Development of Stage-Discharge Ratings for Site 4840 – South Boulder Creek at South Boulder Ditch

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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 4840 – South Boulder Creek at South Boulder Ditch," 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.

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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 4840, South Boulder Creek at South Boulder Ditch. This station, located downstream of the South Boulder Diversion Ditch Structure 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 at least 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 February 3, 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 4840 is located on Boulder County Open Space land just downstream from the diversion structure for the South Boulder Ditch (Figure 1). The site is circled in red in the location map presented in Figure 2. The instrument standpipe is located between the South Boulder Creek river channel and the diversion ditch (Figure 3).

Figure 1. Diversion Structure just Upstream from the Site 4840 PT.

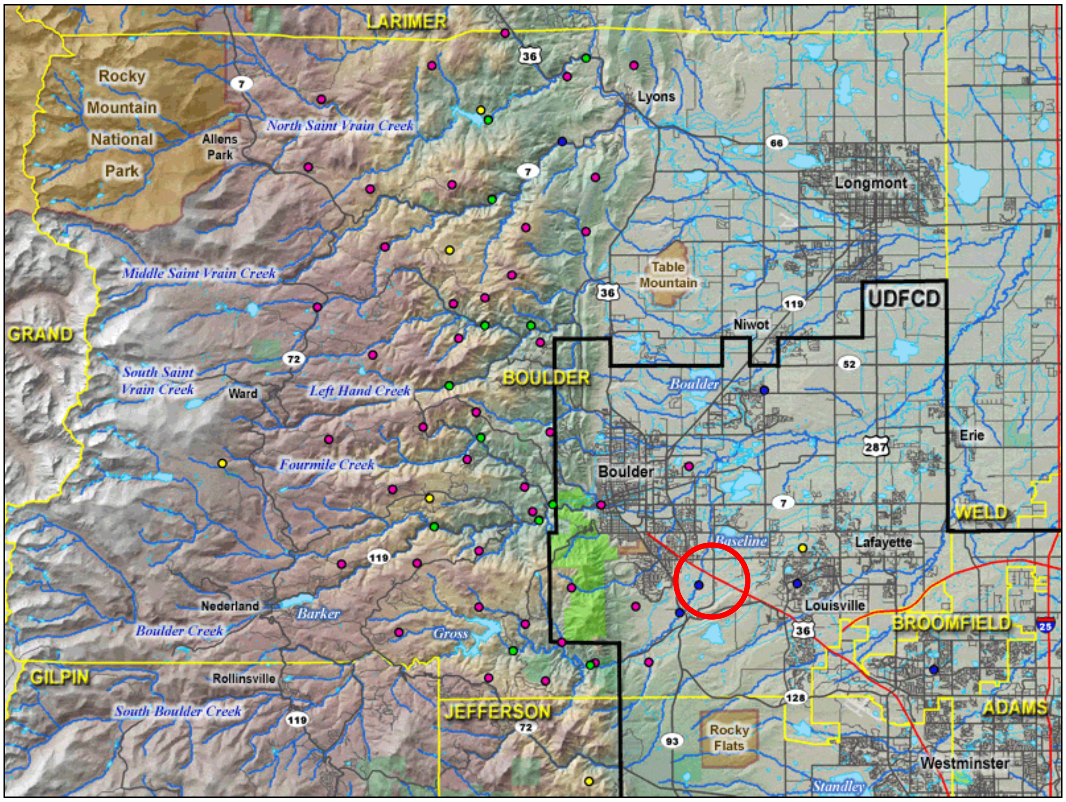

Figure 2. Site 4840 Location Map.


Figure 3. Site 4840 Standpipe Located on the Creek Right Bank.

5.1 Site 4840 Channel Survey

Six cross sections were surveyed by WET staff on February 3, 2006. Approximate locations of landmarks and cross sections are shown in Figure 4. The South Boulder Creek diversion structure is located at Cross-Section 5.0. Photos of each cross section are presented in Figure 5 - Figure 10.

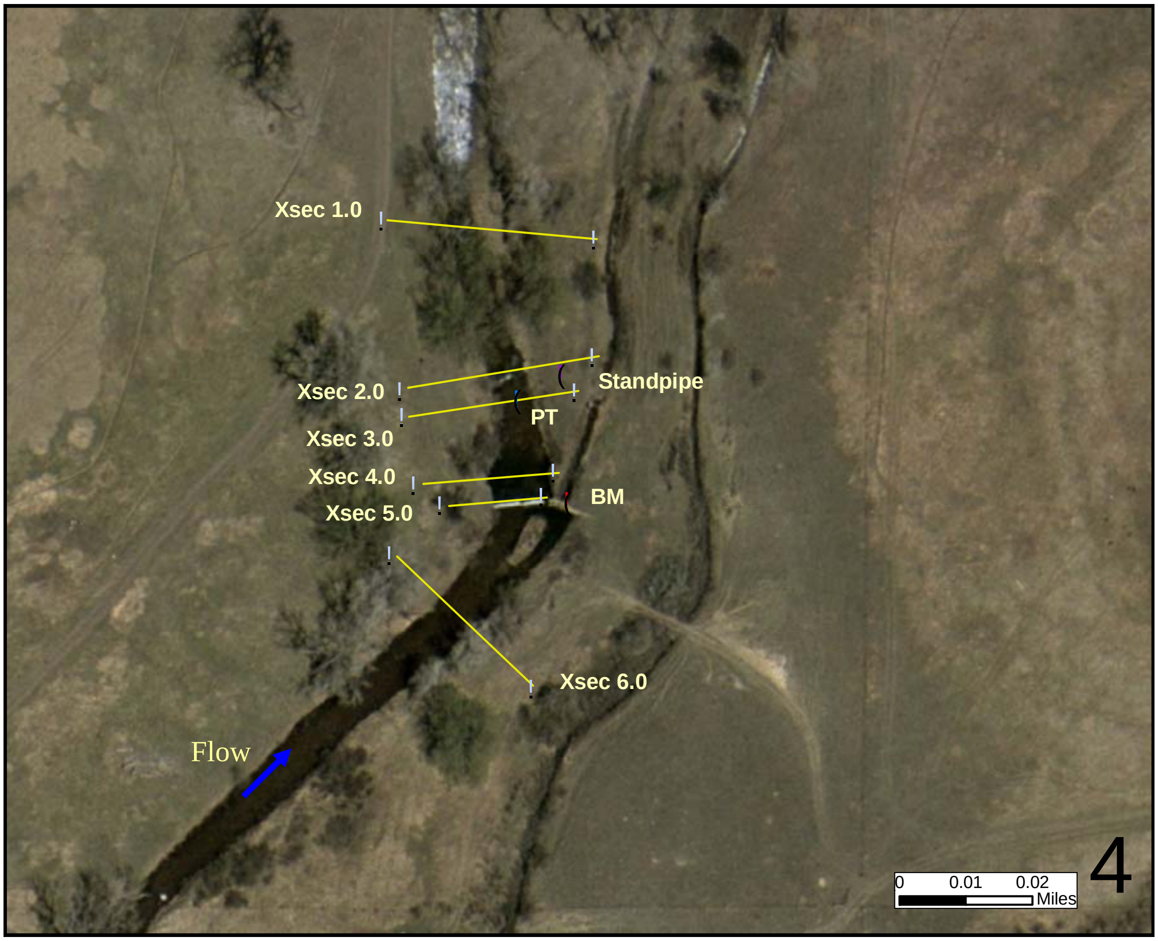

Figure 4. Site 4840 Cross Section and Landmark Locations.

Figure 5. Site 4840 Cross-Section 1.0 Looking Downstream.

