16	81.44	0.69
4830	5.0	PF 18	800.00	5463.43	5467.52		5468.14	0.006922	7.12	154.59	82.66	0.70
4830	5.0	PF 19	900.00	5463.43	5467.66		5468.34	0.007379	7.56	165.82	85.84	0.73
4830	5.0	PF 20	1000.00	5463.43	5467.77		5468.54	0.007888	8.00	176.17	89.26	0.76
4830	5.0	PF 21	1100.00	5463.43	5467.90		5468.72	0.008272	8.38	187.10	92.73	0.78
4830	5.0	PF 22	1200.00	5463.43	5467.98		5468.89	0.008664	8.82	195.55	95.33	0.81
4830	4.0	PF 1	0.10	5463.38	5463.64		5463.64	0.000705	0.33	0.30	1.72	0.14
4830	4.0	PF 2	1.00	5463.38	5463.88		5463.90	0.005802	1.21	0.82	3.11	0.42
4830	4.0	PF 3	5.00	5463.38	5464.13		5464.22	0.020212	2.47	2.03	6.88	0.80
4830	4.0	PF 4	10.00	5463.38	5464.27	5464.27	5464.42	0.029295	3.09	3.24	10.61	0.99
4830	4.0	PF 5	50.00	5463.38	5464.81		5464.98	0.017317	3.27	15.31	32.89	0.84
4830	4.0	PF 6	100.00	5463.38	5465.10		5465.33	0.016195	3.84	26.07	42.07	0.86
4830	4.0	PF 8	200.00	5463.38	5465.48		5465.81	0.013570	4.63	43.18	45.85	0.84
4830	4.0	PF 10	300.00	5463.38	5465.78		5466.21	0.012517	5.26	56.99	46.89	0.84
4830	4.0	PF 12	400.00	5463.38	5466.03		5466.55	0.012156	5.81	68.89	47.77	0.85
4830	4.0	PF 14	500.00	5463.38	5466.23	5466.08	5466.86	0.012525	6.37	78.73	52.47	0.88
4830	4.0	PF 16	600.00	5463.38	5466.39	5466.31	5467.14	0.013241	6.95	87.70	63.14	0.92
4830	4.0	PF 17	700.00	5463.38	5466.54	5466.54	5467.39	0.013615	7.44	97.81	71.62	0.95
4830	4.0	PF 18	800.00	5463.38	5466.74	5466.74	5467.62	0.012420	7.60	113.24	80.57	0.92
4830	4.0	PF 19	900.00	5463.38	5466.92	5466.92	5467.83	0.011626	7.76	128.55	88.45	0.90
4830	4.0	PF 20	1000.00	5463.38	5467.09	5467.09	5468.02	0.011009	7.92	144.02	95.74	0.89
4830	4.0	PF 21	1100.00	5463.38	5467.23	5467.23	5468.19	0.010745	8.12	158.07	101.92	0.88
4830	4.0	PF 22	1200.00	5463.38	5467.40	5467.40	5468.37	0.010115	8.21	176.49	120.30	0.87
4830	3.0	PF 1	0.10	5463.45	5463.56		5463.56	0.002302	0.27	0.38	7.99	0.22
4830	3.0	PF 2	1.00	5463.45	5463.70		5463.70	0.001719	0.41	2.42	21.15	0.22
4830	3.0	PF 3	5.00	5463.45	5463.87		5463.87	0.002017	0.70	7.17	32.32	0.26
4830	3.0	PF 4	10.00	5463.45	5463.97		5463.99	0.002342	0.93	10.77	35.40	0.30
4830	3.0	PF 5	50.00	5463.45	5464.38		5464.43	0.004071	1.86	26.84	46.89	0.43
4830	3.0	PF 6	100.00	5463.45	5464.65		5464.75	0.004614	2.53	39.48	47.65	0.49
4830	3.0	PF 8	200.00	5463.45	5465.03		5465.22	0.005306	3.45	58.02	48.73	0.56
4830	3.0	PF 10	300.00	5463.45	5465.34		5465.60	0.005695	4.11	73.08	49.60	0.60
4830	3.0	PF 12	400.00	5463.45	5465.61		5465.93	0.005852	4.61	89.39	75.41	0.62
4830	3.0	PF 14	500.00	5463.45	5465.83	5465.32	5466.21	0.005935	5.03	108.17	98.48	0.64
4830	3.0	PF 16	600.00	5463.45	5466.06	5465.57	5466.47	0.005512	5.24	133.31	117.68	0.63
4830	3.0	PF 17	700.00	5463.45	5466.25	5465.85	5466.68	0.005360	5.45	155.55	120.81	0.62
4830	3.0	PF 18	800.00	5463.45	5466.37		5466.85	0.005757	5.83	169.55	123.62	0.65
4830	3.0	PF 19	900.00	5463.45	5466.48		5467.01	0.006001	6.15	184.42	127.05	0.67
4830	3.0	PF 20	1000.00	5463.45	5466.59		5467.17	0.006228	6.44	198.56	130.24	0.69
4830	3.0	PF 21	1100.00	5463.45	5466.71		5467.31	0.006340	6.67	213.50	133.52	0.70
4830	3.0	PF 22	1200.00	5463.45	5466.80		5467.45	0.006620	6.96	225.70	137.22	0.72
4830	2.0	PF 1	0.10	5463.34	5463.47		5463.48	0.009659	0.56	0.18	3.64	0.44
4830	2.0	PF 2	1.00	5463.34	5463.63		5463.64	0.005500	0.73	1.37	12.23	0.38
4830	2.0	PF 3	5.00	5463.34	5463.71	5463.69	5463.77	0.030814	2.01	2.49	17.58	0.94
4830	2.0	PF 4	10.00	5463.34	5463.79	5463.79	5463.86	0.030634	2.13	4.69	30.20	0.95
4830	2.0	PF 5	50.00	5463.34	5464.06	5464.06	5464.25	0.027024	3.44	14.53	41.59	1.03
4830	2.0	PF 6	100.00	5463.34	5464.28	5464.28	5464.55	0.022453	4.17	24.12	46.37	1.00
4830	2.0	PF 8	200.00	5463.34	5464.59	5464.59	5465.01	0.019103	5.17	39.46	49.87	1.00
4830	2.0	PF 10	300.00	5463.34	5464.85	5464.85	5465.38	0.017612	5.91	52.10	50.69	1.00
4830	2.0	PF 12	400.00	5463.34	5465.07	5465.07	5465.71	0.016362	6.47	63.79	51.43	0.99
4830	2.0	PF 14	500.00	5463.34	5465.35	5465.35	5466.01	0.013292	6.62	81.11	74.46	0.93
4830	2.0	PF 16	600.00	5463.34	5465.50	5465.50	5466.27	0.013884	7.18	92.53	81.59	0.96
4830	2.0	PF 17	700.00	5463.34	5465.76	5465.76	5466.49	0.011366	7.13	116.70	107.59	0.89
4830	2.0	PF 18	800.00	5463.34	5466.01	5466.01	5466.69	0.009160	6.93	147.13	124.82	0.81
4830	2.0	PF 19	900.00	5463.34	5466.15	5466.15	5466.85	0.008962	7.14	164.48	127.08	0.81
4830	2.0	PF 20	1000.00	5463.34	5466.25	5466.25	5467.00	0.009279	7.46	177.09	128.74	0.83
4830	2.0	PF 21	1100.00	5463.34	5466.36	5466.36	5467.14	0.009335	7.70	191.27	131.62	0.84
4830	2.0	PF 22	1200.00	5463.34	5466.47	5466.47	5467.28	0.009287	7.89	205.89	134.53	0.85
4830	1.0	PF 1	0.10	5461.93	5462.05	5462.05	5462.09	0.048259	1.42	0.07	1.17	1.01
4830	1.0	PF 2	1.00	5461.93	5462.19	5462.19	5462.24	0.046118	1.70	0.59	7.24	1.05
4830	1.0	PF 3	5.00	5461.93	5462.44	5462.34	5462.46	0.005796	0.97	5.15	31.08	0.42
4830	1.0	PF 4	10.00	5461.93	5462.54	5462.41	5462.56	0.005800	1.17	8.58	39.35	0.44
4830	1.0	PF 5	50.00	5461.93	5462.89	5462.68	5462.96	0.005811	2.12	23.57	43.95	0.51
4830	1.0	PF 6	100.00	5461.93	5463.17	5462.89	5463.29	0.005805	2.78	36.02	44.58	0.54
4830	1.0	PF 8	200.00	5461.93	5463.60	5463.21	5463.80	0.005802	3.63	55.23	47.18	0.58
4830	1.0	PF 10	300.00	5461.93	5463.93	5463.48	5464.21	0.005804	4.25	71.98	52.82	0.60
4830	1.0	PF 12	400.00	5461.93	5464.21	5463.73	5464.55	0.005808	4.73	91.89	86.82	0.62
4830	1.0	PF 14	500.00	5461.93	5464.43	5463.95	5464.82	0.005804	5.11	113.54	106.58	0.63
4830	1.0	PF 16	600.00	5461.93	5464.63	5464.26	5465.05	0.005801	5.43	137.63	144.78	0.64
4830	1.0	PF 17	700.00	5461.93	5464.79	5464.46	5465.25	0.005810	5.70	162.87	157.91	0.65
4830	1.0	PF 18	800.00	5461.93	5464.94	5464.74	5465.41	0.005809	5.93	186.67	168.55	0.65
4830	1.0	PF 19	900.00	5461.93	5465.08	5464.87	5465.58	0.005806	6.15	211.92	191.96	0.66
4830	1.0	PF 20	1000.00	5461.93	5465.19	5464.97	5465.70	0.005804	6.32	234.01	194.64	0.66
4830	1.0	PF 21	1100.00	5461.93	5465.30	5465.03	5465.82	0.005800	6.47	255.05	197.16	0.67
4830	1.0	PF 22	1200.00	5461.93	5465.40	5465.27	5465.94	0.005803	6.63	275.10	199.53	0.67

