TR-521
FIELD INVESTIGATION OF HYDRAULIC STRUCTURES FACILITATING FISH ABUNDANCE & PASSAGE THROUGH BRIDGES IN WESTERN IOWA STREAMS

FINAL REPORT

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16. ABSTRACT

The overarching goal of the proposed research was to evaluate the hydraulic performance of twenty two (22) fish-passage structures located in close proximity to bridges in western Iowa and within the HCA (Hungry Canyon Alliance) territory. Such structures include riprap weirs, fish ladders and grouted ripraps. The hydraulic performance of the aforementioned structures was evaluated via detailed field tests for a range of flow conditions relevant to fish migration through bridge waterways in different streams in western Iowa.

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1. INTRODUCTION

1.1 Problem statement and background

In the highly erodible loess area of western Iowa, human disturbances to flood plains and upland areas during much of the 20th century resulted in substantial degradation of stream-channel morphology. Beginning about 1920, some streams throughout the region were reworked directly -being enlarged and straightened- to alleviate frequent and prolonged flooding of productive bottomlands.

The accelerated channel erosion and the formation of canyon-like stream channels, known locally in western Iowa as "hungry canyons," also have resulted in severe damage to highways and county roads infrastructure, pipelines, fiber-optic lines, and loss of farmland adjacent to the channels.

An overall outcome of the altered stream channels that has been common, is the severe problems for the passage of fish through many streams in western Iowa. Commonly, the problems are especially severe at grade-control structures intended to minimize channel erosion. These retaining structures change the profi1e of the stream bed and prevent the formation of knickpoints. Knickpoints typically form downstream of over-steepened reaches when the flow plunges to the bed and creates a plunge pool. Also, such structures often coincide with bridge sites, in an effort to protect bridge foundations. The characteristic that bridge sites have is that the downstream reach of a bridge has typically a much lower depth than the constricted reach found at the bridge waterway. Such discontinuities can impede fish passage, and require means (likely structural) to aid fish passage.

In order to prevent the formation and propagation of knickpoints different grade control structures have been employed on several streams in western Iowa. These are riprap weirs, grouted weirs and fish ladders. Although a considerable number of studies have focused on passage issues for anadromous fish and for riverine structures that are used solely as fish migratory conveyors for irrigation diversion purposes such as denil fishways, V-shape diversion structures, vertical slot fishways, fish ladders in hydroelectric dams and culverts, very little attention has been given on studying fish passage through riprap weirs, grouted weirs and fish ladders.

1.2 Objective and Tasks

The overarching goal of the proposed research was to evaluate the hydraulic performance of twenty two (22) fish-passage structures located in close proximity to bridges in western Iowa and within the HCA (Hungry Canyon Alliance) territory. Such structures include riprap weirs, fish ladders and grouted ripraps. Table 1 represents the names of the structures, their location and the corresponding stream name. Table 2 briefly describes the type of structures and the initial grade control right after their construction. The state map in Figure 1a illustrates the approximate location of the structures in western Iowa.

The hydraulic performance of the aforementioned structures was evaluated via detailed field tests for a range of flow conditions relevant to fish migration through bridge waterways in different streams in western Iowa. Survey of the structures and measurements of flow were conducted during Fall of 2004 (October-November), Spring of 2005 (May-June) as it was preplanned. Due to record low-flow conditions during these periods, additional measurements were performed during Fall of 2005, which are also presented herein. The latter measurements were focused on detailed mapping of turbulence in the vicinity of two structures (riprap weir 69-6114-9-6 and fish ladder 69-6114-1-23).

Table 1. Location of the structures

Site	Location	Stream
69-6114-9-4	Shelby County	Long Br. Cr.
01-20	Crawford County	Miller Cr.
69-6114-0-6	Audubon County	Indian Cr.
69-6114-2-1 (1)	Pottawattamie County	Walnut Cr.
00-20	Crawford County	Coon Cr.
01-10	Montgomery County	Indian Cr.
00-21	Crawford County	Beaver Cr.
00-11 and 04-26	Cass County	Turkey Cr.
00-10	Cass County	Turkey Cr.
69-6114-0-5	Mills County	Silver Cr. Trib.
69-6114-0-8	Page County	Snake Cr.
00-24	Page County	Tarkio R.
03-1-F	Shelby County	Mosquito Cr.
00-5 (1)	Montgomery County	Walnut Cr.
02-1-F	Audubon County	David's Cr.
02-9-F	Page County	Tarkio R.
69-6114-1-23	Page County	E. Tarkio R
69-6114-1-06	Crawford County	Boyer R.
02-15-F and 02-16	Crawford County	Otter Cr.
69-6114-9-6	Montgomery County	Walnut Cr.
03-8-F	Pottawattamie County	Keg Cr.
01-16	Cass County	W. Nodaway R

Table 2. Descriptions of the structures

Site	Description of structure	Grade Control (ft)
69-6114-9-4	sheet pile weir w/ grouted riprap near weir and loose riprap near weir outlet	4
01-20	sheet pile weir w/ grouted riprap near weir and loose riprap near weir outlet	4
69-6114-0-6	sheet pile weir w/ riprap in channel and grouted riprap on banks and at weir	3
69-6114-2-1 (1)	sheet pile weir w/ riprap and barrier rails	3
00-20	hog panel H-pile weir w/ grouted riprap near weir and loose riprap near weir outlet	4
01-10	sheet pile weir w/ riprap	3
00-21	hog panel H-pile weir w/ grouted riprap near weir and loose riprap near weir outlet	4
00-11 and 04-26	sheet pile weir - modified to grouted riprap 15:1 slope	3
00-10	sheet pile weir w/ riprap in channel and grouted riprap on banks near weir	3
69-6114-0-5	sheet pile weir w/ grouted riprap near weir and loose riprap near weir outlet	3
69-6114-0-8	sheet pile weir w/ concrete floor and sideslopes and central grouted riprap fish passage	3
00-24	sheet pile weir w/ concrete floor and sideslopes and central grouted riprap fish passage	3
03-1-F	sheet pile weir w/ grouted riprap near weir and loose riprap near weir outlet	4
00-5 (1)	modified EWP weir to 20:1 riprap slope	4
02-1-F	sheet pile weir w/ riprap and large boulders in channel and grouted riprap on banks	4
02-9-F	sheet pile weir w/ concrete floor and sideslopes and central grouted riprap fish passage w/ baffles	3
69-6114-1-23	sheet pile weir w/ concrete floor and sideslopes and central grouted riprap fish passage w/ baffles	3
69-6114-1-06	sheet pile weir w/ grouted riprap near weir and loose riprap near weir outlet	3
02-15-F and 02-16	sheet pile weir w/ grouted riprap and V-notch	4
69-6114-9-6	sheet pile weir w/ riprap	4
03-8-F	sheet pile weir w/ grouted riprap and V-notch	2.3
01-16	sheet pile weir w/ riprap in channel and grouted riprap on banks near weir	3