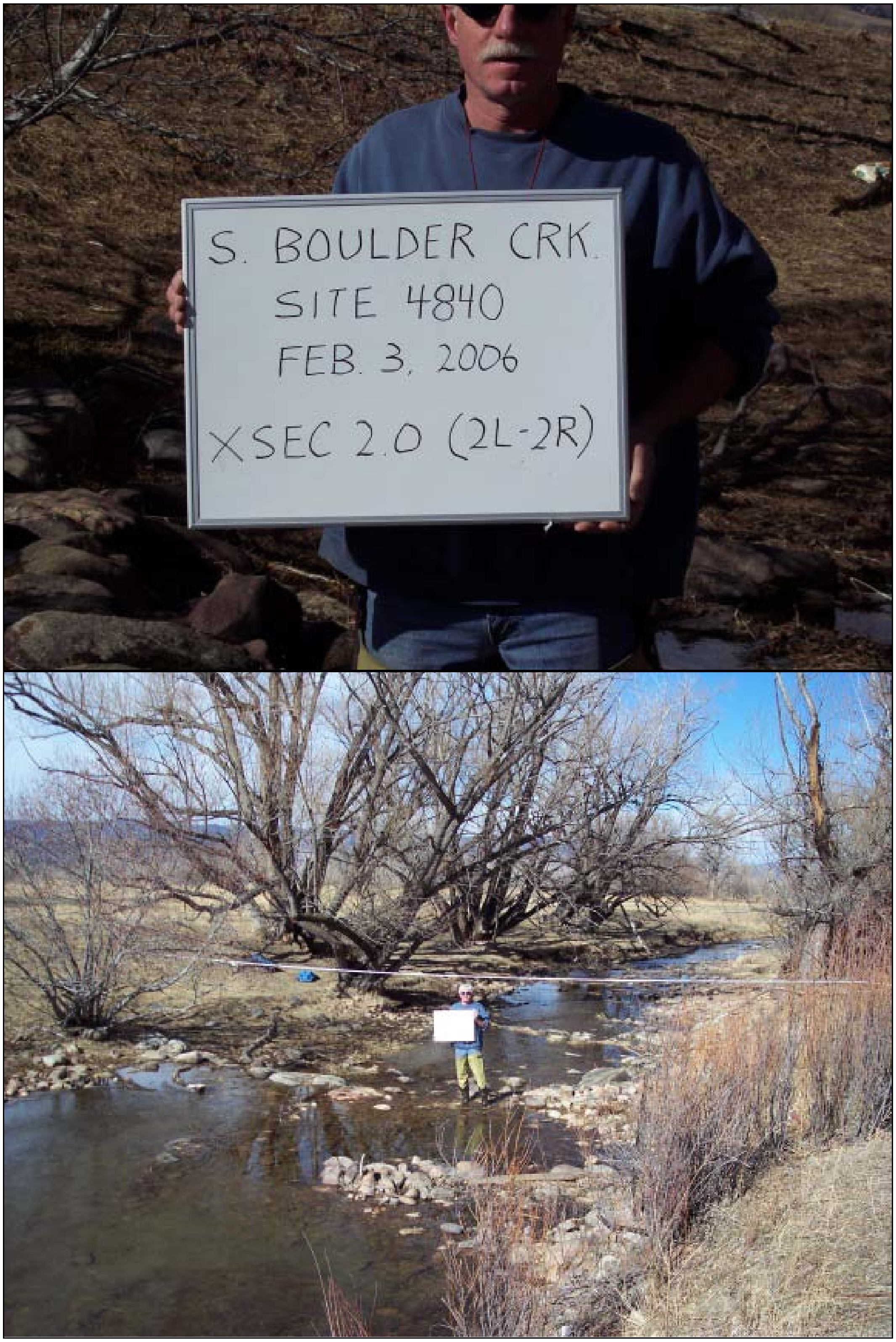

Figure 6. Site 4840 Cross-Section 2.0 Looking Downstream.

Figure 7. Site 4840 Cross-Section 3.0 Looking Downstream.

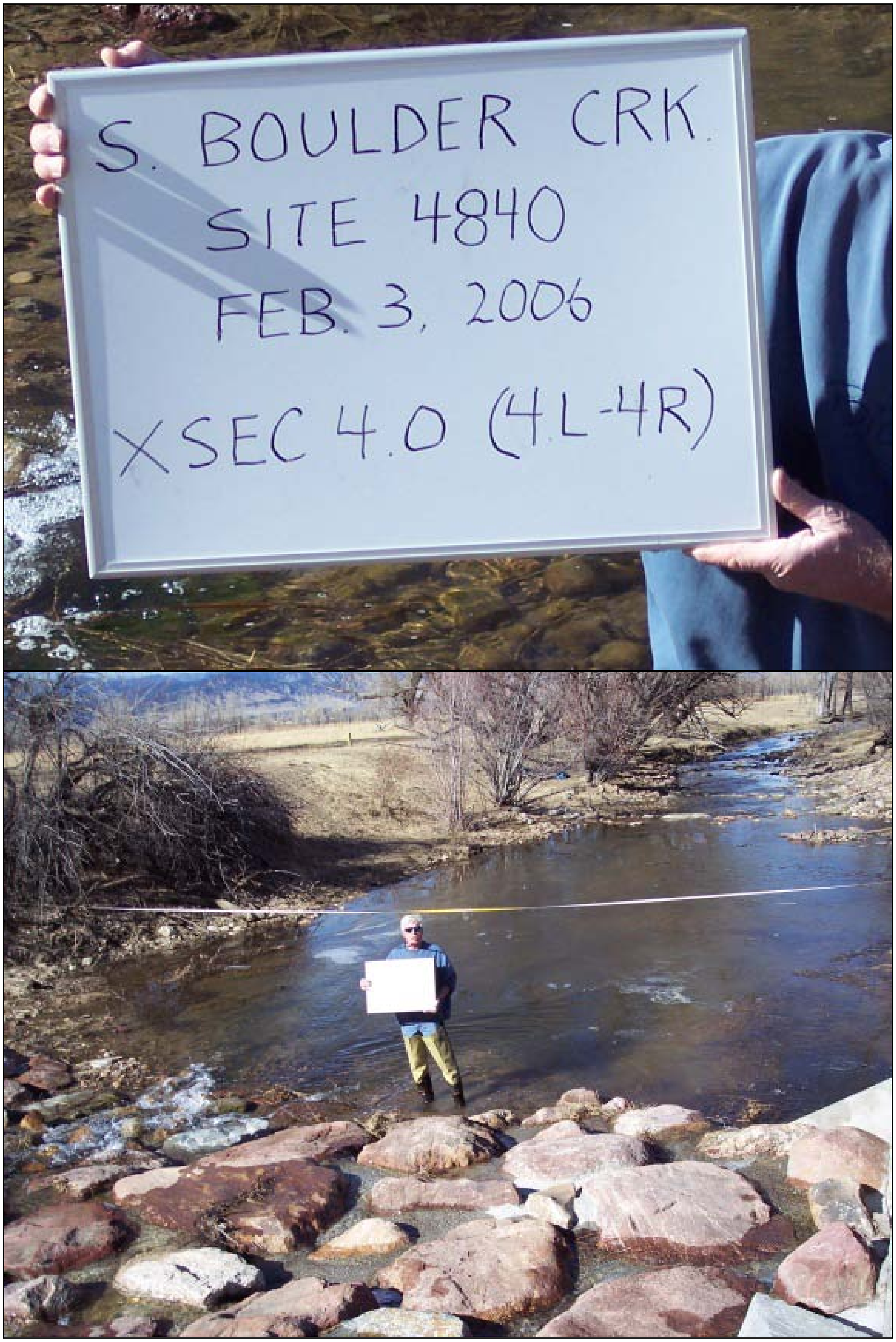

Figure 8. Site 4840 Cross-Section 4.0 Looking Downstream.

Figure 9. Site 4840 Cross-Section 5.0 Looking Downstream.

Figure 10. Site 4840 Cross-Section 6.0 Looking Downstream.

The measured distances between cross-section end points are presented in Figure 11.

Distances Between Cross-Sections		
Cross-Sections	Left Pins (ft)	Right Pins (ft)
1 - 2	126.0	117.6
2 - 3	16.1	10.4
3 - 4	57.3	58.0
4 - 5	30.0	28.6
5 - 6	68.6	142.0

Figure 11. Site 4840 Measured Distances between Cross Sections.

The PT riser pipe is located between the standpipe and South Boulder Creek, in line with Cross-Section 3.0. A photo of the riser pipe with the cap removed is shown in Figure 12.

Figure 12. Site 4840 PT Riser Pipe with the Cap Removed.

Riverbank modifications were observed upstream of the diversion structure. These modifications to strengthen and raise the height of the right river bank are shown in Figure 13. The left riverbank just upstream of Cross-Section 6.0 is shown in Figure 14. When flow overtops the left bank, local flooding of the field and recreational path beyond are likely to occur and will not be captured by the PT stage measurement.

Figure 13. Site 4840 Right Riverbank Modifications near Cross-Section 6.0 Looking Upstream.

Figure 14. Site 4840 Low Left Riverbank near Cross-Section 6.0 Looking Upstream.

The elevation of a bench mark located on the diversion structure was measured using a Trimble GPS unit. Differential correction of a set of over 100 logged data points were used to define the elevation of this marker (BM1) that is used as a vertical control for this survey. The elevations of these points are presented in **Figure 15**. A photo of the marker and the location indicated by the red arrow are presented in Figure 16.

Landmark Data

	HI (ft amsl)	Rod (ft)	Elevation (ft amsl)	Comments
HI1	5393.95	5.05	5388.90	BM1, Structure BM, corrected GPS measurement
		11.00	5382.95	BM2, top of PT w/o cap
		4.45	5389.51	BM3, top of concrete at pin 5R
HI2	5391.40	2.50	5391.40	Second Instrument Placement

Figure 15. Site 4840 Landmark Elevation Data.

Reduced field survey notes for the six cross sections are presented in Figure 17.

Figure 16. Site 4840 Bench Mark Located on the Structure.

Cross Section 1.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5391.40	0.0	6.35	5385.05	Pin 1L at bike path
	22.5	6.81	5384.59	
	30.0	8.63	5382.77	
	34.0	9.60	5381.80	
	40.5	10.74	5380.66	
	46.0	11.52	5379.88	TOB
	47.3	13.76	5377.64	
	49.6	14.06	5377.34	LEW
	51.5	13.92	5377.48	
	52.0	14.21	5377.19	
	54.0	14.29	5377.11	
	55.8	14.02	5377.38	
	58.3	14.60	5376.80	
	62.0	14.35	5377.05	
	63.5	13.83	5377.57	
	65.3	14.30	5377.10	
	67.5	13.74	5377.66	
	70.5	13.76	5377.64	REW
	73.8	13.06	5378.34	
	78.2	12.10	5379.30	
	87.0	11.03	5380.37	
	99.0	9.14	5382.26	
	112.6	4.96	5386.44	TOB
	119.5	4.37	5387.03	
	130.0	4.84	5386.56	
	139.0	5.27	5386.13	
	147.0	5.26	5386.14	
	162.0	5.13	5386.27	
	167.5	6.14	5385.26	Pin 1R at ditch