Figure 15. Site 4830 HEC-RAS Model Output.

An instantaneous discharge measurement was taken using a Marsh-McBirney flowmeter on January 26, 2006. Water depth and velocity were measured across the channel at a cross section between surveyed Sections 5.0 and 4.0. The calculation of the channel discharge from the depth and velocity measurements is presented in Figure 16.

DISCHARGE MEASUREMENTS NOTES

Location:	Site 2830 South Boulder Ck at Sans	Project:	A212-UDFCD Ratings Development	start Time(hrs):	1435 MST	Weather: sunny, cool and windy
Meter:	Marsh-McBirney	Date:	Jan 26, 2006	start Stage(ft):	5463.98	Cross section: downstream of cross section 5.0
Serial No.		Party:	Hanna/Wright	stop Time(hrs):	1505 MST	Gage condition: clear, some vegetation/leaves
Computed By:	Hanna Date: 1/26/2006	Checked By:	Spotts Date: 1/26/2006	stop Stage(ft):	5463.98	Other:

Horiz. station (ft)	Width (ft)	Total Depth of water (ft)	Water surface to Bot. of Ice (ft)	Effect. Depth (ft)	Prop. Depth	Point velocity (ft/sec)	Mean And/ or Ice Cor. vertical velocity (ft/sec)	Cell Area (sq ft)	Cell Disch. (cfs)	Other/Comments
0.50	LEW	0.00								
2.00	1.25	0.40		0.40		0.00	0.00	0.50	0.000	
3.00	1.00	0.53		0.53		0.52	0.52	0.53	0.276	
4.00	0.95	0.40		0.40		0.69	0.69	0.38	0.262	
4.90	1.00	0.73		0.73		1.21	1.21	0.73	0.883	
6.00	0.95	0.50		0.50		0.79	0.79	0.48	0.379	
6.80	0.85	0.60		0.60		0.89	0.89	0.51	0.454	
7.70	1.05	0.53		0.53		1.38	1.38	0.56	0.773	
8.90	1.25	0.70		0.70		1.15	1.15	0.88	1.012	
10.20	1.35	0.70		0.70		0.66	0.66	0.95	0.627	
11.60	1.40	0.50		0.50		0.36	0.36	0.70	0.252	
13.00	1.20	0.45		0.45		0.10	0.10	0.54	0.054	
14.00	1.00	0.25		0.25		0.03	0.03	0.25	0.008	
15.00	1.35	0.40		0.40		0.26	0.26	0.54	0.140	
16.70	1.95	0.40		0.40		0.07	0.07	0.78	0.055	
18.90 REW		0.00		0.00		0.00	0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
	0.00			0.00			0.00	0.00	0.000	
TOTALS	16.55							8.33	5.175	

Figure 16. Site 4830 Flow Measurement Calculation.