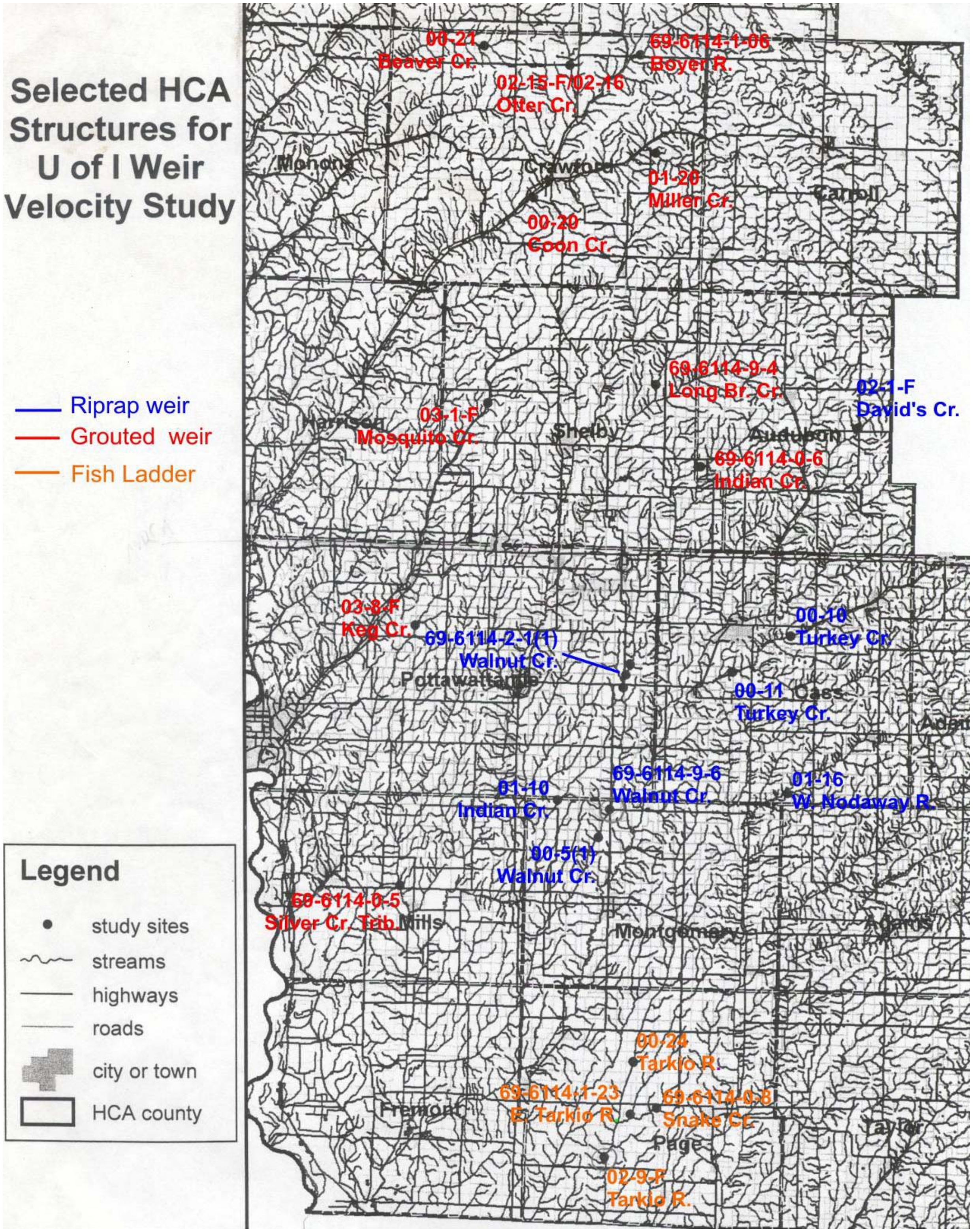


Figure 1a. Map of the sites in HCA area

This research entailed the following sequence of tasks:

1. Specify the structures for conducting flow measurements based on the IDNR and HCA recommendations. The HCA compiled the list of structures presented in Table 1 (O=original).

2. Obtain basin characteristic for all corresponding sites. This includes drainage area, stream-bed gradient and land factor (A=added).

3. Visual inspection of structures. This involved observations for scour formation, presence of debris and vegetation, bank failure and rock (riprap) displacement (A=added).

4. Stability assessment of structures. This included detailed survey of the structures, recording of the median size for the riprap weirs and documentation of the structures through still photography (O=original).

5. Define hydraulic measurement procedures and perform measurements. A set of state-of-the-art, non-intrusive instruments, as well as visual inspections were employed. The monitoring effort entailed the following activities:

    i. Select fixed (e.g. Acoustic Doppler Velocimeter (ADV), Acoustic Doppler Current Profiler (ADCP)) and portable (e.g. Large-Scale Particle Image Velocimetry, LSPIV) instruments to obtain flow measurements including the magnitude of the permissible velocity and turbulence level.

    ii. Perform flow point measurements with the ADV upstream, atop and downstream of a structure (Fall of 2004) (O=original).

    iii. Perform remote flow measurements via LSPIV per site (Fall of 2004 and Spring of 2005) (O=original).

    iv. Measure energy dissipation downstream of a structure (Fall of 2004) (A=added).

    v. Measure turbulence in the vicinity of two structures (riprap weir 69-6114-9-6 and fish ladder 69-61114-1-23) (Fall of 2005) (A=added).

6. Evaluate the performance of different structure types. Evaluation was based on structure stability, permissible velocity criteria and water depth atop the structures. (O=original)

7. Provide recommendations based on data interpretation (O=original).

The only task from the original list (as appeared in the proposal) that was not performed was the demonstration of three laboratory experiments with live-fish. The goal sought of the three experiments was to evaluate the behavior of fish. Scale issues, time and cost constraints led to the cancellation of these experiments.

Figure 1b outlines the objective, approach and goals of this investigation. It illustrates the different steps considered in order to meet the goals of this study.

SKETCH

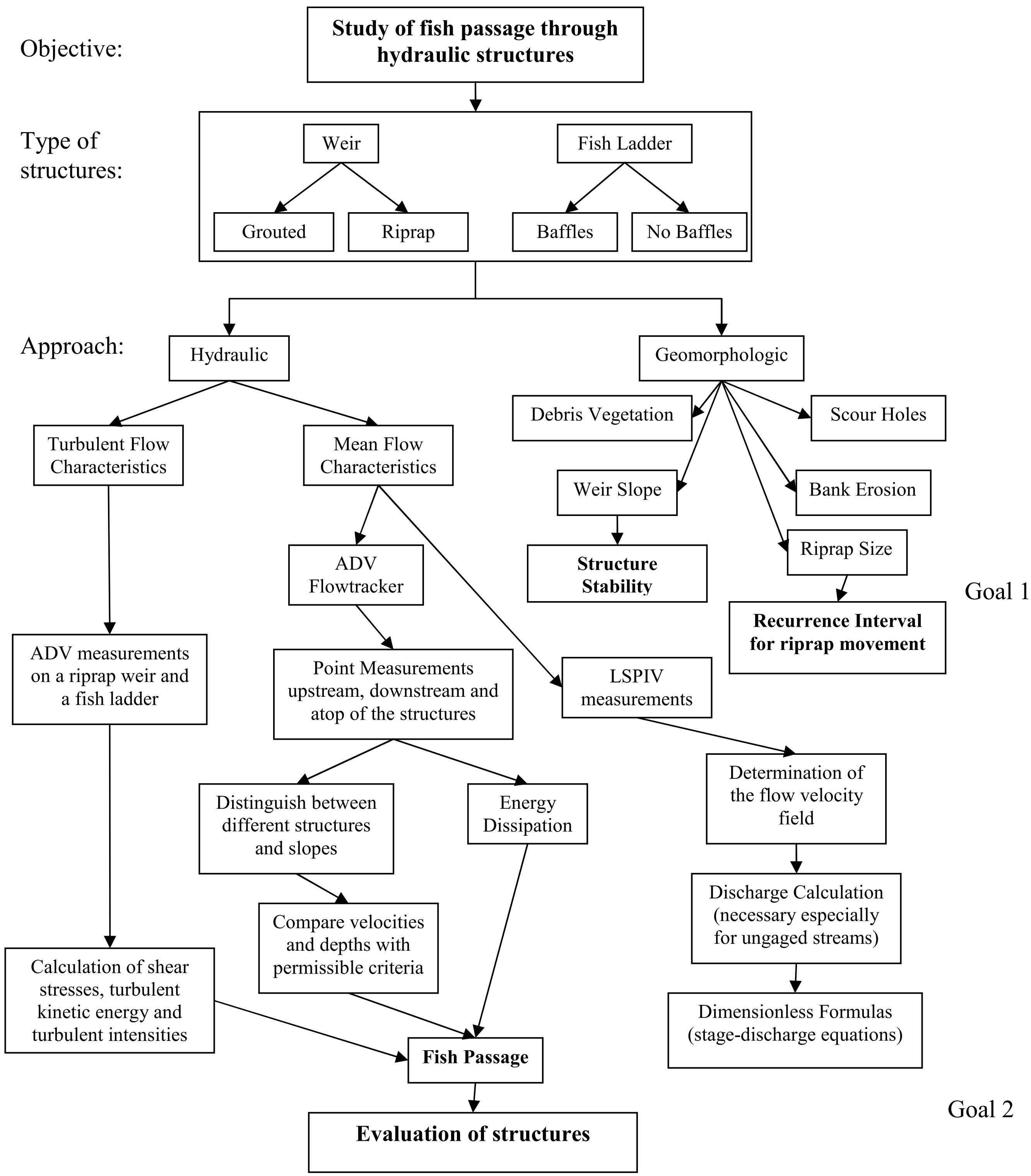


Figure 1b. An outline of this research

1.3 Methodology

The methodology that has been used is based on four different procedures:

1. Survey of all the sites

The survey helped us determine the cross sections, the longitudinal profile, the weir slopes, flowpaths, scour holes and other basic topographic details (e.g. vegetation, debris).