Cross Section 2.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5393.95	0.0	7.1	5386.88	Pin 2L, at bike path elevation
	7.0	7.2	5386.75	cow path
	14.0	6.7	5387.28	
	25.0	5.9	5388.04	
	33.5	6.3	5387.64	
	40.0	8.6	5385.36	
	46.8	11.1	5382.83	bushes
	52.0	12.0	5381.92	bushes
	58.5	13.3	5380.70	TOB
	59.0	12.6	5381.32	
	60.0	13.6	5380.36	
	61.3	12.8	5381.15	
	62.9	13.6	5380.37	LEW
	64.0	12.9	5381.04	
	64.4	13.8	5380.17	
	65.5	14.0	5380.00	
	66.9	13.4	5380.54	
	68.7	14.1	5379.90	
	69.5	13.2	5380.72	
	70.5	13.9	5380.05	
	70.9	14.0	5379.95	
	71.6	13.1	5380.84	
	74.5	13.4	5380.52	
	76.5	13.6	5380.32	
	78.0	13.3	5380.70	
	79.5	13.8	5380.17	
	82.0	13.9	5380.06	CL
	83.0	13.4	5380.56	
	84.4	13.8	5380.13	
	87.3	13.8	5380.14	
	88.5	13.4	5380.56	
	89.4	13.8	5380.17	
	92.7	13.5	5380.47	REW
	97.2	12.7	5381.23	
	99.5	11.5	5382.49	TOB
	103.8	10.2	5383.75	
	109.0	8.4	5385.59	
	115.0	6.2	5387.75	
	118.0	6.0	5387.95	standpipe
	122.0	5.9	5388.08	
	132.0	6.2	5387.73	
	136.0	6.1	5387.82	
	139.0	7.0	5386.94	
	140.8	8.0	5386.00	Pin 2R at edge of ditch

Cross Section 3.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5393.95	0.0	7.22	5386.73	Pin 3L, at bike path elevation
	1.5	7.34	5386.61	cow path
	10.0	7.05	5386.90	
	20.0	5.94	5388.01	
	30.0	6.12	5387.83	
	33.0	6.55	5387.40	
	38.0	8.15	5385.80	
	42.5	10.00	5383.95	
	46.0	11.67	5382.28	
	48.5	12.27	5381.68	bushes
	49.5	13.83	5380.12	
	55.0	13.08	5380.87	
	59.1	13.36	5380.59	LEW
	59.8	13.65	5380.30	
	61.0	13.45	5380.50	
	62.2	14.15	5379.80	
	64.6	14.91	5379.04	
	65.7	14.95	5379.00	
	68.0	14.51	5379.44	
	70.0	14.55	5379.40	
	72.7	14.09	5379.86	
	73.0	13.56	5380.39	
	77.0	13.94	5380.01	
	78.2	13.45	5380.50	
	79.8	13.95	5380.00	on PT intake pipe
	81.2	13.75	5380.20	
	81.6	12.94	5381.01	
	83.0	12.64	5381.31	
	85.0	13.53	5380.42	
	85.6	13.04	5380.91	
	86.2	13.67	5380.28	
	88.8	13.31	5380.64	
	90.8	13.61	5380.34	
	91.8	13.41	5380.54	REW
	93.3	12.64	5381.31	
	93.7	12.99	5380.96	
	97.0	10.62	5383.33	
	98.3	10.03	5383.92	
	104.0	8.49	5385.46	
	113.5	5.90	5388.05	
	121.0	5.62	5388.33	
	127.0	5.71	5388.24	
	130.0	6.43	5387.52	Pin 3R at edge of ditch

Cross Section 4.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5393.95	0.0	6.90	5387.05	Pin 4L
	15.0	6.74	5387.21	
	18.0	6.68	5387.27	cow path
	32.0	5.50	5388.45	
	42.5	5.73	5388.22	
	47.0	7.70	5386.25	TOB
	50.0	10.13	5383.82	
	54.0	11.65	5382.30	
	54.7	12.71	5381.24	
	56.2	12.81	5381.14	LEW
	59.8	13.20	5380.75	
	61.2	13.10	5380.85	
	63.6	13.06	5380.89	
	69.3	13.62	5380.33	
	73.0	13.36	5380.59	edge of flow
	76.8	13.49	5380.46	
	78.5	13.68	5380.27	
	79.6	14.00	5379.95	in channel
	82.5	14.02	5379.93	
	85.6	13.82	5380.13	
	87.0	13.88	5380.07	
	91.6	14.54	5379.41	
	93.4	13.03	5380.92	
	96.4	13.09	5380.86	
	97.0	13.67	5380.28	
	98.8	13.48	5380.47	edge of wall
	99.4	11.68	5382.27	on angled wall
	101.0	14.60	5379.35	in outlet channel
	105.5	14.58	5379.37	in outlet channel
	105.7	6.45	5387.50	top of wall
	107.0	6.47	5387.48	
	112.5	5.61	5388.34	
	116.0	6.03	5387.92	edge of ditch
	119.6	8.36	5385.59	Pin 4R

Cross Section 5.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5393.95	0.0	4.63	5389.32	Pin 5L
	6.0	3.72	5390.23	
	9.5	3.63	5390.32	
	19.0	5.02	5388.93	
	32.3	5.88	5388.07	top of wall
	32.4	9.55	5384.40	bottom of wall
	34.0	9.50	5384.45	LEW
	43.8	9.50	5384.45	on concrete top edgew
	49.8	9.40	5384.55	
	51.1	9.63	5384.32	
	52.0	10.41	5383.54	
	54.9	10.37	5383.58	CL
	57.4	10.47	5383.48	
	58.3	9.78	5384.17	
	59.7	9.40	5384.55	
	63.9	9.35	5384.60	
	69.3	9.41	5384.54	
	74.4	9.44	5384.51	
	78.1	9.41	5384.54	REW, bottom of wall
	78.2	4.45	5389.50	top of lower wall
	82.0	4.43	5389.52	top of upper wall
	82.0	2.48	5391.47	top of upper wall
	119.0	2.49	5391.46	Pin 5R, end of upper wall

Cross Section 6.0

HI (ft amsl)	Station (ft)	Rod (ft)	Elevation (ft amsl)	Comments
5393.95	0.0	5.52	5388.43	Pin 6L
	18.0	7.30	5386.65	
	20.5	7.70	5386.25	TOB
	21.5	8.60	5385.35	LEW
	25.2	9.10	5384.85	
	28.5	9.35	5384.60	
	34.2	8.98	5384.97	
	35.6	9.05	5384.90	
	39.3	8.80	5385.15	
	43.6	9.02	5384.93	
	49.7	8.88	5385.07	
	56.3	9.06	5384.89	
	59.2	9.05	5384.90	
	61.2	8.60	5385.35	REW
	62.0	7.56	5386.39	TOB
	67.8	6.92	5387.03	
	74.5	5.52	5388.43	
	86.0	3.58	5390.37	
	96.2	4.05	5389.90	
	101.0	2.90	5391.05	
	130.2	1.37	5392.58	Pin 6R, bank continues uphill

Figure 17. Site 4840 Reduced Survey Notes.

5.2 Site 4840 HEC-RAS Modeling

The six cross sections were input to the HEC-RAS modeling system. A range of discharge was simulated, and the water surface elevation at the PT cross section was calculated and analyzed. Manning n values for in-channel areas were assigned 0.035; overbank sections were assigned 0.05 for each cross section. This simulation assumes that the gate to the South Boulder Ditch is closed and all flow remains in South Boulder Creek throughout the surveyed reach (i.e., all flow that crosses upstream Cross-Section 6.0, leaves at downstream Cross-Section 1.0). Downstream normal depth control was assumed as the modeling boundary condition, with an average channel bed slope of 0.024 ft/ft.

The discharges modeled range from zero flow to the point where water is predicted to flow out of any point in the surveyed channel bank. This overflow condition is predicted to occur near Cross-Section 6.0 above the diversion structure, on the left bank at 1,050 cfs. Given the topography and the bend in the creek, flow leaving the channel on the left bank would flood the adjacent field and recreation path and not return to the channel upstream of the PT. In a flooding situation, where water leaves the creek bank at locations upstream of the diversion structure, the PT at the current location is likely not to measure this overbank flow.

The simulated water surface elevations corresponding to a discharge of 1,050 cfs flowing through the surveyed cross sections are presented in Figure 18. Tabular HEC-RAS output is presented in Figure 19. Longitudinal flow profiles predicted throughout the reach are presented in Figure 20.