The predicted water surface elevations describing the stage–discharge rating at Cross-Section 3.0 are presented in Figure 17.

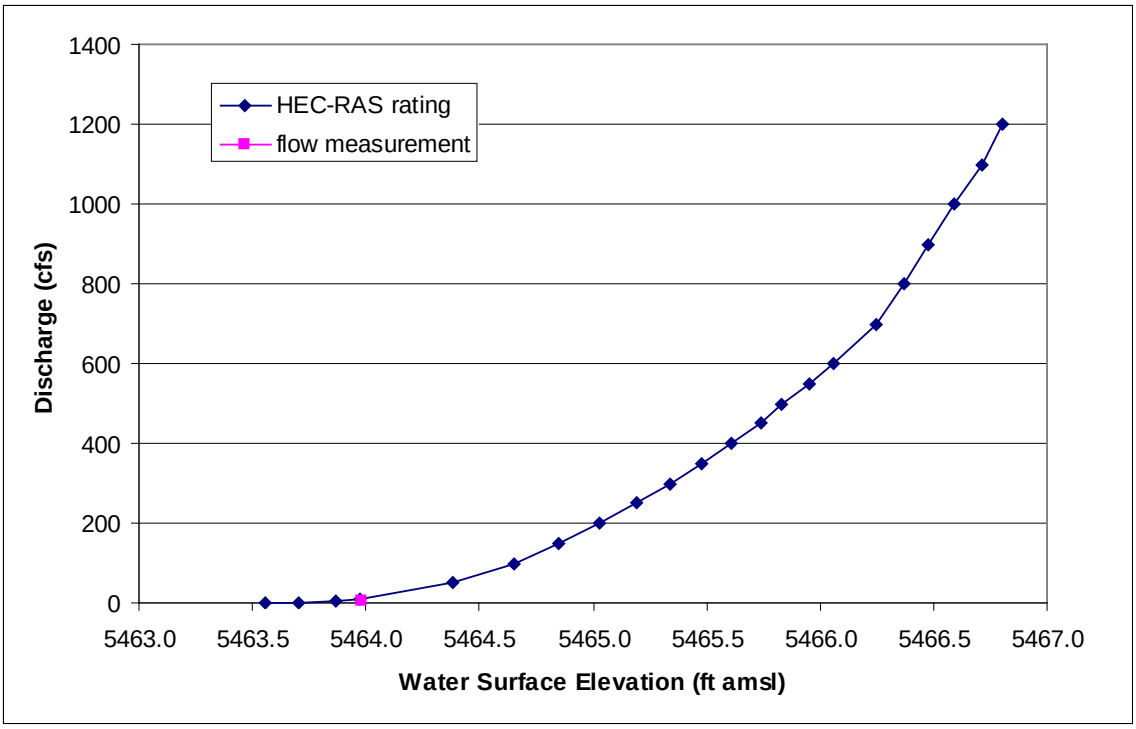

Figure 17. Site 4830 Predicted Stage – Discharge Rating.

5.3 Site 4830 Depth above PT Discharge Rating

The rating desired by UDFCD is expressed as stream discharge as a function of water depth at the PT. The reference elevation for the PT is set to the stream bed elevation at the PT cross section (5,463.45 ft amsl). The minimum channel elevation at all cross sections downstream of the PT is lower, therefore the zero flow depth at the PT cross section is 0.0 feet. These values are used to calculate depth of water above the PT from the HEC-RAS water surface elevation predictions for a range of discharge values. The stage-discharge rating is shown in Table 1. The current UDFCD rating is presented in Table 2.

Table 1. Site 4830 Stage-Discharge Rating.

Water Surface Elevation (ft amsl)	Depth above the PT (ft)[1]	Discharge (cfs)	Condition
5,463.45	0.0	0	
5,463.56	0.11	0.1	
5,463.70	0.25	1	
5,463.87	0.42	5	
5,463.97	0.52	10	
5,464.38	0.93	50	
5,464.65	1.2	100	
5,464.85	1.4	150	
5,465.03	1.58	200	
5,465.19	1.74	250	
5,465.34	1.89	300	
5,465.48	2.03	350	
5,465.61	2.16	400	
5,465.74	2.29	450	
5,465.83	2.38	500	
5,465.95	2.5	550	
5,466.06	2.61	600	
5,466.25	2.8	700	
5,466.37	2.92	800	
5,466.48	3.03	900	
5,466.59	3.14	1,000	
5,466.71	3.26	1,100	
5,466.80	3.35	1,200	Flow overbank, standpipe base flooded

[1] Depth is calculated as predicted water surface elevation minus minimum surveyed channel elevation at Cross-Section 3.0 (5,463.45 ft amsl)

Table 2. Current UDFCD Rating for Site 4830.