2. Use of the large scale particle image velocimetry technique (LSPIV)

The LSPIV is a unique technique to measure the free surface velocity upstream, downstream and atop of the hydraulic structures. LSPIV is a cheap but robust method as it needs, basically, inexpensive video equipment (digital Canon camera with 48x digital zoom) and a geodetic survey to describe the region of interest (ROI). LSPIV measurements are based on the concept of pattern recognition used in human vision. Velocity vectors over an area are obtained by estimating displacements of floating fluid-markers.

The video images are subsequently digitized and processed using a commercial particle image velocimetry (LSPIV2) program, which calculates the 2-D flow field on the water surface as a function of time. The LSPIV technique does not require calibration and it is well-suited for measuring in very shallow flows quickly and accurately. In conjunction with bathymetry data the program can estimate the flow discharge Q and be used for gaging flow stream and for developing stage (depth) – discharge (Q) relations.

3. ADV time-averaged flow point measurements

The Acoustic Doppler Velocimeter (ADV) FlowTracker by Sontek is used in our study to get point velocity measurements upstream, downstream and at specific characteristic points atop of the structures. It has a velocity range: ± 0.001 m/s to 5 m/s (0.003 to 16 ft/s) and an accuracy ±1% of measured velocity. The ADV FlowTracker does not require an external computer since data are transmitted into a datalogger attached to the instrument. Hence the FlowTracker is suitable for extensive field measurements.

4. ADV turbulent flow measurements

A field ADV was also used to perform the turbulent measurements. It is based on the same technique as the ADV Flowtracker but it needs an external computer and commercial software (Horizon ADV) to import the data. The field ADV provided the information for calculating the turbulent intensities, the Reynolds stresses, the turbulent kinetic energy, the friction velocity and the shear stress, which is applied for the movement of sediment and of the riprap.

2. RESULTS

2.1 Geomorphologic performance of the structures

2.1.1 Recurrence Interval for riprap movement

Based on the basin characteristics of all corresponding sites the flow discharge for recurrence periods of 1, 2, 5, 10, 50 and 100 years was calculated. These calculations were used as a comparative measure with the collected flow measurements by the investigators. Table 3 summarizes the values of Q_1, Q_2, Q_5, Q_{10}, Q_{50}, and Q_{100} per structure.

Table 3. Discharge estimation for different recurrence periods

Site	Structure	Stream	Q_1 (ft^3/s)	Q_2 (ft^3/s)	Q_5 (ft^3/s)	Q_{10} (ft^3/s)	Q_{50} (ft^3/s)	Q_{100} (ft^3/s)
69-6114-9-4	Grouted Weir	Long Br. Cr.	1758.8	2166.8	2854.9	3517.3	5709.4	7034.0
01-20	Grouted Weir	Miller Cr.	963.6	1187.1	1564.1	1927.0	3128.0	3853.7
69-6114-0-6	Grouted Weir	Indian Cr.	1903.9	2345.7	3090.6	3807.6	6181.0	7614.7
69-6114-2-1(1)	Riprap Weir	Walnut Cr.	2275.2	2803.0	3693.2	4550.0	7385.9	9099.4
00-20	Grouted Weir	Coon Cr.	1362.1	1678.1	2211.1	2724.1	4421.9	5447.8
01-10	Riprap Weir	Indian Cr.	1322.7	1629.6	2147.1	2645.2	4293.9	5290.1
00-21	Grouted Weir	Beaver Cr.	1286.7	1585.2	2088.6	2573.2	4176.9	5146.0
00-11 and 04-26	Riprap Weir	Turkey Cr.	3708.5	4569.0	6019.9	7416.5	12039.0	14832.1
00-10	Riprap Weir	Turkey Cr.	2660.1	3277.3	4318.1	5319.9	8635.6	10639.1
69-6114-0-5	Grouted Weir	Silver Cr. Trib.	557.3	686.6	904.7	1114.6	1809.3	2229.1
69-6114-0-8	Fish ladder	Snake Cr.	1249.6	1539.5	2028.5	2499.1	4056.6	4997.8
00-24	Fish ladder	Tarkio R.	3113.7	3836.1	5054.4	6227.0	10108.0	12453.1
03-1-F	Grouted Weir	Mosquito Cr.	2472.6	3046.3	4013.7	4944.9	8026.9	9889.2
00-5(1)	Riprap Weir	Walnut Cr.	3371.2	4153.3	5472.3	8883.0	10943.8	13482.8
02-1-F	Riprap Weir	David's Cr.	1811.7	2232.0	2940.9	3623.1	5881.3	7245.7
02-9-F	Fish ladder	Tarkio R.	4522.9	5572.3	7341.9	9045.3	14682.9	18089.3
69-6114-1-23	Fish ladder	E. Tarkio R	2113.1	2603.4	3430.2	4226.0	6859.9	8451.3
69-6114-1-06	Grouted Weir	Boyer R.	5143.7	6337.0	8349.6	10287.0	16698.1	20572.0
02-15-F and 02-16	Grouted Weir	Otter Cr.	1875.8	2310.1	3044.9	3751.3	6089.4	7502.1
69-6114-9-6	Riprap Weir	Walnut Cr.	3075.2	3788.6	4991.9	6145.0	9983.0	12299.1
03-8-F	Grouted Weir	Keg Cr.	3038.2	3743.0	4931.8	6076.0	9862.8	12151.0
01-16	Riprap Weir	W. Nodaway R	3475.8	4282.1	5642.1	6951.0	11283.4	13901.1

The low recurrence period discharges (Q_1, Q_2, and Q_5) are useful for examining the performance of structures with respect to fish passage. The high occurrence events (Q_{10}, Q_{50}) are useful for examining the stability of structures. It was found that all structures would satisfy the minimum water depth criterion of 1ft for fish passage during low recurrence period discharges (Figures 2-23, Appendix A). The permissible velocity criterion (4 ft/s) was violated for all structures and for all recurrence periods (Figures 2-23, Appendix A).

The recurrence interval for movement of loose riprap on weirs varied between 1 to 50 years. For loose riprap weirs, riprap movement will occur in storm events exceeding the 1 year storm for 4:1 slopes, the 5 year storm for 12:1 slopes, the 25 year storm for 16:1 slopes and the 50 year storm for 22:1 slopes. As the gradient of the structure increases, the recurrence interval for riprap movement reduces (Tables 4a and 4b). Nevertheless, all structures performed satisfactory with respect to stability. Tables 4a and 4b also show the design and the measured slope for all the structures.

Table 4a. Geomorphological Parameters for Fall Period

Site	**Structure**	**Design Slope**	**Measured Slope**	**Stability (Riprap Weirs)**					**Debris**
				d_{50} (ft)	**n**	**V^{cr} (ft/s)**	**V^{cr}/V_a**	**R.I.**	
69-6114-9-4	Grouted Weir	4:1	4:1	-	0.035	-	-	-	H
01-20	Grouted Weir	4:1		-	0.035	-	-	-	H
69-6114-0-6	Grouted Weir	4:1		-	0.035	-	-	-	L
69-6114-2-1(1)	Riprap Weir	4:1	5:1	2	0.066	9.84	3.9	1 yr	M
00-20	Grouted Weir	6:1	6:1	-	0.035	-	-	-	M
01-10	Riprap Weir	4:1		1.5	0.0613	8.63	3.3	1 yr	L
00-21	Grouted Weir	6:1		-	0.035	-	-	-	H
00-11 and 04-26	Riprap Weir	10:1	12:1	2	0.058	12.5	10.4	5 yrs	M
00-10	Riprap Weir	10:1	14:1	-	-	-	-	-	M
69-6114-0-5	Grouted Weir	10:1		-	0.035	-	-	-	H
69-6114-0-8	Fish ladder	14.5:1	14.5:1	-	-	-	-	-	M
00-24	Fish ladder	15.5:1	15.5:1	-	-	-	-	-	M
03-1-F	Grouted Weir	15:1	16:1	-	0.035	-	-	-	L
00-5(1)	Riprap Weir	20:1		2	0.055	13.7	2.4	25 yrs	M
02-1-F	Riprap Weir	20:1	20:1	-	-	-	-	-	M