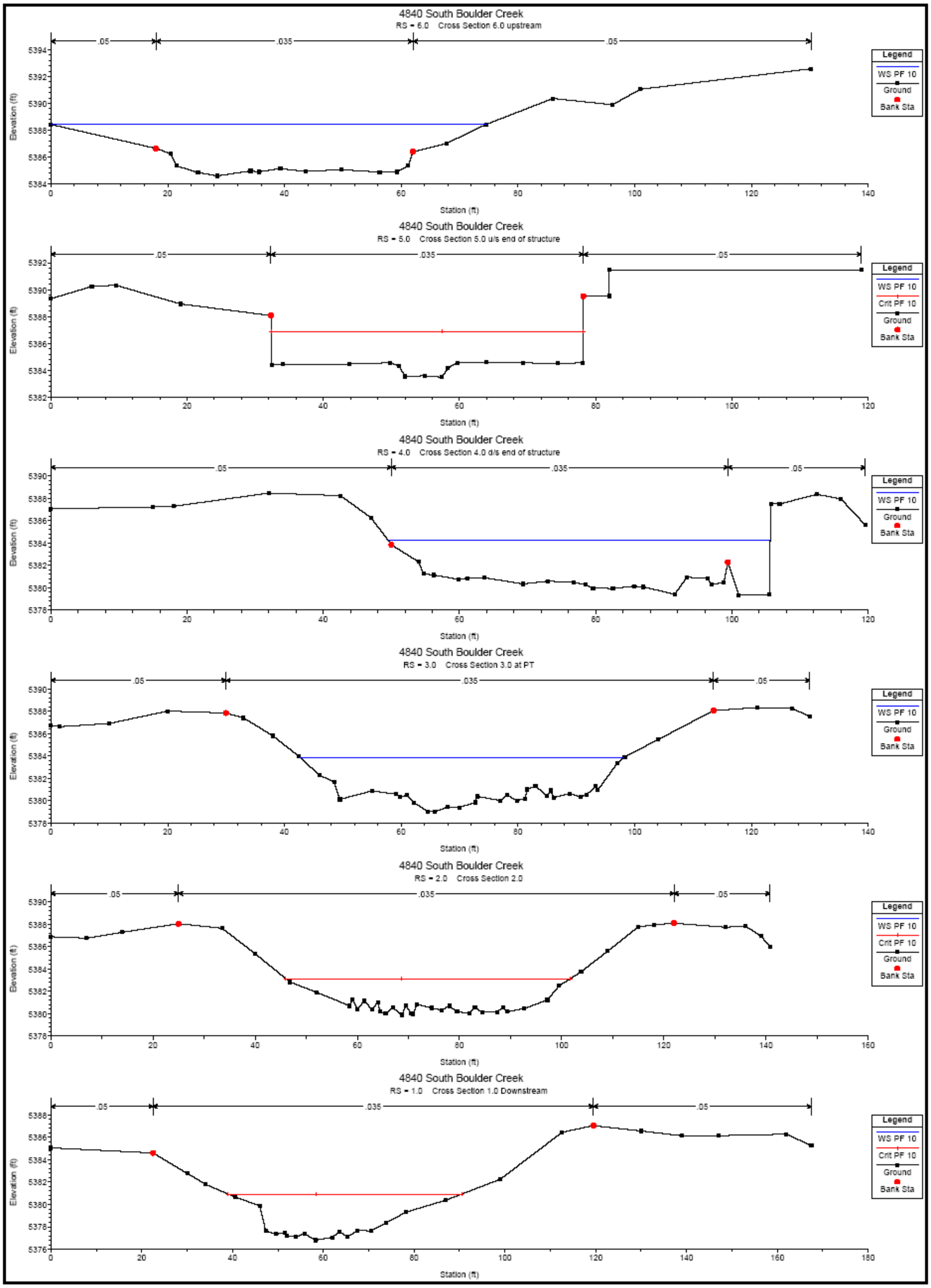

Figure 18. Site 4840 HEC-RAS Water Surface Elevations at Maximum Flow at Cross-Section 6.0.

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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)	
4840	6.0	PF 1	0.10	5384.60	5384.73	5384.68	5384.73	0.004224	0.44	0.23	3.62	0.31
4840	6.0	PF 2	1.00	5384.60	5384.92	5384.80	5384.93	0.004663	0.68	1.47	12.99	0.35
4840	6.0	PF 3	10.00	5384.60	5385.18		5385.20	0.004689	1.12	8.97	37.65	0.40
4840	6.0	PF 4	50.00	5384.60	5385.63		5385.68	0.003486	1.89	26.50	40.21	0.41
4840	6.0	PF 5	100.00	5384.60	5385.93		5386.03	0.004041	2.58	38.74	40.78	0.47
4840	6.0	PF 6	250.00	5384.60	5386.55		5386.78	0.004965	3.85	64.99	44.82	0.56
4840	6.0	PF 7	500.00	5384.60	5387.26		5387.67	0.005378	5.15	100.97	56.98	0.62
4840	6.0	PF 8	750.00	5384.60	5387.82		5388.37	0.005368	6.00	135.51	65.39	0.64
4840	6.0	PF 9	1000.00	5384.60	5388.35		5388.98	0.005072	6.56	171.74	73.18	0.64
4840	6.0	PF 10	1050.00	5384.60	5388.45		5389.09	0.004993	6.64	179.29	74.58	0.64
4840	5.0	PF 1	0.10	5383.48	5383.56	5383.56	5383.58	0.071381	1.03	0.10	3.53	1.09
4840	5.0	PF 2	1.00	5383.48	5383.64	5383.64	5383.70	0.061895	2.04	0.49	5.71	1.22
4840	5.0	PF 3	10.00	5383.48	5384.00	5384.00	5384.21	0.025789	3.66	2.73	6.60	1.00
4840	5.0	PF 4	50.00	5383.48	5384.70	5384.70	5384.87	0.027035	3.30	15.17	45.71	1.01
4840	5.0	PF 5	100.00	5383.48	5384.89	5384.89	5385.16	0.023809	4.17	23.96	45.72	1.02
4840	5.0	PF 6	250.00	5383.48	5385.33	5385.33	5385.83	0.019865	5.66	44.17	45.74	1.01
4840	5.0	PF 7	500.00	5383.48	5385.90	5385.90	5386.69	0.017502	7.12	70.20	45.77	1.01
4840	5.0	PF 8	750.00	5383.48	5386.40	5386.40	5387.41	0.015975	8.09	92.75	45.79	1.00
4840	5.0	PF 9	1000.00	5383.48	5386.82	5386.82	5388.05	0.015494	8.93	111.99	45.81	1.01
4840	5.0	PF 10	1050.00	5383.48	5386.89	5386.89	5388.18	0.015454	9.09	115.54	45.82	1.01
4840	4.0	PF 1	0.10	5379.41	5380.09		5380.09	0.000001	0.01	5.95	16.54	0.01
4840	4.0	PF 2	1.00	5379.41	5380.22		5380.22	0.000034	0.11	8.38	18.89	0.04
4840	4.0	PF 3	10.00	5379.41	5380.57		5380.58	0.000628	0.57	16.74	32.51	0.16
4840	4.0	PF 4	50.00	5379.41	5381.12		5381.15	0.001527	1.29	39.18	48.13	0.27
4840	4.0	PF 5	100.00	5379.41	5381.50		5381.54	0.001794	1.81	57.67	50.33	0.31
4840	4.0	PF 6	250.00	5379.41	5382.21		5382.32	0.002300	2.83	93.82	51.44	0.38
4840	4.0	PF 7	500.00	5379.41	5383.01		5383.24	0.002789	3.92	136.06	53.45	0.44
4840	4.0	PF 8	750.00	5379.41	5383.62		5383.95	0.003156	4.73	169.07	55.07	0.48
4840	4.0	PF 9	1000.00	5379.41	5384.12		5384.55	0.003412	5.43	196.98	55.98	0.52
4840	4.0	PF 10	1050.00	5379.41	5384.21		5384.67	0.003458	5.56	202.04	56.10	0.52
4840	3.0	PF 1	0.10	5379.00	5380.09		5380.09	0.000000	0.01	7.50	13.01	0.00
4840	3.0	PF 2	1.00	5379.00	5380.22		5380.22	0.000014	0.11	9.48	17.04	0.02
4840	3.0	PF 3	10.00	5379.00	5380.54		5380.55	0.000452	0.59	16.93	30.32	0.14
4840	3.0	PF 4	50.00	5379.00	5381.03		5381.06	0.001553	1.42	35.15	42.00	0.27
4840	3.0	PF 5	100.00	5379.00	5381.37		5381.43	0.002152	2.00	50.04	45.56	0.34
4840	3.0	PF 6	250.00	5379.00	5382.02		5382.17	0.003001	3.11	80.31	48.05	0.42
4840	3.0	PF 7	500.00	5379.00	5382.76		5383.05	0.003683	4.25	117.55	51.21	0.49
4840	3.0	PF 8	750.00	5379.00	5383.33		5383.73	0.004156	5.10	146.93	53.18	0.54
4840	3.0	PF 9	1000.00	5379.00	5383.79		5384.32	0.004577	5.81	172.20	55.18	0.58
4840	3.0	PF 10	1050.00	5379.00	5383.88		5384.43	0.004656	5.94	176.87	55.54	0.59
4840	2.0	PF 1	0.10	5379.90	5380.08	5380.04	5380.09	0.018735	0.79	0.13	2.31	0.60
4840	2.0	PF 2	1.00	5379.90	5380.20	5380.17	5380.22	0.019705	1.14	0.88	10.05	0.68
4840	2.0	PF 3	10.00	5379.90	5380.44	5380.41	5380.52	0.025839	2.34	4.27	19.88	0.89
4840	2.0	PF 4	50.00	5379.90	5380.80	5380.77	5380.99	0.024032	3.53	14.16	33.31	0.95
4840	2.0	PF 5	100.00	5379.90	5381.03	5381.03	5381.34	0.024804	4.45	22.49	38.17	1.02
4840	2.0	PF 6	250.00	5379.90	5381.54	5381.54	5382.05	0.020471	5.74	43.58	43.69	1.01
4840	2.0	PF 7	500.00	5379.90	5382.14	5382.14	5382.91	0.017898	7.01	71.37	48.11	1.01
4840	2.0	PF 8	750.00	5379.90	5382.65	5382.65	5383.58	0.016124	7.74	96.92	52.21	1.00
4840	2.0	PF 9	1000.00	5379.90	5383.07	5383.07	5384.16	0.015494	8.39	119.16	55.27	1.01
4840	2.0	PF 10	1050.00	5379.90	5383.14	5383.14	5384.27	0.015344	8.50	123.47	55.75	1.01
4840	1.0	PF 1	0.10	5376.80	5376.90	5376.90	5376.92	0.038837	1.11	0.09	1.86	0.89
4840	1.0	PF 2	1.00	5376.80	5377.04	5377.04	5377.10	0.035469	1.90	0.52	4.48	0.98
4840	1.0	PF 3	10.00	5376.80	5377.40	5377.38	5377.50	0.023832	2.63	3.81	14.73	0.91
4840	1.0	PF 4	50.00	5376.80	5377.81	5377.81	5378.07	0.023816	4.10	12.19	24.09	1.02
4840	1.0	PF 5	100.00	5376.80	5378.12	5378.12	5378.51	0.020810	5.05	19.80	25.70	1.01
4840	1.0	PF 6	250.00	5376.80	5378.79	5378.79	5379.45	0.017542	6.55	38.18	29.19	1.01
4840	1.0	PF 7	500.00	5376.80	5379.61	5379.61	5380.55	0.015822	7.80	64.08	34.54	1.01
4840	1.0	PF 8	750.00	5376.80	5380.31	5380.31	5381.36	0.014986	8.26	90.84	43.40	1.01
4840	1.0	PF 9	1000.00	5376.80	5380.83	5380.83	5381.99	0.014441	8.65	115.66	50.37	1.01
4840	1.0	PF 10	1050.00	5376.80	5380.92	5380.92	5382.11	0.014430	8.74	120.08	51.42	1.01

Figure 19. Site 4840 HEC-RAS Model Output.