Depth (ft)	Discharge (cfs)
0	0
0.25	5
1	50
1.4	100
2.7	500
3.85	1,500
5.2	5,740
5.9	10,300

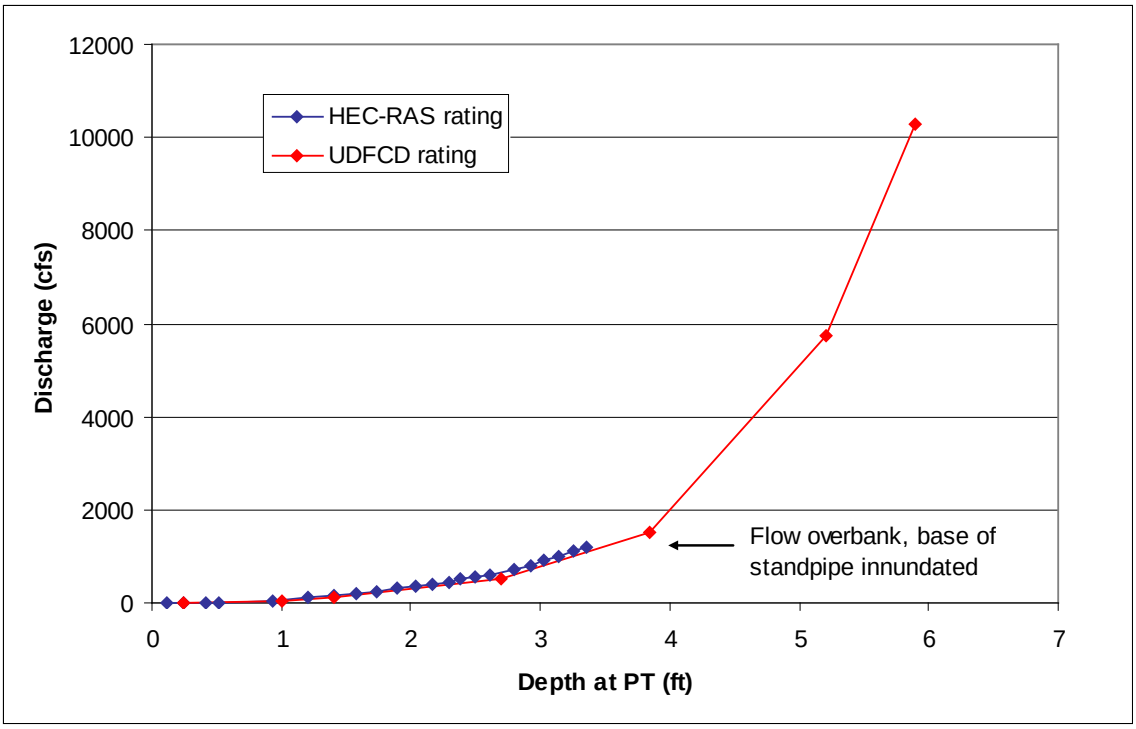

Figure 18. Site 4830 Stage-Discharge Rating Comparisons.

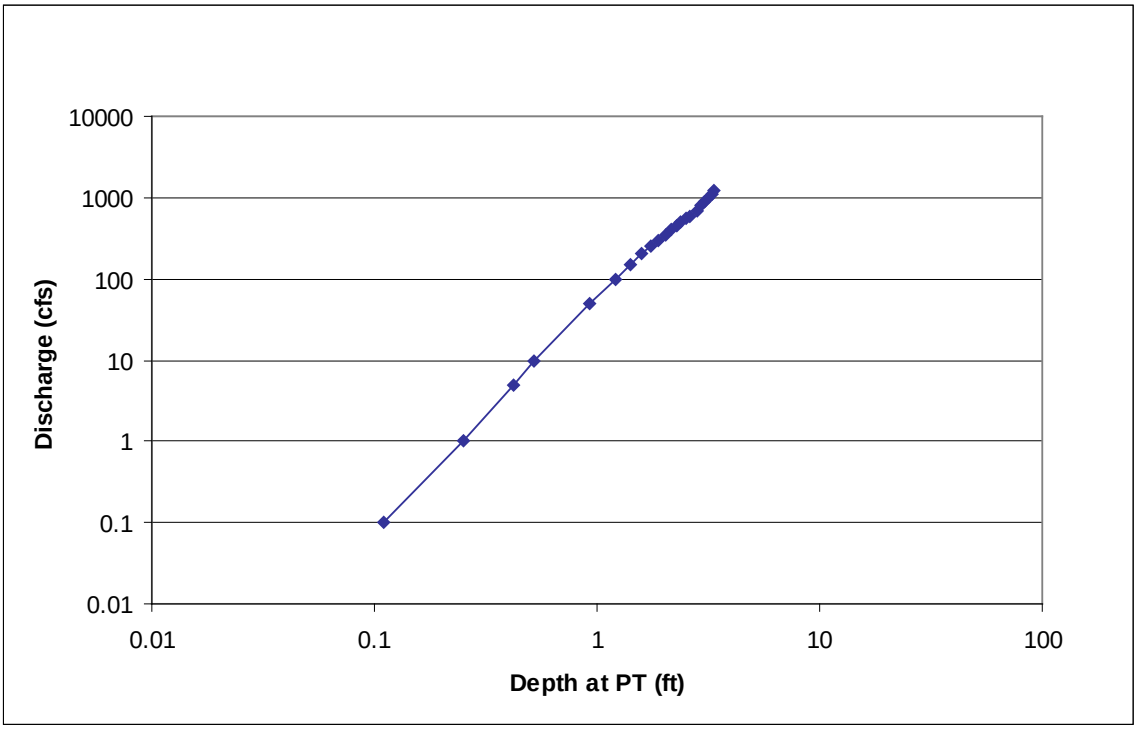

Figure 19. Site 4830 Stage-Discharge Relationship Log-Log Plot.

5.4 Site 4830 Discussion of Rating Results

The stage-discharge rating developed for Site 4830 utilized detailed cross section survey data and one-dimensional steady flow modeling to calculate water surface elevations for a range of discharges. The range of discharges for this rating describes zero flow depth at the low end to the discharge at the point where water begins to flow over the right river bank at the PT cross section.

The rating of the depth of water above the PT is based on the reference level of the minimum channel elevation at the PT cross section of 5,463.45 ft amsl or 2.40 ft below the top of the PT riser pipe with the cap removed. Before using this rating with confidence, the elevation of the installed PT should be verified in the field and a field verification of water depth above the reference level should be performed using the installed PT reading and a field measurement of water surface elevation.