Site	Structure	Design Slope	Measured Slope	Stability (Riprap Weirs)					Debris
				d_{50} (ft)	n	V^{cr} (ft/s)	V^{cr}/V_a	R.I.	
02-9-F	Fish ladder	20:1	20:1	-	-	-	-	-	L
69-6114-1-23	Fish ladder	20:1		-	-	-	-	-	M
69-6114-1-06	Grouted Weir	10:1	22:1	-	0.035	-	-	-	L
02-15-F and 02-16	Grouted Weir	20:1		-	0.035	-	-	-	M
69-6114-9-6	Riprap Weir	20:1		1.7	0.0514	13.7	-	50 yrs	L
03-8-F	Grouted Weir	20:1	25:1	-	0.035	-	-	-	L
01-16	Riprap Weir	20:1		2	0.0517	14.4	3.0	50 yrs	L

Table 4b. Geomorphological Parameters for Spring Period

Site	Structure	Design Slope	Measured Slope	Debris
69-6114-9-4	Grouted Weir	4:1	4:1	L
69-6114-0-6	Grouted weir	4:1		L
00-24	Fish ladder	15.5:1	15.5:1	L
02-1-F	Grouted weir	20:1	20:1	L
02-9-F	Fish ladder	20:1		L
69-6114-1-23	Fish ladder	20:1		L
02-15-F and 02-16	Grouted weir	20:1	22:1	L
69-6114-9-6	Riprap weir	20:1		L

Notation

d_{50} = Median riprap size
n = Manning's n
V^{cr} = Critical velocity for riprap motion
V_a = Surface velocity atop of the structure
R.I. = Recurrence Interval (in years) when the riprap will start to move
H = High
M = Medium
L = Low

2.1.2 Comments based on visual observations of the structures

Visual observations of the structures provided some insights about the response of the structures to the flow. It was shown that all structures had a small effect on bank erosion. Localized bank erosion was observed at the downstream end of few structures (e.g. 00-10). Scour holes where present downstream of the structures. Possible causes are the formation of a hydraulic jump downstream of the weirs (e.g. structure 69-6114-2-1) and the formation of a submerged jet at the exit of the fish ladders (e.g. 69-6114-1-23).

A ubiquitous feature of the grouted riprap weirs was the formation of preferential flow paths atop the structures. Water depth was not evenly distributed atop grouted weirs that had small drainage areas: in some locations the weir surface was completely dry. Observations on grouted weir 00-21 indicate that flow was occurring underneath the structure, probably because there wasn't a sheetpile cut-off wall to force flow over the weir. Another feature of the grouted weirs was the presence of constricted/expanded cross sections upstream and downstream of the grouted structures.

Finally, grouted weirs with small drainage areas and fish ladders caught the most debris. Structures with large drainage areas had flow events occurring on a routine basis. In this case, strong energetic flow events occurred more frequently causing the removal of most of the deposited debris. Fish ladders have been shown to catch debris, probably due to the large quantity of vertical steel sheet pile exposed. Tables 4a and 4b provide a status about the debris (Figures 24-52, Appendix B).

2.1.3 Stability of the structures

Comparison of the measured slope and the design slope in Table 4a shows that many of the weir gradients are milder than expected. For the riprap weirs this may indicate the movement of riprap following construction. However, during the period of the project no motion of riprap material could occur due to low flow conditions. For the grouted weirs, the milder slopes may indicate that they were simply constructed that way or it is possible that flow occurring underneath the structures may have caused settlement of the structures and in turn changes in the gradient of these structures. Figures 24-52 (Appendix B) illustrate also the riprap size and document the conditions of the structures upstream and downstream. Survey of the structures provided the width b of the structures and the length L (Table 5a and 5b). Longer-term monitoring is needed to determine the exact period that such a slope change was initiated.

2.2 Hydraulic performance of the structures

2.2.1 Mean flow characteristics

2.2.1.1 Flow point measurements

The flow point measurements upstream, atop and downstream of the structures are summarized in tables 5a and 5b. This includes the flow depth and the velocity obtained at a height equal to 0.9 of the total depth per measuring location. It was found that the velocity atop of the structures was about 10 to 15 times greater in magnitude than the velocities upstream or downstream. Along the same lines the depth obtained its minimum value atop of the structures. For the riprap weirs the depth atop of the structure was about ⅓ or ½ the depth upstream while for the grouted ripraps was about the same as upstream. Due to the presence of a scour hole the downstream part was 10 to 15 times higher than the depth atop. The above measurements revealed that for evaluating the performance of structures with respect of fish passage, measurements only atop of the structures are required. These measurements are adequate for providing the critical conditions for satisfying fish passage requirements. Please note, that because our measurements coincided with record low flow conditions, these findings are on the conservative side.

Tables 5a and 5b provide also the velocity magnitude at 40% from the bottom of the structures. Specifically, Table 5a outlines the magnitude atop of the structures at z= $0.4Y_a$ for the Fall season and Table 5b the velocity magnitude upstream of the structures at z= $0.4Y_u$. It is shown that structures 69-6114-0-8 (fish ladder without baffles), 00-5(1) (riprap weir) and 01-16 (riprap weir) do not satisfy the maximum velocity requirement of 4ft/s.

Table 5a. Hydraulic Parameters for Fall Period

Site	Structure	Drainage Area (miles^2)	b (ft)	L (ft)	Q (ft^3/s)	Y_u (ft)	Y_a (ft)	Y_d (ft)	V_u (ft/s)	V_a (ft/s)	$V_{a\,(z=0.4Ya)}$ (ft/s)	V_d (ft/s)	Fr_a	ΔH (ft)	ε (W/ft^3)
69-6114-9-4	Grouted Weir 4:1	26.4	38.6	127.6	4.94	1.3	0.4	1.1	0.12	4.2	3.68	0.43	1.17	4.67	-
01-20	Grouted Weir 4:1	8.0	25.4	47.6	0.71	0.6	0.6	1.4	0.05	-	-	0.11	-	4.70	-
69-6114-0-6	Grouted Weir 4:1	30.9	32.8	100.7	-	-	0.6	-	-	3.12	2.74	-	0.71	-	-
69-6114-2-1(1)	Riprap Weir 5:1	44.0	18.9	32.15	2.65	1.2	0.5	1.6	0.19	2.54	2.23	0.06	0.63	10.3	-
00-20	Grouted Weir 6:1	15.9	25.4	24.9	1.17	0.7	0.4	1.9	0.09	0.71	0.62	0.35	0.20	3.54	-
01-10	Riprap Weir 6:1	15.0	10.5	33.5	1.33	0.6	0.6	0.9	0.25	2.64	2.32	0.16	0.60	2.10	-
00-21	Grouted Weir 6:1	14.2	16.5	54.5	0.26	0.8	0.0	2.8	0.03	0.0	0.0	0.28	-	-	-
00-11 and 04-26	Riprap Weir 12:1	116.0	32.4	39.7	1.77	1.5	0.4	1.17	0.05	1.20	1.05	0.96	0.33	2.29	-
00-10	Riprap Weir 14:1	60.0	33.0	47.9	2.79	1.5	0.5	2.4	0.08	1.83	1.61	0.26	0.46	2.40	-
69-6114-0-5	Grouted Weir 14:1	2.7	9.28	76.1	0.14	0.4	0	0.4	0.05	0.0	0.0	0.74	-	4.60	-
69-6114-0-8 (without baffles)	Fish ladder 14.5:1	13.4	15.4	40.4	1.27	1.5	0.4	1.1	0.08	7.77	6.82	0.63	2.17	3.38	-
00-24 (without baffles)	Fish ladder 15.5:1	82.0	19.8	41.0	2.01	1.4	-	-	0.09	3.28	2.88	-	-	3.43	-
03-1-F	Grouted Weir 16:1	51.9	26.1	90.9	0.99	0.5	0.5	1.1	0.05	3.52	3.09	1.79	0.88	3.95	-
00-5(1)	Riprap Weir 16:1	96.0	42.1	80.7	13.49	2.0	0.5	1.1	0.18	5.64	4.95	0.47	1.41	4.90	-
02-1-F	Riprap Weir 20:1	28.0	30.0	75.1	7.63	3.4	0.9	2.4	0.10	3.62	3.18	0.60	0.67	2.59	-