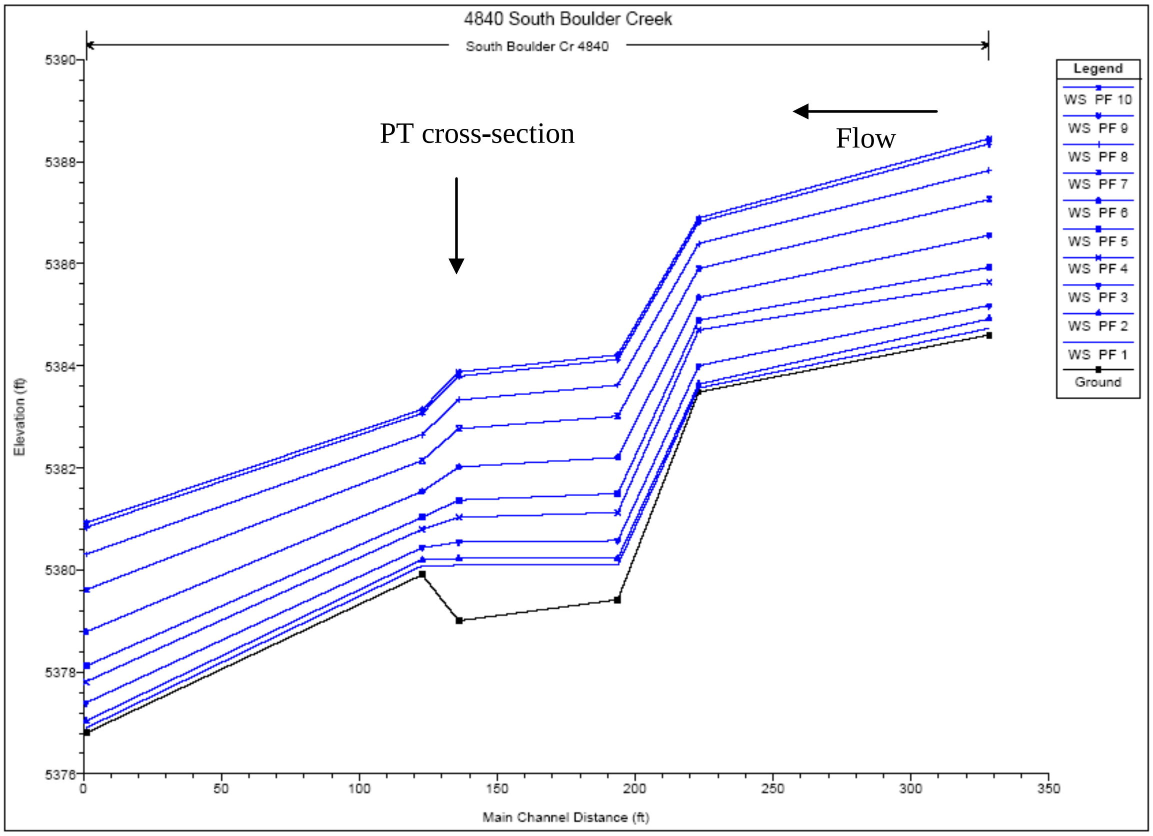

Figure 20. Site 4840 HEC-RAS Longitudinal Water Surface Profiles.

On February 3, 2006 a discharge measurement was taken at the 4840 site. A Marsh-McBirney current meter was used to measure the water depth and velocity along a cross section just downstream of Cross-Section 1.0. The measured data and calculated discharge are presented in Figure 21. The flow measured on February 3, 2006 was 3.6 cfs.

DISCHARGE MEASUREMENTS NOTES

Location:	Site 4840 S. Boulder Ck at S.B. Ditch	Project:	A212-UDFCD Ratings Development	Start Time(hrs): 1535 mst	Weather: sunny, cool and windy
Meter:	Marsh-McBirney	Date:	Feb 3, 2006	Start Stage(ft): 5380.57	Cross Section: downstream of cross section 1.0
Serial No.		Party:	Hanna/Wright	Stop Time(hrs): 1605 mst	Gage Condition: clear, some vegetation/leaves
Computed By:	Hanna Date: 2/4/2006	Checked By:	Spotts Date: 2/4/2006	Stop Stage(ft): 5380.57	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
0.00	LEW	0.00								
3.70	2.40	0.78		0.78		0.00	0.00	1.87	0.000	
4.80	1.15	1.08		1.08		0.10	0.10	1.24	0.124	
6.00	1.10	1.05		1.05		-0.79	-0.79	1.16	-0.916	
7.00	1.05	0.65		0.65		-0.72	-0.72	0.68	-0.490	
8.10	1.00	0.83		0.83		0.23	0.23	0.83	0.191	
9.00	0.95	0.88		0.88		0.13	0.13	0.84	0.109	
10.00	1.10	0.88		0.88		0.03	0.03	0.97	0.029	
11.20	1.10	1.13		1.13		0.69	0.69	1.24	0.856	
12.20	1.20	1.05		1.05		1.41	1.41	1.26	1.777	
13.60	1.10	1.10		1.10		0.72	0.72	1.21	0.871	
14.40	0.95	0.85		0.85		0.85	0.85	0.81	0.689	
15.50	1.15	0.81		0.81		0.79	0.79	0.93	0.735	
16.70	1.15	0.65		0.65		0.03	0.03	0.75	0.023	
17.80	1.20	0.50		0.50		-0.72	-0.72	0.60	-0.432	
19.10	1.10	0.00		0.00		-0.79	-0.79	0.00	0.000	
20.00	REW			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	17.70							14.39	3.566	

Figure 21. Site 4840 Measured Discharge Calculation.

The HEC-RAS model predictions for water surface elevation at the PT cross section for the modeled range of discharges are presented in Figure 22. The flow measurement datum point has been added for comparison to the predicted rating. The discharge for the water surface elevation of 5,380.57 ft amsl at the PT was measured slightly lower than predicted by the model.

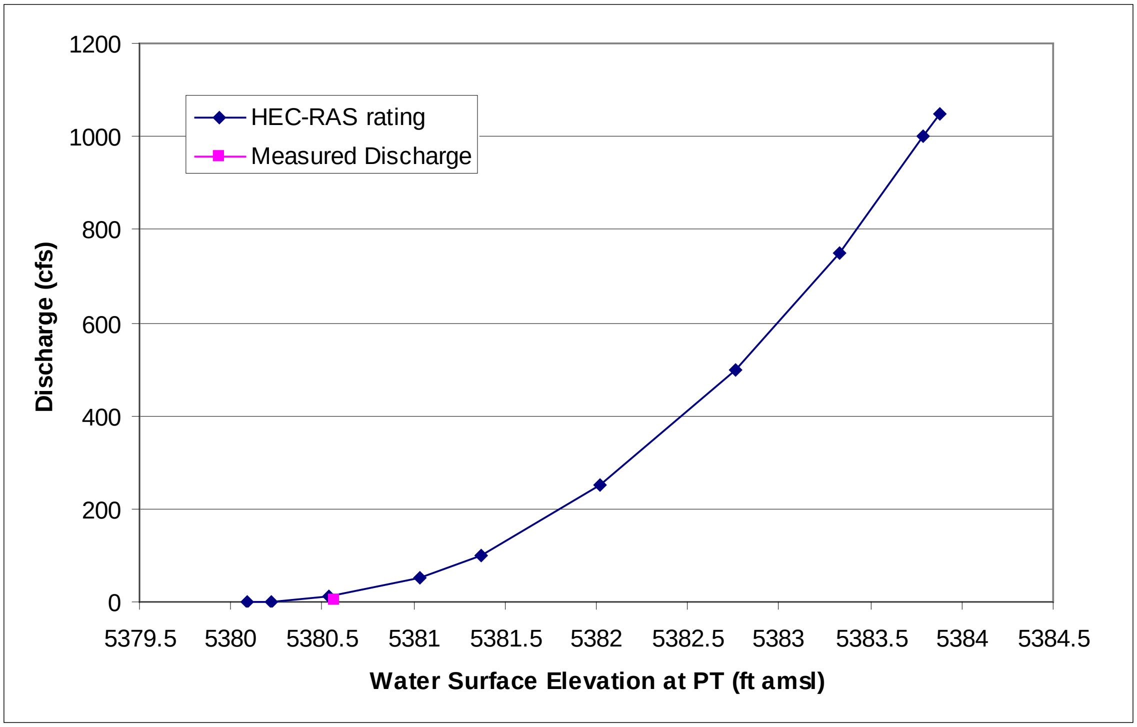

Figure 22. Site 4840 Stage-Discharge Relationship at the PT.

5.3 Site 4840 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 (5,379.00 ft amsl). The minimum channel elevation at Cross-Section 2.0, downstream of the PT is slightly higher (5,379.90 ft amsl) pooling water to a depth of 0.9 feet before flow in the river begins. Therefore the zero flow depth at the PT cross section is 0.9 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 (Table 1).

Table 1. Site 4840 Predicted Stage-Discharge Relationship Tabular Data.