The current UDFCD rating compares well with the rating developed here for discharge as a function of depth above the channel bed. However, the elevation of the channel bed at the PT cross section was measured at 5,463.45 ft amsl, compared to 5,471 ft amsl measured by UDFCD.

At high flows at this site (3-ft of depth at the PT), a small split-flow will develop upstream of the PT cross section and follow channels shown in Figure 9. This discharge is predicted to flow into the main river channel and be measured at the PT location.

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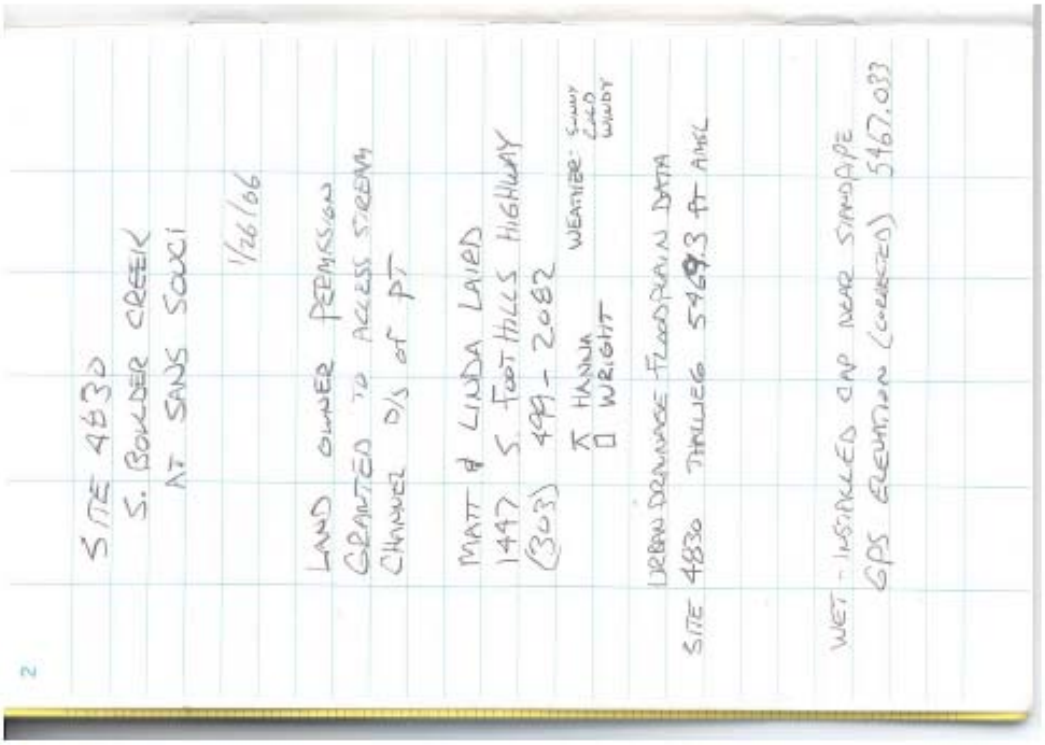
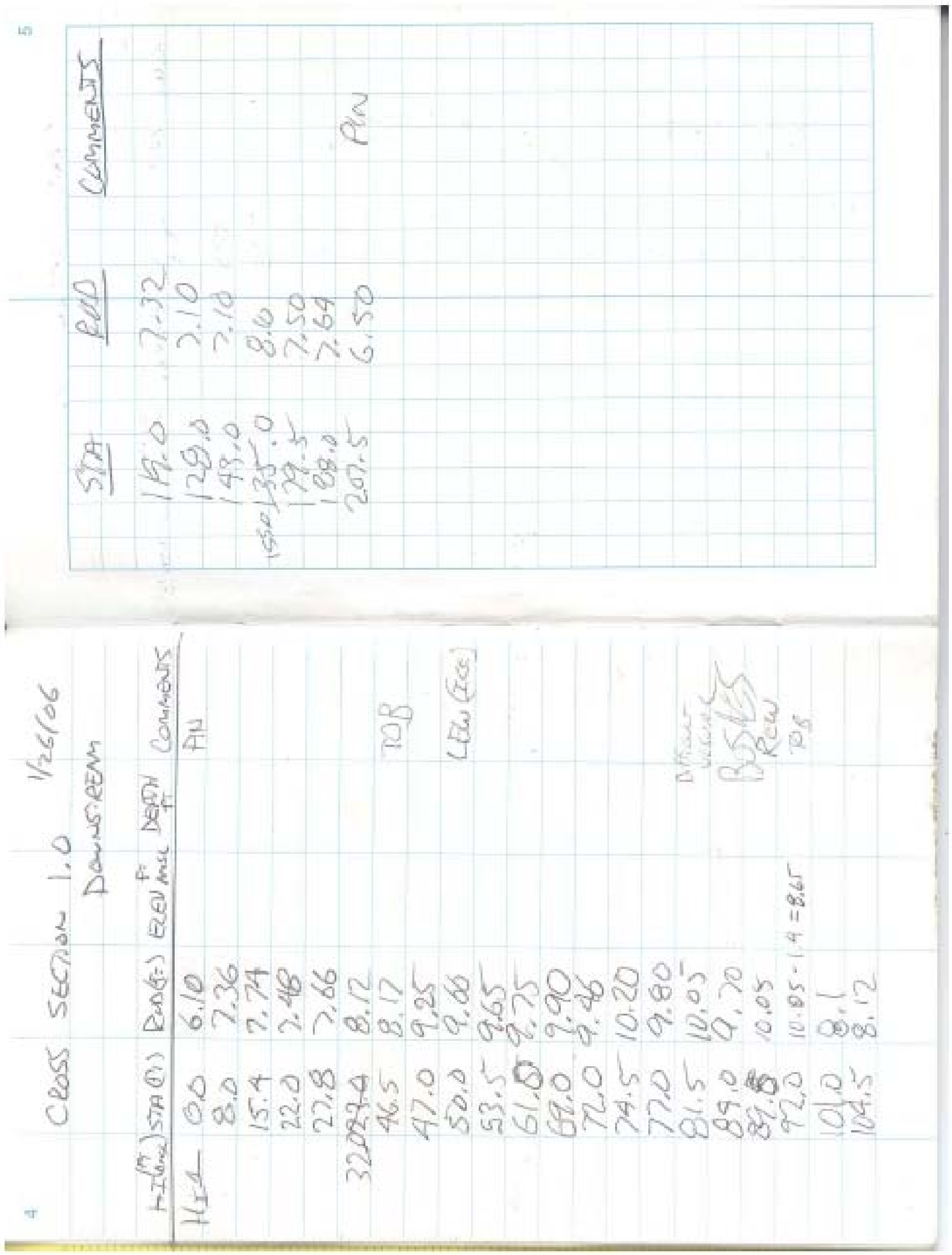
7.0 SURVEY FIELD NOTES