Site	Structure	Drainage Area (miles^2)	b (ft)	L (ft)	Q (ft^3/s)	Y_u (ft)	Y_a (ft)	Y_d (ft)	V_u (ft/s)	V_a (ft/s)	$V_{a\,(z=0.4Ya)}$ (ft/s)	V_d (ft/s)	Fr_a	ΔH (ft)	ε (W/ft^3)
02-9-F (baffles)	Fish ladder 20:1	172.0	57.3	32.8	2.19	0.9	0.8	1.8	0.03	1.66	1.46	-	0.33	-	3.59
69-6114-1-23 (baffles)	Fish ladder 20:1	38.0	15.3	31.5	1.59	1.5	0.65	2.3	0.11	0.66	0.58	-	0.14	-	3.48
69-6114-1-06	Grouted Weir 22:1	222.0	45.7	135.2	6.75	1.2	1.0	1.3	0.18	3.10	2.72	0.76	0.55	3.64	-
02-15-F and 02-16	Grouted Weir 22:1	30.0	15.4	100.7	2.40	1.2	0.5	-	0.14	-	-	-	-	-	-
69-6114-9-6	Riprap Weir 22:1	80.0	41.9	120.7	11.65	1.7	-	-	0.28	-	-	-	-	-	-
03-8-F	Grouted Weir 25:1	78.1	26.8	110.2	6.99	1.0	0.7	0.3	0.25	4.45	3.90	2.54	0.94	5.08	-
01-16	Riprap Weir 25:1	102.0	26.9	122.4	20.62	2.2	0.5	1.4	0.37	4.78	4.19	0.71	1.19	5.17	-
69-6114-1-23 (Fall 2005)	Fish ladder 20:1	38.0	15.3	31.5	1.31	2.0	0.52	-	0.05	1.19	1.04	-	0.29	-	3.85

Table 5b. Hydraulic Parameters for Spring Period

Site	Structure	Drainage Area (miles^2)	b (ft)	L (ft)	Q (ft^3/s)	Y_u (ft)	V_u (ft/s)	$V_{u\,(z=0.4Yu)}$ (ft/s)
69-6114-9-4	Grouted Weir 4:1	26.4	38.6	127.6	17.5	2.13	0.32	0.28
69-6114-0-6	Grouted weir 4:1	30.9	32.8	100.7	40.65	4.59	0.40	0.35
00-24	Fish ladder 15.5:1	82.0	19.8	41.0	58.77	4.43	0.58	0.51
02-1-F	Grouted weir 20:1	28.0	30.0	75.1	30.05	2.62	0.42	0.37
02-9-F	Fish ladder 20:1	172.0	57.3	32.8	166.05	4.43	0.91	0.8
69-6114-1-23	Fish ladder 20:1	38.0	15.3	31.5	45.48	4.27	0.50	0.44
02-15-F and 02-16	Grouted weir 22:1	30.0	15.4	100.7	17.50	2.79	0.25	0.22
69-6114-9-6	Riprap weir 22:1	80.0	41.9	120.7	69.05	2.46	0.68	0.60

Notation

b = Width of the weir
L = Length of the structure
Q = Discharge
$\mathbf{Y_u}$ = Approach depth upstream of the structure
$\mathbf{Y_a}$ = Depth atop of the structure
$\mathbf{Y_d}$ = Depth downstream of the structure
$\mathbf{V_u}$ = Surface velocity upstream of the structure
$\mathbf{V_a}$ = Surface velocity atop of the structure
$\mathbf{V_{a\,(z=0.4Ya)}}$ = Velocity at the lower 40% of the water column, atop of the structure
$\mathbf{V_{u\,(z=0.4Yu)}}$ = Velocity at the lower 40% of the water column, upstream of the structure
$\mathbf{V_d}$ = Surface velocity downstream of the structure
$\mathbf{Fr_a}$ = Froude number atop of the structure
ΔH = Energy loss
ε = Energy dissipation in fish ladders (with baffles)

The velocities at the lower 40% of the water column were calculated by using the power-law velocity distribution $V(z) = V_{max}\left(\frac{z}{Y}\right)^{1/7}$ where V_{max} is the velocity at the free surface, z is the distance from the bed and Y is the water depth.

2.2.1.2 Remote flow measurements via LSPIV

The LSPIV measurements provided values for discharge during Fall of 2004 and Spring of 2005 (Tables 5a and 5b).

2.2.1.3 Stage-Discharge equations

A subsequent outcome was the development of stage-discharge relations for the Fall and Spring periods. These relations are linear regression equations and were developed for the weirs (riprap and grouted) and for the fish ladders. These relations are presented in dimensionless form and their utility is that they can be used for making discharge predictions in ungaged channels as long as the width b, the approach depth Y_u upstream of the structure, and the gradient of the structure S are known (Table 6). Due to low flow conditions that existed during the monitoring period these relations may not be good predictors for conditions exceeding a recurrence period of 1 year. More measurements are needed to be performed in the near future for a wide range of flow conditions. Figures 53a, 53b, 54a and 54b illustrate the fitting lines equations and the corresponding R^2 values.

Table 6. Summary of the dimensionless formulas

	WEIRS	FISH LADDERS
Fall Period	$\frac{Q}{\sqrt{gSb^5}} = 0.0156\frac{Y_u}{b} - 0.00005$ (R^2=0.42)	$\frac{Q}{\sqrt{gSb^5}} = 0.0102\frac{Y_u}{b} + 0.00001$ (R^2=0.86)
Spring Period	$\frac{Q}{\sqrt{gSb^5}} = 0.0335\frac{Y_u}{b} + 0.0005$ (R^2=0.53)	$\frac{Q}{\sqrt{gSb^5}} = 0.1114\frac{Y_u}{b} - 0.0014$ (R^2=0.99)