Predicted Water Surface Elevation (ft amsl)	Depth above PT (ft)[1]	Discharge (cfs)	Condition
5,379.90[2]	0.90	0	
5,380.09	1.09	0.1	
5,380.22	1.22	1	
5,380.54	1.54	10	
5,381.03	2.03	50	
5,381.37	2.37	100	
5,382.02	3.02	250	
5,382.76	3.76	500	
5,383.33	4.33	750	
5,383.79	4.79	1,000	
5,383.88	4.88	1,050	Overbank flow begins upstream of diversion dam

[1] Depth is calculated as predicted water surface elevation minus minimum measured channel elevation at Cross-Section 3.0 (5,379.00 ft amsl)
[2] The zero flow elevation is the minimum measured channel depth at Cross-Section 2.0 (5,379.90 ft amsl)

The current UDFCD rating for the site is presented in Table 2.

Table 2. Current UDFCD Rating for Site 4840.

Depth (ft)[1]	Discharge (cfs)
0	0
0.5	50
1.25	200
2.43	500
4.73	1,650
8.3	6,000
9.14	10,650

A comparison plot of the current rating and the HEC-RAS rating developed here is presented in Figure 23. A comparison of these ratings shows that predicted stage for a given discharge is higher for this rating, as compared to the current UDFCD rating. This discrepancy is possibly due to the fact that a much larger scale model was used to develop the previous UDFCD rating, where valley wide flood flows are simulated. For a unit change in discharge, the change in stage for a wide flow would be small in comparison to the change in stage for a narrow focused flow like the present rating. Additionally, the present rating includes a stage of 0.9 ft for the zero flow condition, whereas the current UDFCD rating indicates zero stage at zero flow. Shifting the

UDFCD rating 0.9 ft to the right in Figure 23 would result in a much better correlation to the new HEC-RAS rating, particularly at the lower flows.

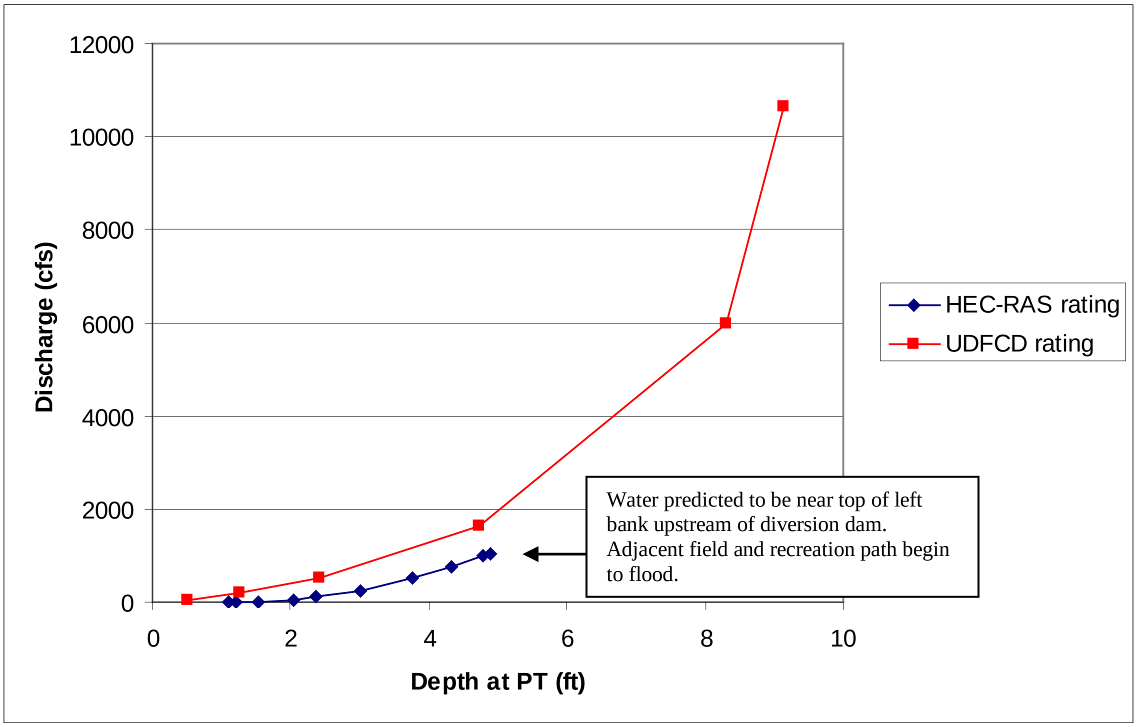

Figure 23. Site 4840 Stage-Discharge Relationship Comparison.

The HEC-RAS rating on a Log-Log plot is presented in Figure 24.

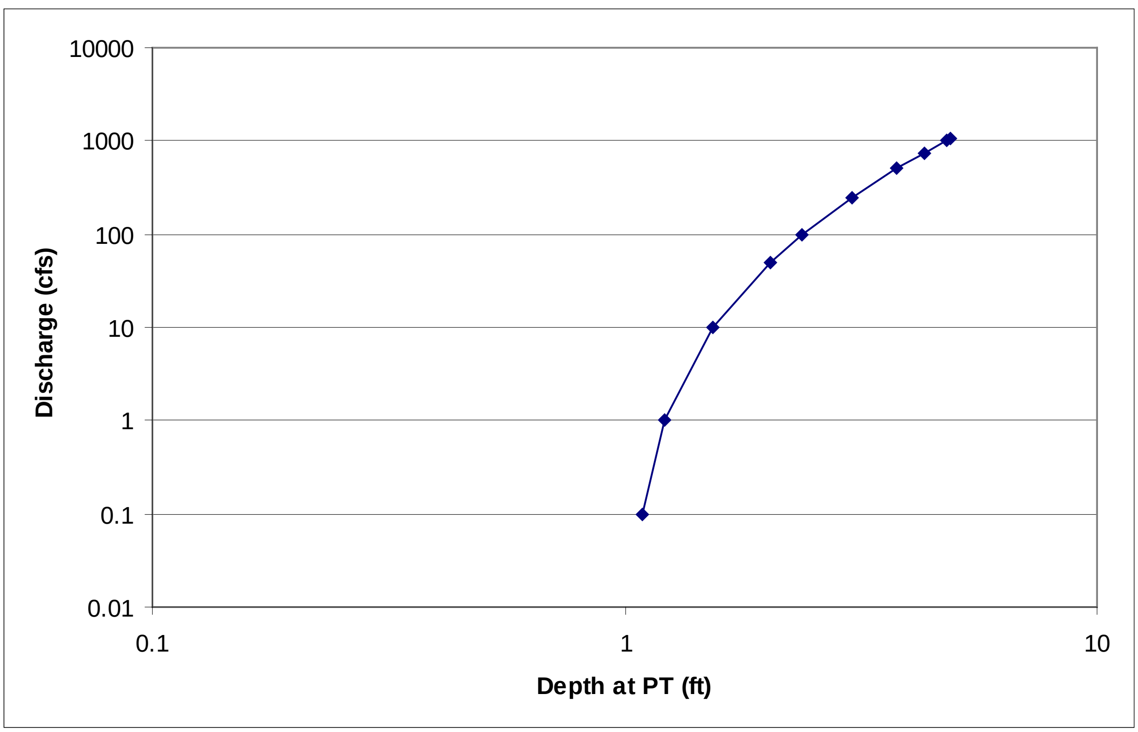

Figure 24. Site 4840 Stage-Discharge Relationship Log-Log Plot.

5.4 Site 4840 Discussion of Rating Results

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 5,379.00 ft amsl or 3.95 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 rating developed here describes the discharge in the South Boulder Creek below the South Boulder Creek diversion structure only and will not measure any flow leaving the channel above the structure either by flooding of adjacent fields or by diversion at the structure.

At water depths in the channel at the PT cross section above 4.9 ft (measured from the channel bed), flooding of the adjacent fields and the recreation path is likely to occur.

Model simulations indicate that flooding will occur above the diversion structure on the river left bank at high flows. Riverbank modifications to increase the bank heights on the left riverbank are recommended to allow for more channel carrying capacity.

6.0 REFERENCES

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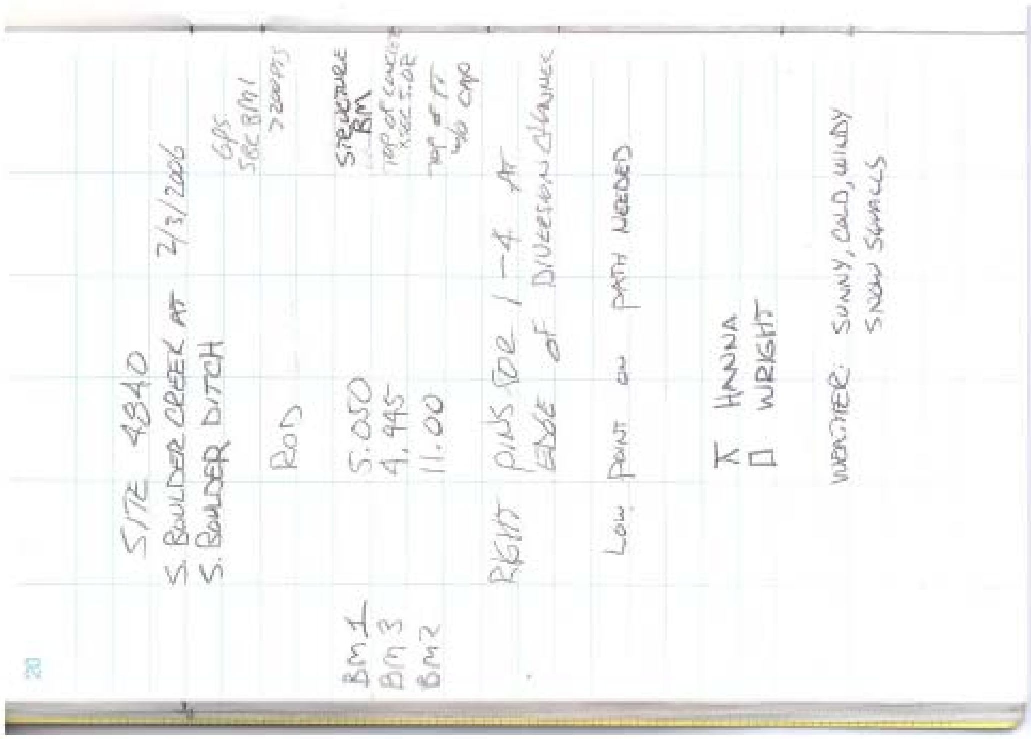
7.0 SURVEY FIELD NOTES