4

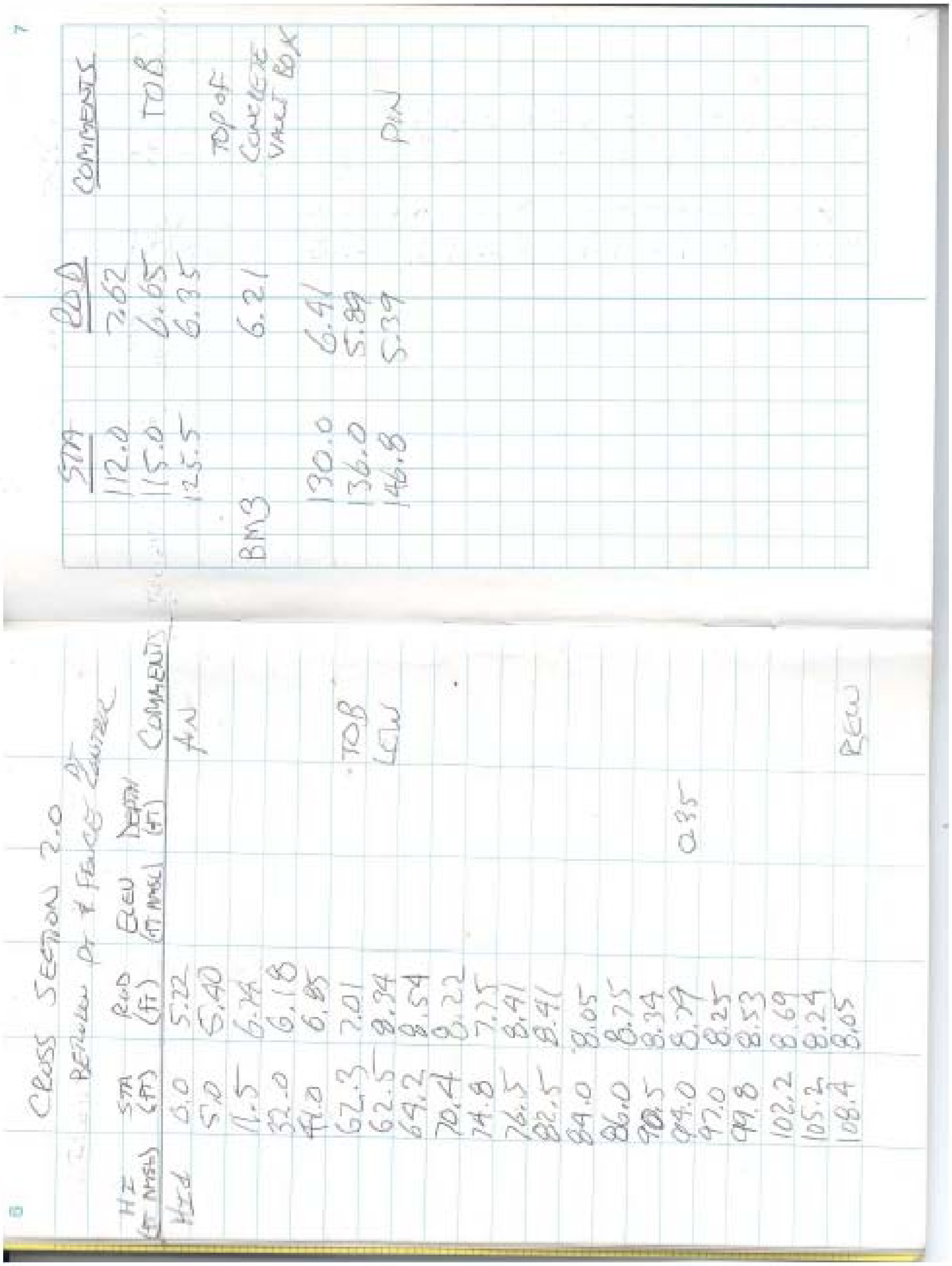
CROSS SECTION 1.0 1/26/06

DOWNSTREAM

HI (ft)	STA (ft)	ROD (ft)	ELEV ft MSL	DEPTH ft	COMMENTS
HI-1	0.0	6.10			PIN
	8.0	7.36			
	15.4	7.74			
	22.0	7.48			
	27.8	7.66			
	32.0	8.12			
	46.5	8.17			TOB
	47.0	9.25			
	50.0	9.66			LEW (ICE)
	53.5	9.65			
	61.0	9.75			
	69.0	9.90			
	72.0	9.46			
	74.5	10.20			
	77.0	9.80			
	81.5	10.05			[illegible]
	89.0	9.70			BUSHES
	89.5	10.05			REW
	92.0	10.05 - 1.4 = 8.65			TOB
	101.0	8.1			
	104.5	8.12			