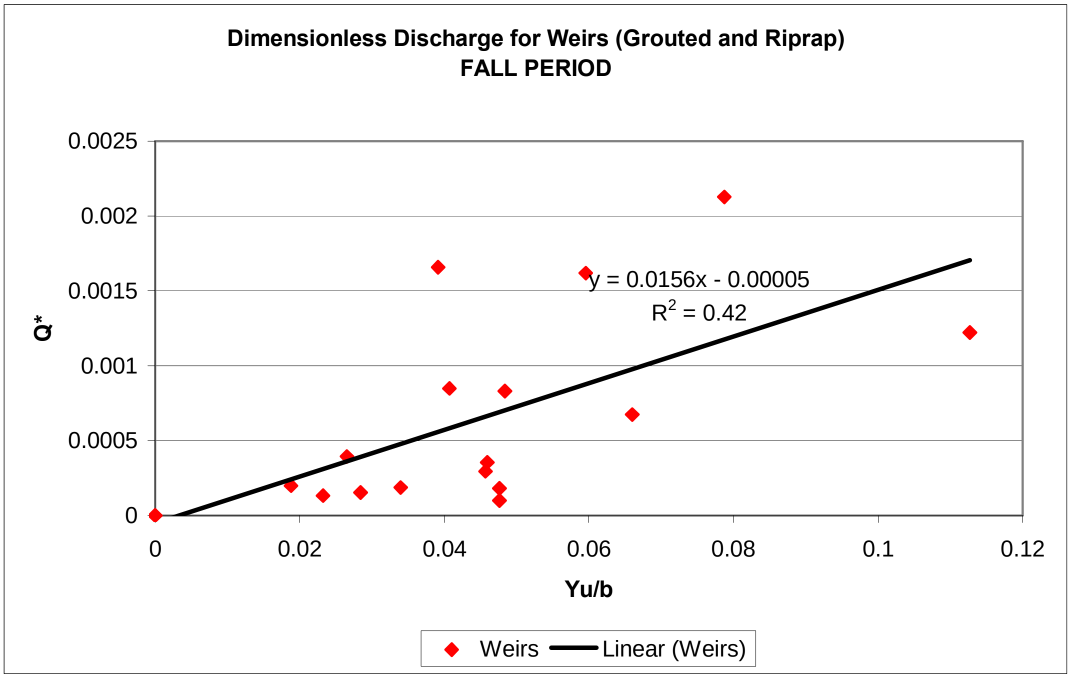


Figure 53a. Regression line for weirs in the Fall period

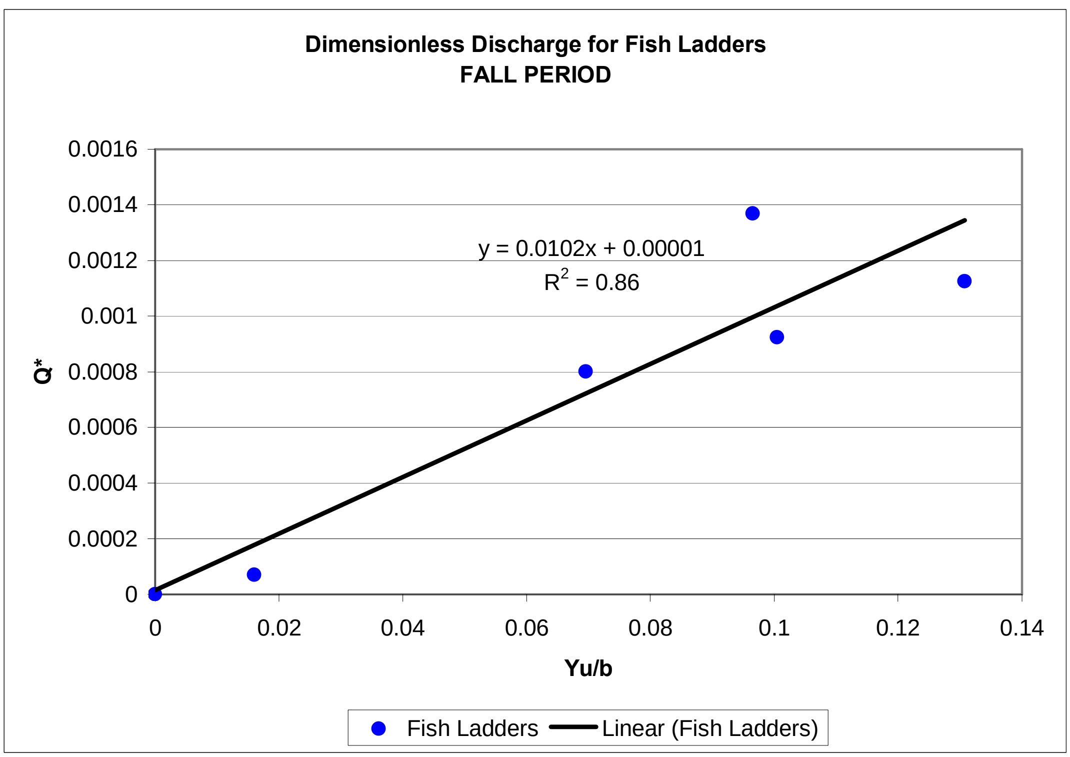


Figure 53b. Regression line for fish ladders in the Fall period

The dimensionless formulas are:

For weirs in the Fall Period:

$$Q^* = 0.0156\frac{Y_u}{b} - 0.00005 \Rightarrow \frac{Q}{\sqrt{gSb^5}} = 0.0156\frac{Y_u}{b} - 0.00005 \ \ (R^2=0.42)$$

For fish ladders in the Fall Period:

$$Q^* = 0.0102\frac{Y_u}{b} + 0.00001 \Rightarrow \frac{Q}{\sqrt{gS\,b^5}} = 0.0102\frac{Y_u}{b} + 0.00001 \ (R^2=0.86)$$

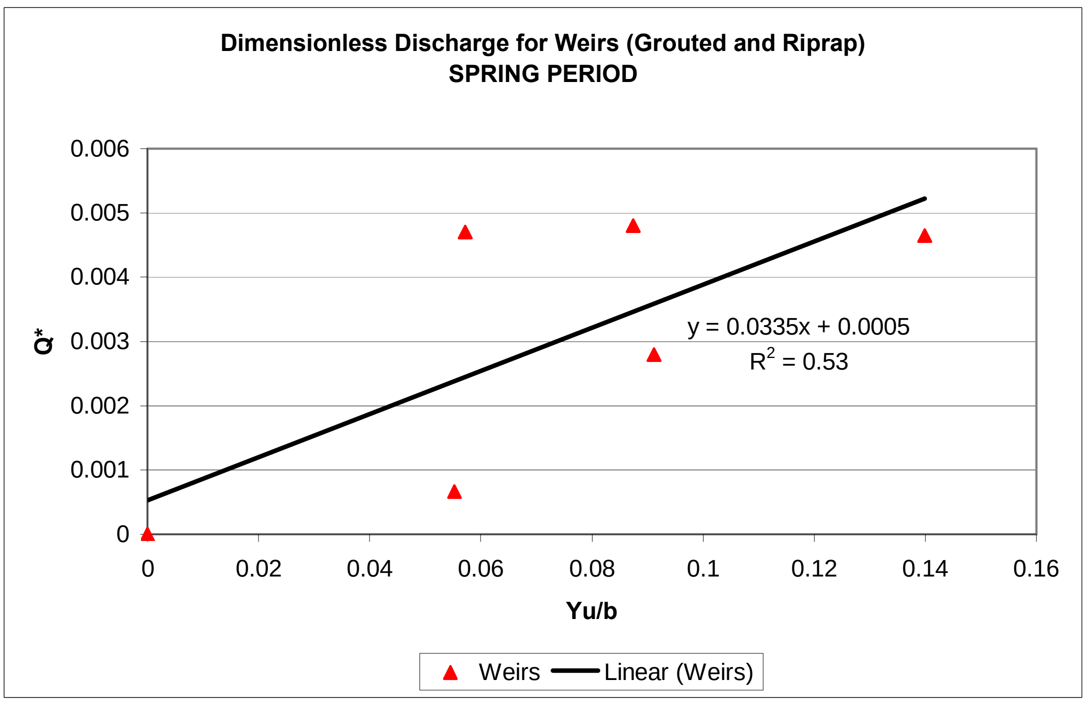


Figure 54a. Regression line for weirs in the Spring period

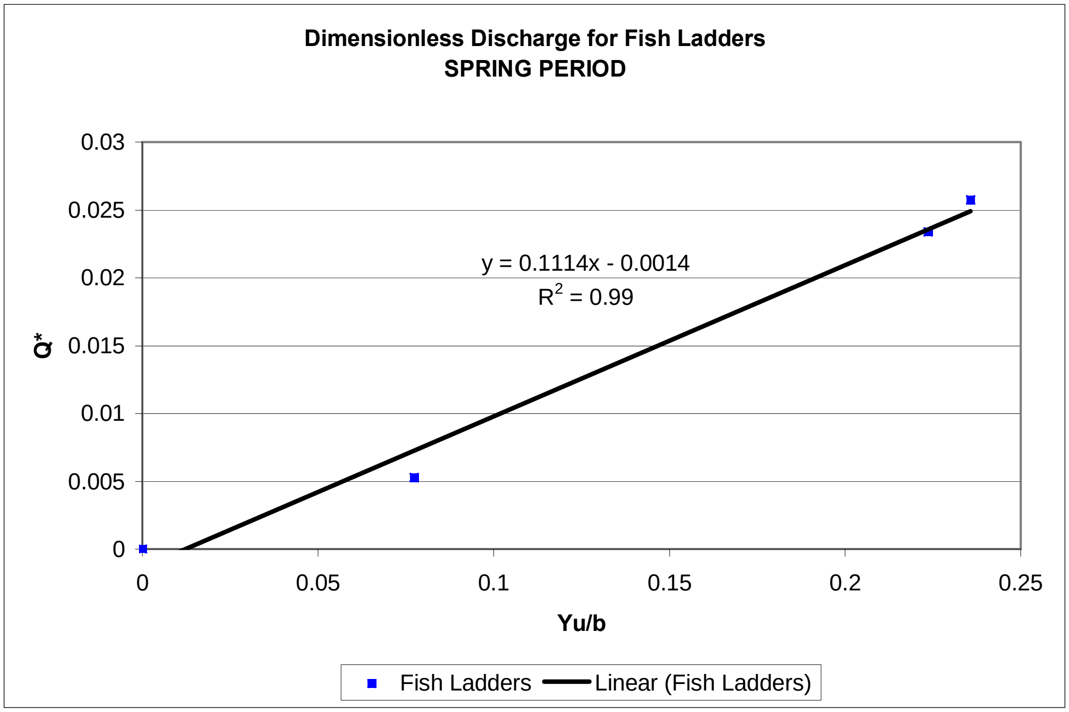


Figure 54b. Regression line for fish ladders in the Spring period

The dimensionless formulas are:

For weirs in the Spring Period:

$$Q^* = 0.0335\frac{Y_u}{b} + 0.0005 \Rightarrow \frac{Q}{\sqrt{gSb^5}} = 0.0335\frac{Y_u}{b} + 0.0005 \ (\mathrm{R}^2{=}0.53)$$

For fish ladders in the Spring Period:

$$Q^* = 0.1114\frac{Y_u}{b} - 0.0014 \Rightarrow \frac{Q}{\sqrt{gSb^5}} = 0.1114\frac{Y_u}{b} - 0.0014\,(\mathrm{R}^2{=}0.99)$$

2.2.2 Turbulent flow characteristics

Existing biological studies highlight the need to perform detailed turbulent flow measurements for assessing fish passage through these structures. To address this need detailed turbulent measurements where performed for structures 69-6114-9-6 (riprap weir) and 69-6114-1-23 (fish ladder) during Fall 2005 (Figures 55a-h and 56a-g, Appendix C). The measurements were performed at low flow conditions when the role of turbulence is pronounced. In high flow conditions the advective nature of the flow minimizes the impact of turbulence on fish. A review of the flow characteristics for the two structures (Figures 55a, 55b and figures 56a, 56b and 56c, Appendix C) reveals that the approach flow for the riprap structure is highly 3-d (u, v, w obtain measurable values, where u denotes the velocity in the longitudinal x direction, v denotes the velocity in the traverse y direction and w denotes the velocity in the vertical z direction) while flow upstream of the fish ladder is 2-d with the vertical mean flow component being almost less than unity.

In the riprap case the variation of the velocity around the zero value for the v and w profiles suggest the presence of strong secondary currents. The genesis of these currents is mostly attributed to the transitional change of the channel from the expanded cross section to the constricted cross section found atop of the structure. Figure 55d (Appendix C) shows that turbulent intensities in the vertical direction obtain significantly higher values than the other turbulent intensities (in the longitudinal and traverse directions). This implies a high level of turbulence in the vertical direction, caused by the eddy stretching of the flow in that direction, due to the presence of the sheet pile at the entrance of the structures (Figure 55d, Appendix C). The high magnitude vertical turbulent intensity leads to high magnitude shear stress values at the entrance of the structure. Stress values greater than 35 lbf/ft^2 can cause fish mortality. This criterion was not violated for both cases.

Finally, in the case of the fish ladder the flow presents a similar behaviour with respect to turbulence. High magnitude vertical turbulent intensities are observed in Figure 56d (Appendix C).

2.2.3 Energy dissipation

As expected the control structures behave as energy dissipators. The head difference for the grouted and riprap weirs is reported in Table 5a. For the fish ladders the rate of energy dissipation is reported. This rate on an average is close to 3.7 W/ft^3. Dissipation values greater that 5.41 W/ft^3 would indicate the existence of turbulent conditions within the pool that are not favorable to fish. For fish ladders 69-6114-0-8 and 00-24 the rate of energy dissipation is not reported since these structures do not have baffles. In this case the head difference is reported.

3. EVALUATION OF THE STRUCTURES

3.1 General observations

The evaluation of the structures was performed using:

(1) the measurements collected during Fall 2004 through Fall 2005 and
(2) based on flows with different recurrence periods (Q_1, Q_2, Q_5, Q_{10}, Q_{50}, and Q_{100})

1. With respect to the recurrence interval for riprap movement, it was found that grouted weirs and fish ladders did not have any problems. Riprap weirs' recurrence interval varied between 1 to 50 years. The recurrence interval of the riprap weirs reduces as the gradient of the structure increases.
2. With respect to the observed patterns of flow atop the structures, flow over grouted weirs with small drainage areas was not evenly distributed during the lowest flow events, with flow occurring through or underneath the structure. It was observed that for grouted weirs flow depth upstream and flow depth atop of the grouted weirs is about the same. This may suggest that grouted weirs may impede fish passage during low flow events.
3. With respect to the minimum required flow depth (1ft), measurements collected atop the three types of structures indicate that fish ladder and riprap weirs perform the best. The Fall 2004 measurements where ideal for evaluating the performance of structures with respect to the minimum depth requirements.
4. The measurements performed here reveal that the flow atop a structure is about 10 times greater in magnitude than the approach flow. This is a useful finding for future studies (Figures 58a, 58b, 58c and 59a, 59b, 59c).
5. With respect to the maximum velocity requirements (4ft/s) it was shown that even during the lowest flow season two grouted weirs exceeded the limit by 8% (Figure 59a), one riprap weir (the one with the smallest gradient) exceeded the limit by 19% (Figure 59b) and the fish ladder (without baffles) by 97% (Figure 59c). However although those measurements can not be conclusive because they were conducted at low flow conditions, it is certain that for bankfull flow events the maximum velocity requirement will not be satisfied.
6. With respect to turbulence, riprap weirs had lower levels of turbulence compared to fish ladder with baffles. High turbulence tends to disorient fish.
7. Use of the Manning's equation to evaluate the performance of the structures led to underestimation of the mean flow depth for all structures and to underestimation of the measured flow velocity. This suggests that use of the Manning's equation to evaluate performance of structures does not constitute an adequate tool (Figures 60a and 60b).

- Comments 1, 3, 4, 6, 7 are conclusive.
- Comment 2 is somewhat conclusive.
- Comment 5 requires the performance of future studies.