SITE 4840 2/3/2006
S. BOULDER CREEK AT
S. BOULDER DITCH
GPS SBC BM1 >200PTS
ROD
BM1 5.050 STRUCTURE BM
BM3 4.945 TOP OF CONCRETE XSEC 2.0E
BM2 11.00 TOP OF PT W/ CAP
RIGHT PINS FOR 1-4 AT
EDGE OF DIVERSION CHANNEL
LOW POINT ON PATH NEEDED
⊼ HANNA
□ WRIGHT
WEATHER: SUNNY, COLD, WINDY
SNOW SQUALLS
20

22

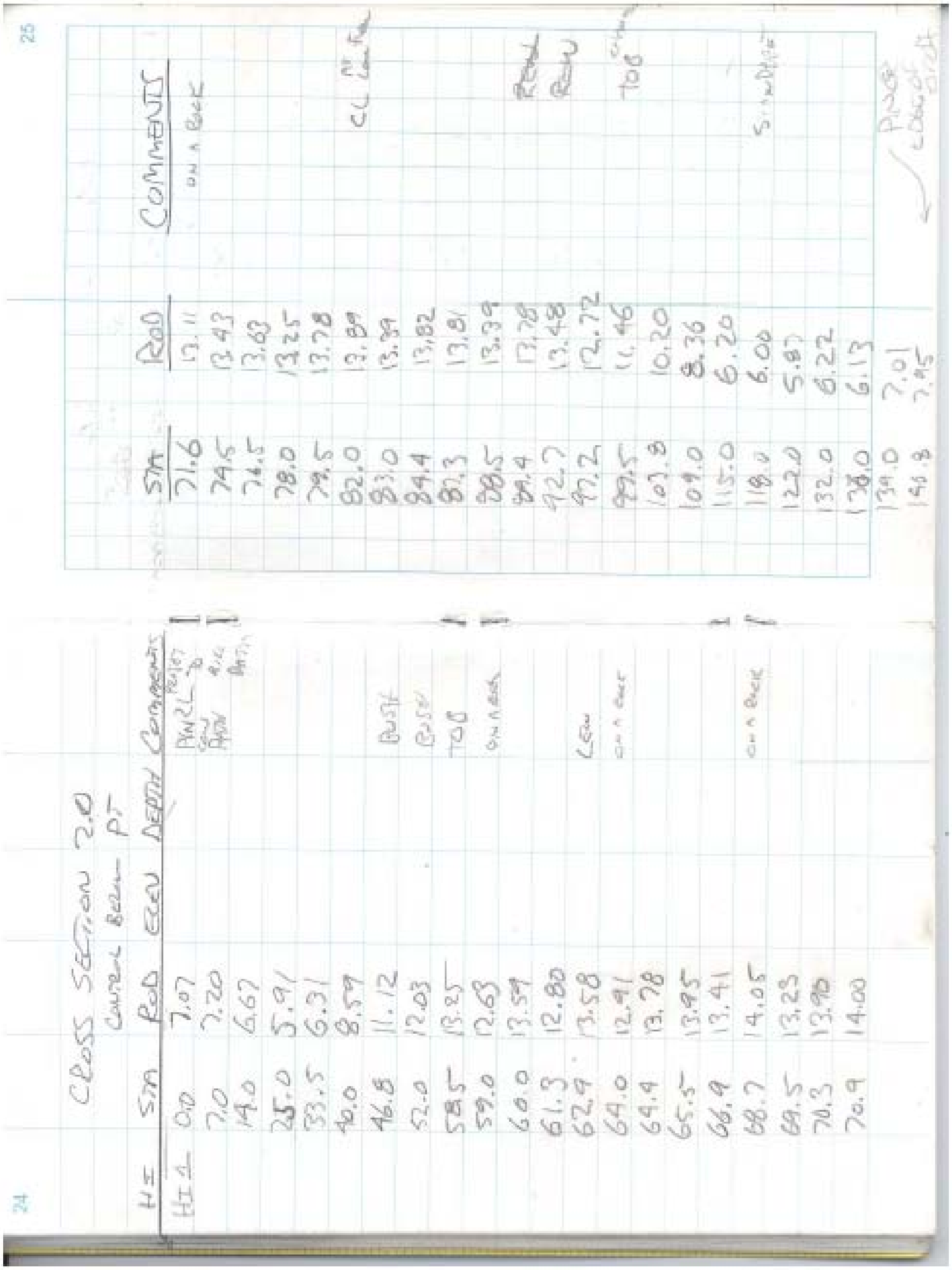
CROSS SECTION 1.0

DOWNSTREAM

HI	STA	ROD	ELEV	DEPTH	COMMENTS
HI1	0.0				
	1.0	9.90			
	9.0	9.0 est			
	20.0	9.19			
	24.0	9.60			
	28.0	10.65			
	34.0	12.18			
	40.5	13.31			
	46.0	14.1 est			TOB
	47.3	16.30 est			LEW
		Other ROD			
HI2		2.50			BS to BM
					@ Bridge PIN/2
	0.0	6.35			
	22.5	6.81			
	30.0	8.63			
	34.0	9.60			
	40.5	10.74			
	46.0	11.52			TOB
	47.3	13.76			
	49.6	14.06			LEW

23

STA	ROD	COMMENTS
51.5	13.92	
52.0	14.21	
54.0	14.29	
55.8	14.02	~~0.20~~ 0.02
58.3	14.60	0.6
62.0	14.35	0.38
63.5	13.83	0.0
65.3	14.30	0.48
67.5	13.74	
70.5	13.76	R
73.8	13.06	
78.2	12.10	TOB
87.0	11.03	
99.0	9.14	
112.6	4.96	TOB
119.5	4.37	
130.0	4.84	
139.0	5.27	
147.0	5.26	
162.0	5.13	~~[illegible]~~
167.5	6.14	PIN



CROSS SECTION 2.0

CONTROL BEAM PT

HI	STA	ROD	ELEV	DEPTH	COMMENTS
HI 1	0.0	7.07			PIN 2L
	7.0	7.20			
	14.0	6.67			
	25.0	5.91			
	33.5	6.31			
	40.0	8.59			
	46.8	11.12			BUSH
	52.0	12.03			BUSH
	58.5	13.25			TOB
	59.0	12.63			ON A ROCK
	60.0	13.59			
	61.3	12.80			
	62.9	13.58			LEW
	64.0	12.91			ON A ROCK
	64.4	13.78			
	65.5	13.95			
	66.9	13.41			
	68.7	14.05			ON A ROCK
	69.5	13.23			
	70.3	13.90			
	70.9	14.00			

STA	ROD	COMMENTS
71.6	13.11	ON A ROCK
74.5	13.43	
76.5	13.63	
78.0	13.25	
79.5	13.78	
82.0	13.89	CL
83.0	13.39	
84.4	13.82	
87.3	13.81	
88.5	13.39	
89.4	13.78	
92.7	13.48	REW
97.2	12.72	
99.5	11.46	TOB
103.8	10.20	
109.0	8.36	
115.0	6.20	
118.0	6.00	
122.0	5.87	
132.0	6.22	
138.0	6.13	
139.0	7.01	
140.8	7.95	