5

STA	ROD	COMMENTS
119.0	7.32	
128.0	7.10	
143.0	7.10	
150 135.0	8.0	
179.5	7.50	
188.0	7.64	
207.5	6.50	PIN



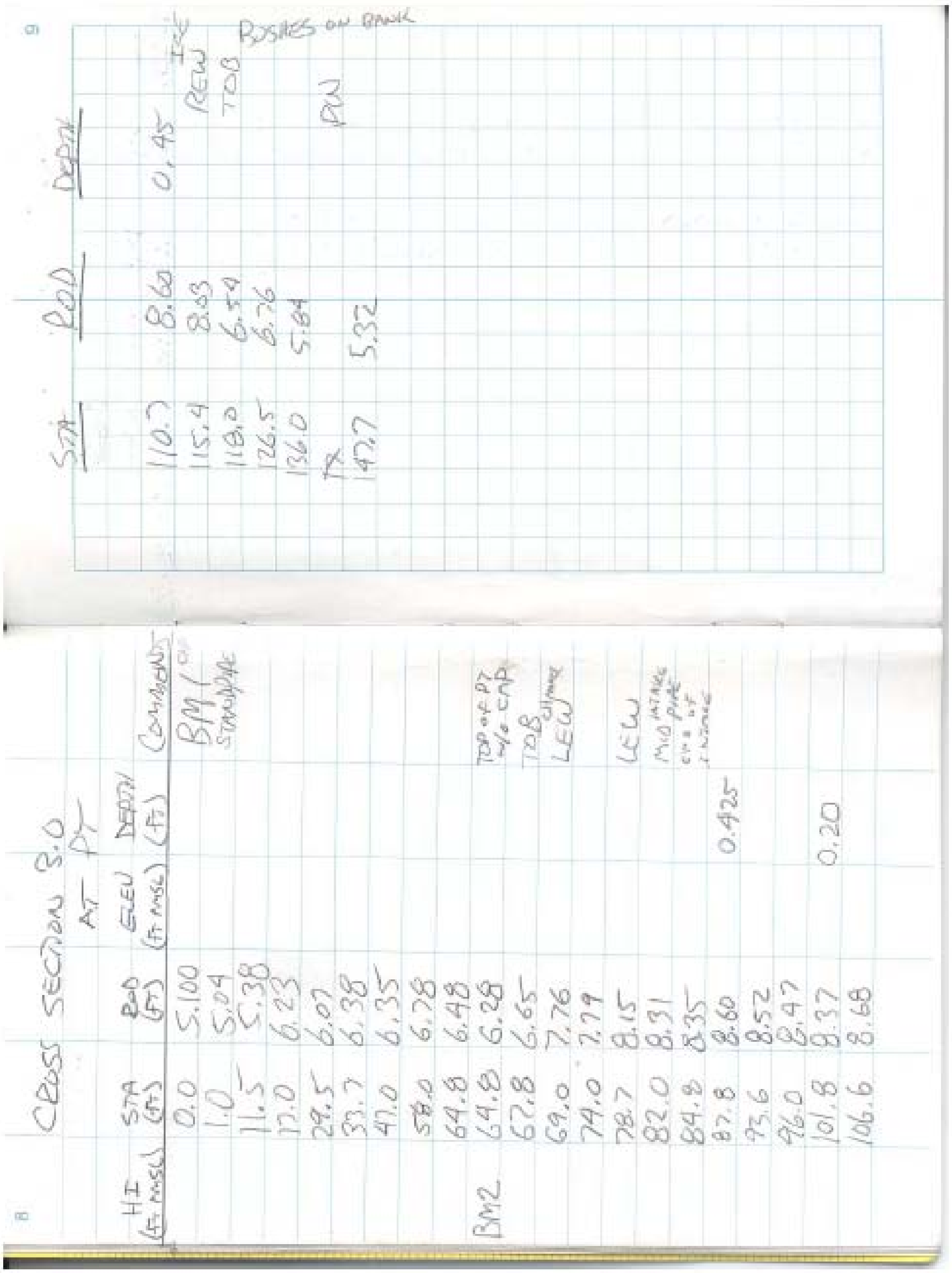
6

CROSS SECTION 2.0
BETWEEN PT & FENCE AT CENTER

HI (FT AMSL)	STA (FT)	ROD (FT)	ELEV (FT AMSL)	DEPTH (FT)	COMMENTS
HI-1	0.0	5.22			AN
	5.0	5.40			
	11.5	6.74			
	32.0	6.18			
	41.0	6.85			
	62.3	7.01			TOB
	62.5	8.34			LEW
	64.2	8.54			
	70.4	8.22			
	74.8	7.75			
	76.5	8.41			
	82.5	8.41			
	84.0	8.05			
	86.0	8.75			
	90.5	8.34			
	94.0	8.79		0.35	
	97.0	8.25			
	99.8	8.53			
	102.2	8.69			
	105.2	8.24			
	108.4	8.05			REW

7

	STA	ROD	COMMENTS
	112.0	7.62	
	115.0	6.65	TOB
	125.5	6.35	
BM3		6.21	TOP OF CONCRETE VAULT BOX
	130.0	6.41	
	136.0	5.89	
	146.8	5.39	PIN



8

CROSS SECTION 3.0
AT PT

HI (FT MSL)	STA (FT)	ROD (FT)	ELEV (FT MSL)	DEPTH (FT)	COMMENTS
	0.0	5.100			BM1 [illegible] STANDPIPE
	1.0	5.04			
	11.5	5.38			
	17.0	6.23			
	29.5	6.07			
	33.7	6.38			
	47.0	6.35			
	58.0	6.78			
	64.8	6.48			
BM2	64.8	6.28			TOP OF PT w/o CAP
	67.8	6.65			TOB
	69.0	7.76			LEW CHANGE
	74.0	7.79			
	78.7	8.15			LEW
	82.0	8.31			MID INTAKE PIPE
	84.8	8.35			END OF INTAKE
	87.8	8.60		0.425	
	93.6	8.52			
	96.0	8.47			
	101.8	8.37		0.20	
	106.6	8.68			