CROSS SECTION 8.0

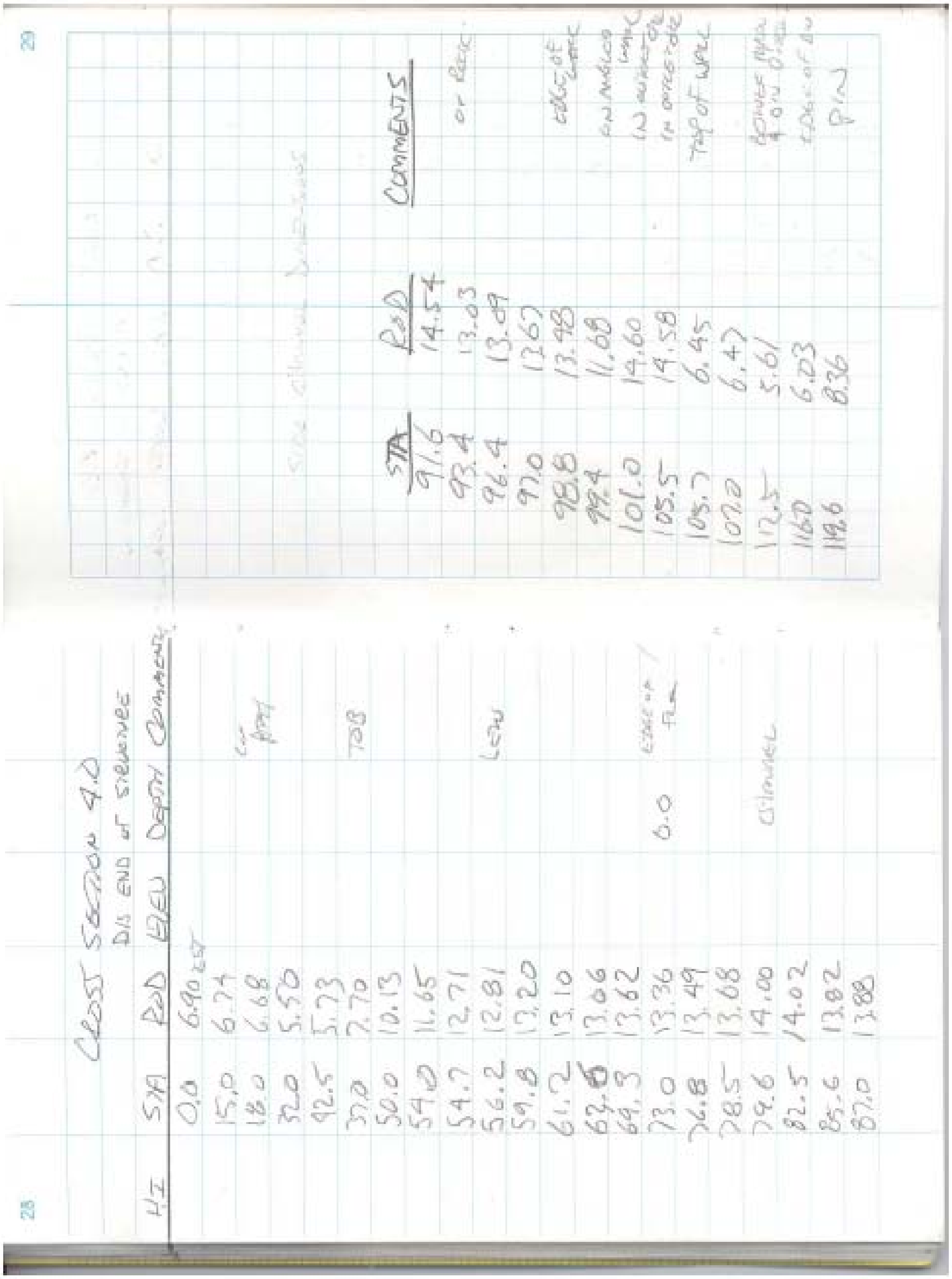
AT PT

HI	STA	ROD	ELEV	DEPTH	COMMENTS
	0.0	7.22			PIN [illegible]
	1.5	7.34			
	10.0	7.05			
	20.0	5.94			
	30.0	6.12			
	33.0	6.55			
	38.0	8.15			
	42.5	10.00			
	46.0	11.67			
	48.5	12.27			BUSH
	49.5	13.83			
	55.0	13.08			
	59.1	13.36			LEW
	59.8	13.65			
	61.0	13.45			
	62.2	14.15			
	64.6	14.91		1.51	
	65.7	14.95		1.51	
	68.0	14.51			
	70.0	14.55		1.15	
	72.7	14.09			

11.00

TOP OF PT w/ CAP

STA	ROD	DEPTH	COMMENTS
73.0	13.56	0.18	
77.0	13.94	0.55	
78.2	13.45		
79.8	13.95	0.58	
81.2	13.75		
81.6	12.94	REW	
83.0	12.64	cut BACK	
85.0	13.53		
85.6	13.04		
86.2	13.67	0.29	
88.8	13.36		
90.8	13.61	0.21	
91.8	13.41		REW
93.3	12.64		BUSHES
97.7	12.99		
97.0	10.62		
98.3	10.03		
104.0	8.49		
113.5	5.90		
121.0	5.62		
128.0	5.71		
130.0	6.93		PIN

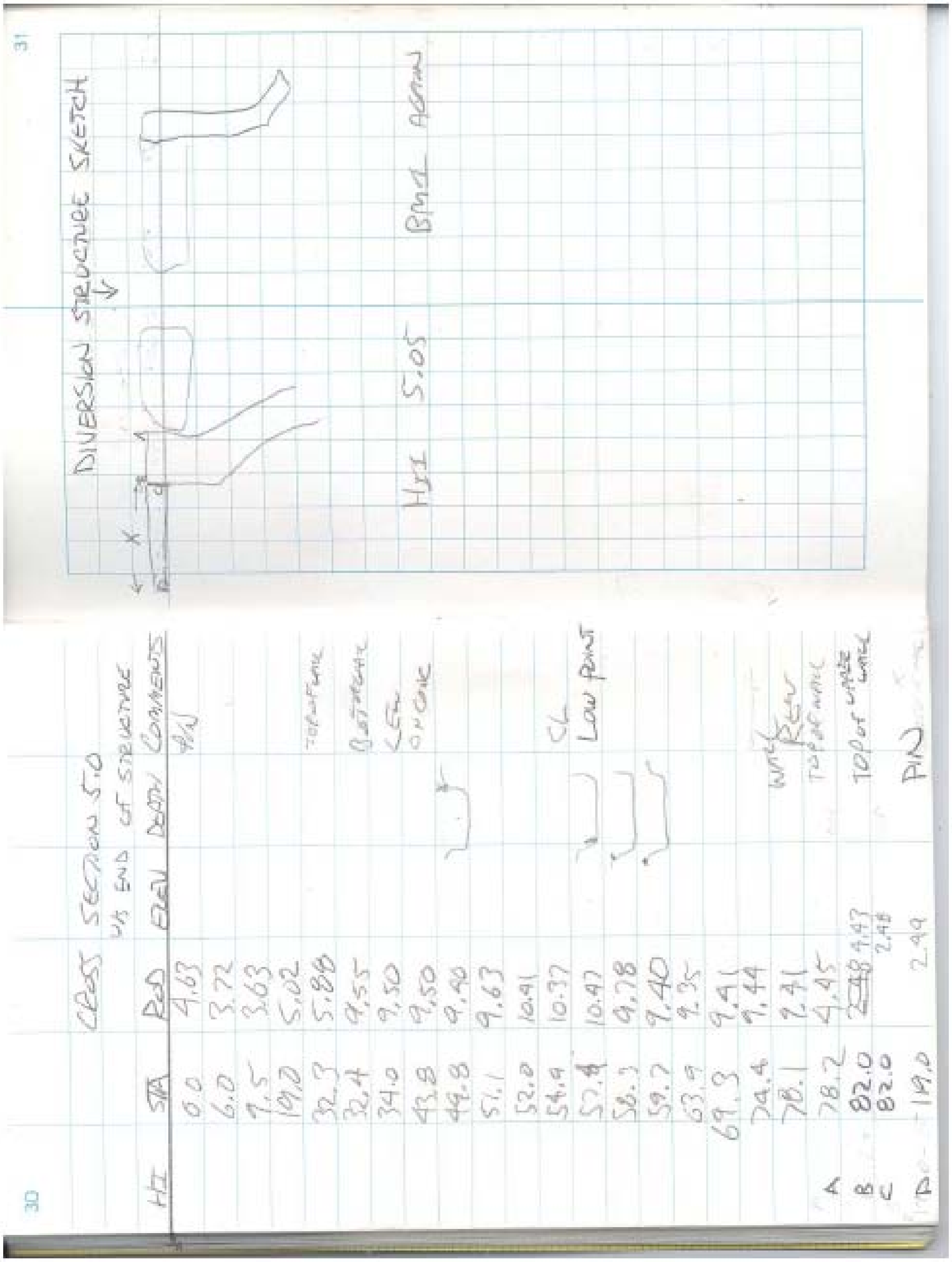


CROSS SECTION 4.0
D/S END OF STRUCTURE

HI	STA	ROD	ELEV	DEPTH	COMMENTS
	0.0	6.90 EST			
	15.0	6.74			
	18.0	6.68			[illegible]
	32.0	5.50			
	42.5	5.73			
	37.0	7.70			TOB
	50.0	10.13			
	54.0	11.65			
	54.7	12.71			
	56.2	12.81			LEW
	59.8	13.20			
	61.2	13.10			
	63.6	13.06			
	64.3	13.62			
	73.0	13.36		0.0	EDGE OF [illegible]
	76.8	13.49			
	78.5	13.68			
	79.6	14.00			CHANNEL
	82.5	14.02			
	85.6	13.82			
	87.0	13.88			

SIDE CHANNEL [illegible]

STA	ROD	COMMENTS
91.6	14.54	
93.4	13.03	ON ROCK
96.4	13.09	
97.0	13.67	
98.8	13.48	EDGE OF WATER
99.4	11.68	ON ANGLED [illegible]
101.0	14.60	IN [illegible]
105.5	14.58	IN OUTSIDE [illegible]
105.7	6.45	TOP OF WALL
107.0	6.47	
112.5	5.61	[illegible]
116.0	6.03	EDGE OF [illegible]
119.6	8.36	PIN



CROSS SECTION 5.0

U/S END OF STRUCTURE

HI	STA	ROD	ELEV	DEPTH	COMMENTS
	0.0	4.63			PIN
	6.0	3.72			
	9.5	3.63			
	19.0	5.02			
	32.3	5.88			TOP OF WALL
	32.4	9.55			BOT WALL
	34.0	9.50			LEW ON CONC
	43.8	9.50			
	49.8	9.40			
	51.1	9.63			
	52.0	10.41			
	54.9	10.37			CL
	57.4	10.47			LOW POINT
	58.3	9.78			
	59.7	9.40			
	63.9	9.35			
	69.3	9.41			
	74.4	9.44			
	78.1	9.41			WALL REW
A	78.2	4.45			TOP OF WALL
B	82.0	~~2.48~~ 4.43			TOP OF UPPER WALL
C	82.0	2.48			
D	119.0	2.49			PIN

DIVERSION STRUCTURE SKETCH

X

HI 5.05

BM1 AGAIN