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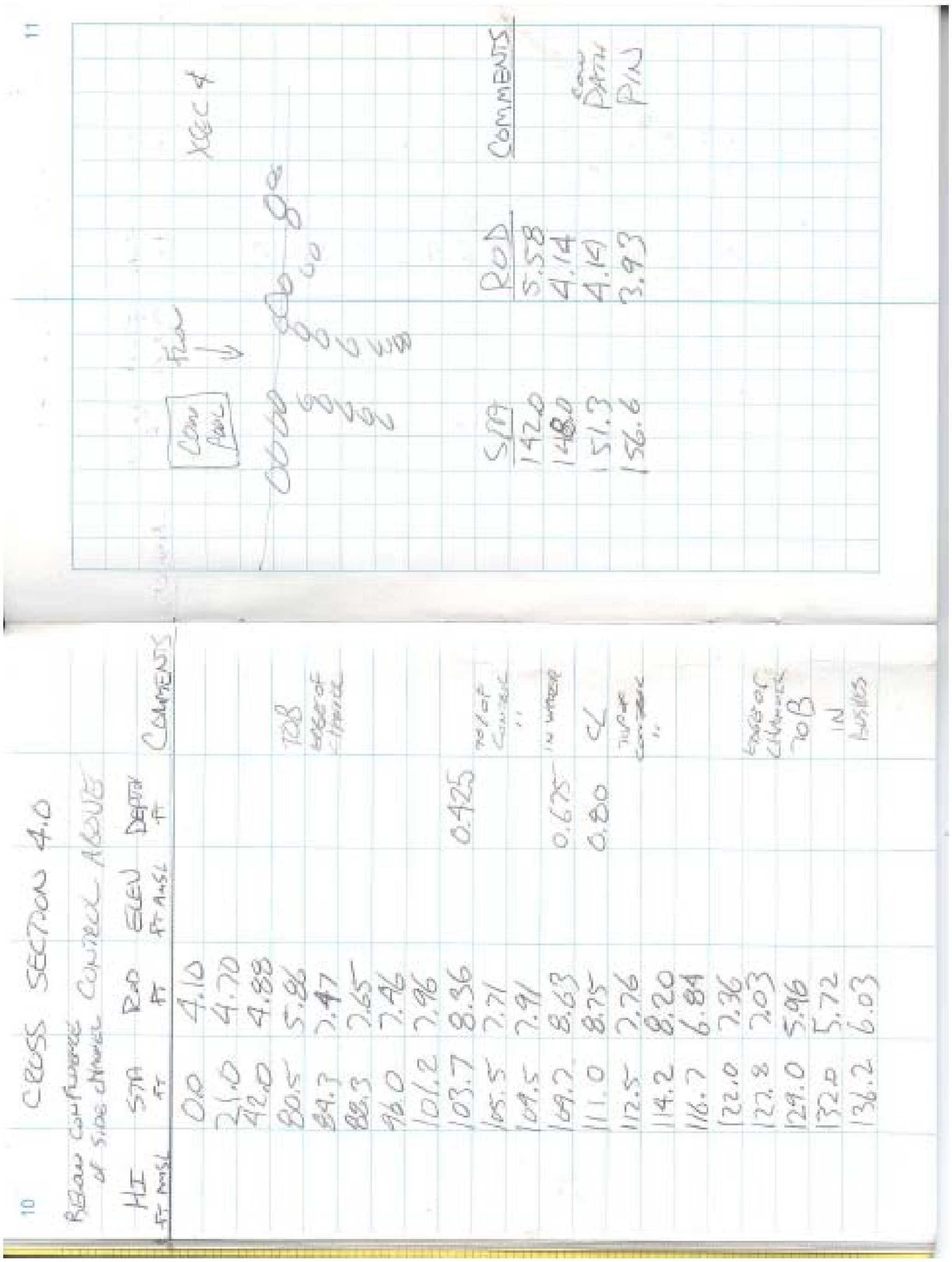
STA	ROD	DEPTH	
110.7	8.60	0.45	ICE
115.4	8.83		REW
118.0	6.54		TOB
126.5	6.76		
136.0	5.84		
TX			PW
142.7	5.32		

BUSHES ON BANK



10

CROSS SECTION 4.0

BELOW CONFLUENCE OF SIDE CHANNEL CONTROL ABOVE

HI Ft AMSL	STA Ft	ROD Ft	ELEV Ft AMSL	DEPTH Ft	COMMENTS
	0.0	4.10			
	21.0	4.70			
	42.0	4.88			
	80.5	5.86			TOB EDGE OF CHANNEL
	84.3	7.47			
	88.3	7.65			
	96.0	7.46			
	101.2	7.96			
	103.7	8.36		0.425	
	105.5	7.71			TOP OF CONTROL
	109.5	7.91			"
	109.7	8.63		0.675	IN WATER
	111.0	8.75		0.80	CL
	112.5	7.76			TOP OF CONTROL
	114.2	8.20			"
	116.7	6.84			
	122.0	7.36			
	127.8	7.03			EDGE OF CHANNEL TOB
	129.0	5.96			
	132.0	5.72			IN BUSHES
	136.2	6.03			

11

STA	ROD	COMMENTS
142.0	5.58	
148.0	4.14	
151.3	4.14	[illegible] PATH PIN
156.6	3.93	

12

CROSS SECTION 5.0

HI (FT MSL)	STA (FT)	ROD (FT)	EOD (FT MSL)	DEPTH (FT)	COMMENTS
	0.0				FW
	12.0	+1.25			EST.
	35.0	3.55			
	61.0	4.58			
	66.0	6.25			
	78.0	5.80			
	80.5	6.35			
	89.0	7.18			
	93.0	7.96			
	94.4	5.65			
	108.5	5.07			
	113.5	5.46			
	114.5	8.05			BANK
	118.3	7.80		0.0	LEW
	118.7	8.20		0.80	
	120.5	8.59		0.20	
	124.4	8.50			
	125.4	7.90			
	127.0	7.82			
	127.5	8.32			
	129.8	8.45			

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STA	ROD	COMMENTS
132.2	7.94	REW
138.8	-1.9	
139.5	5.64	
143.5	4.68	TOB
150.0	2.90	
152.0	2.90	
158.0	2.90	
163.6	2.76	

DIN DISTANCES

5L - 4L	56.7
5R - 4R	51.6
4L - 3L	62.2
4R - 3R	75.5
3L - 2L	21.5
3R - 2R	19.9
2L - 1L	85.7
2R - 1R	144.5