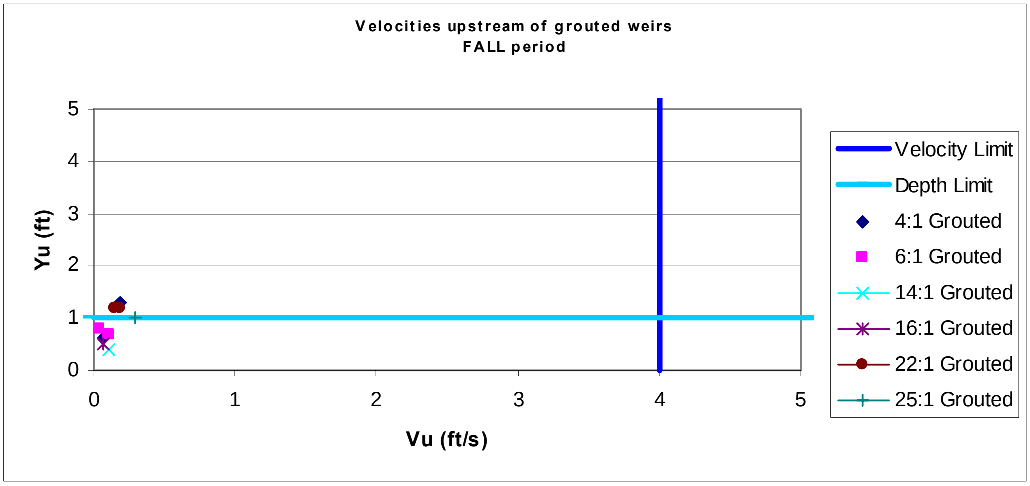


Figure 58a. Velocities upstream of grouted weirs for Fall period

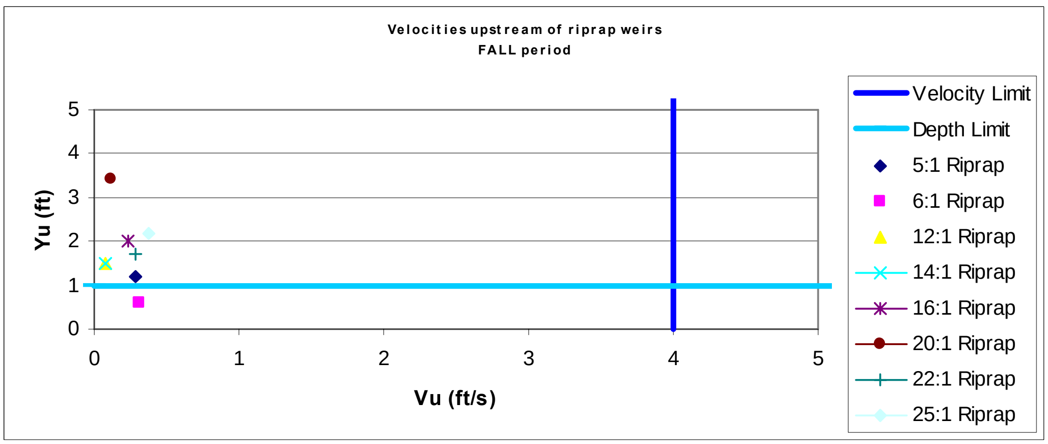


Figure 58b. Velocities upstream of riprap weirs for Fall period

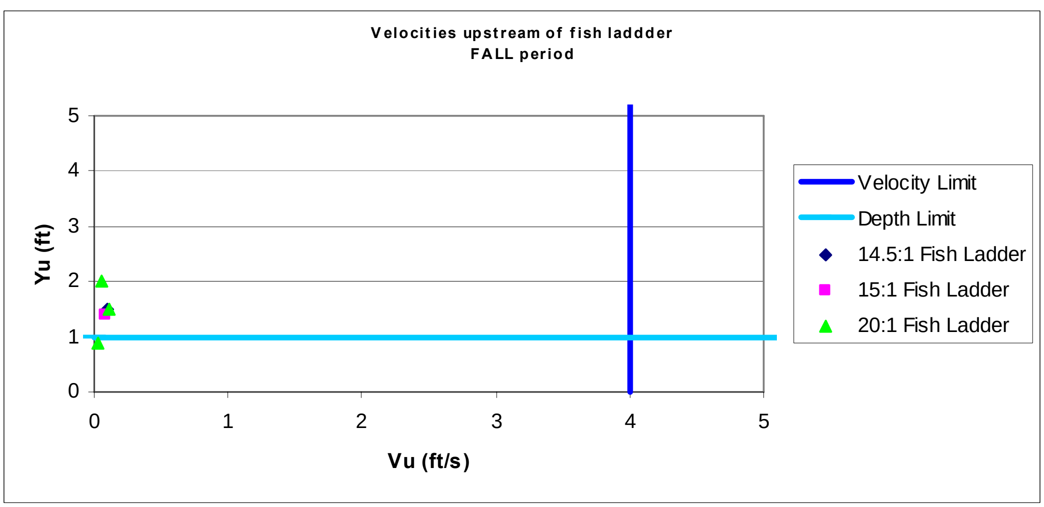


Figure 58c. Velocities upstream of fish ladder for Fall period

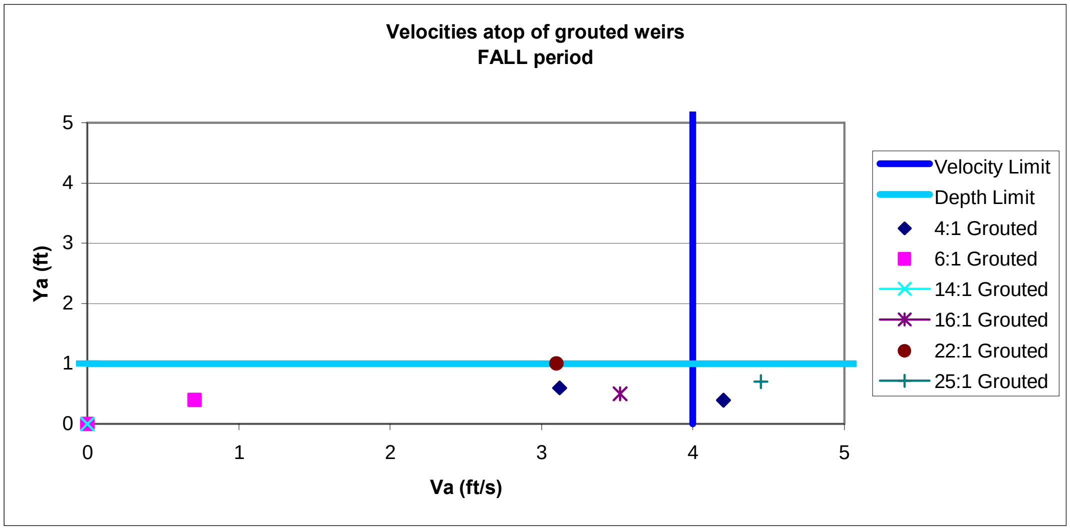


Figure 59a. Velocities atop of grouted weirs for Fall period

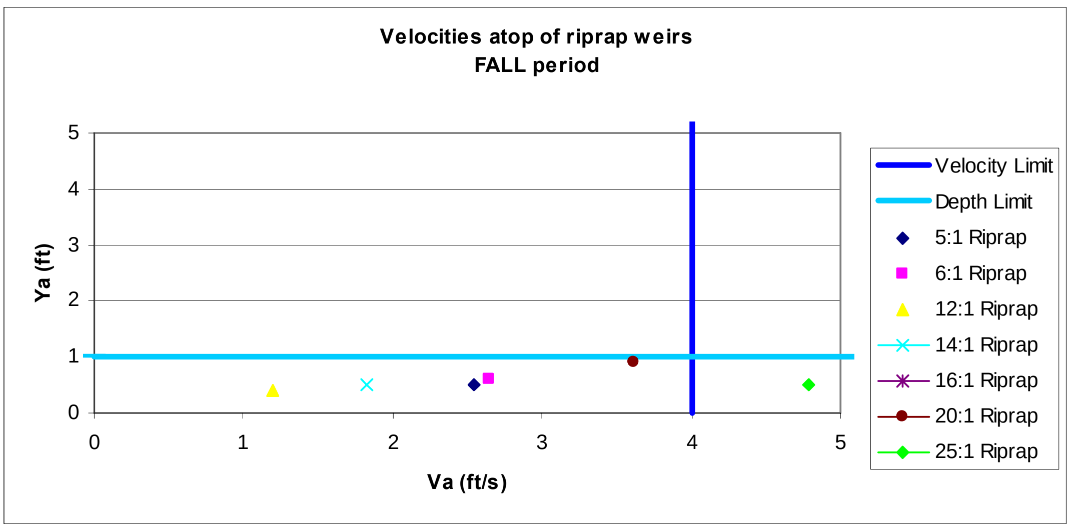


Figure 59b. Velocities atop of riprap weirs for Fall period

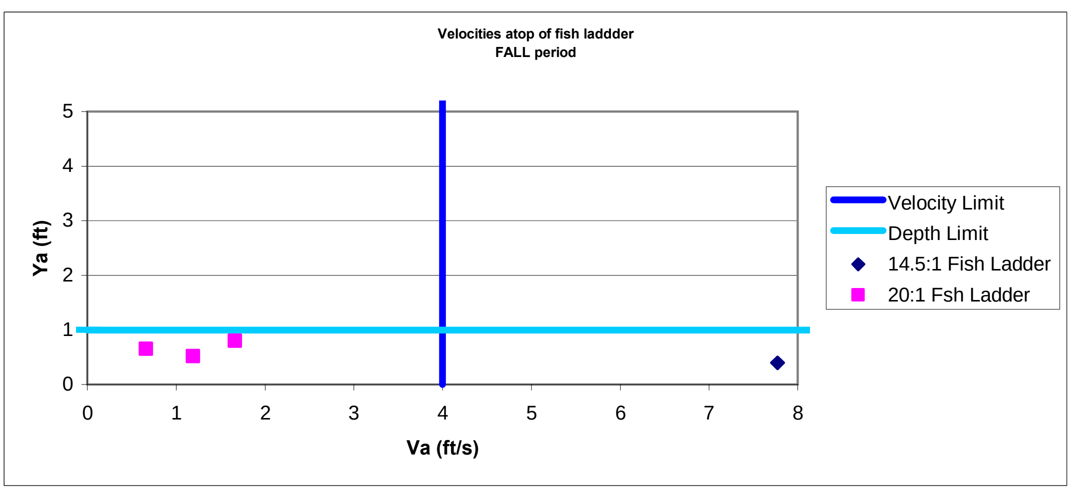


Figure 59c. Velocities atop of fish ladders for Fall period

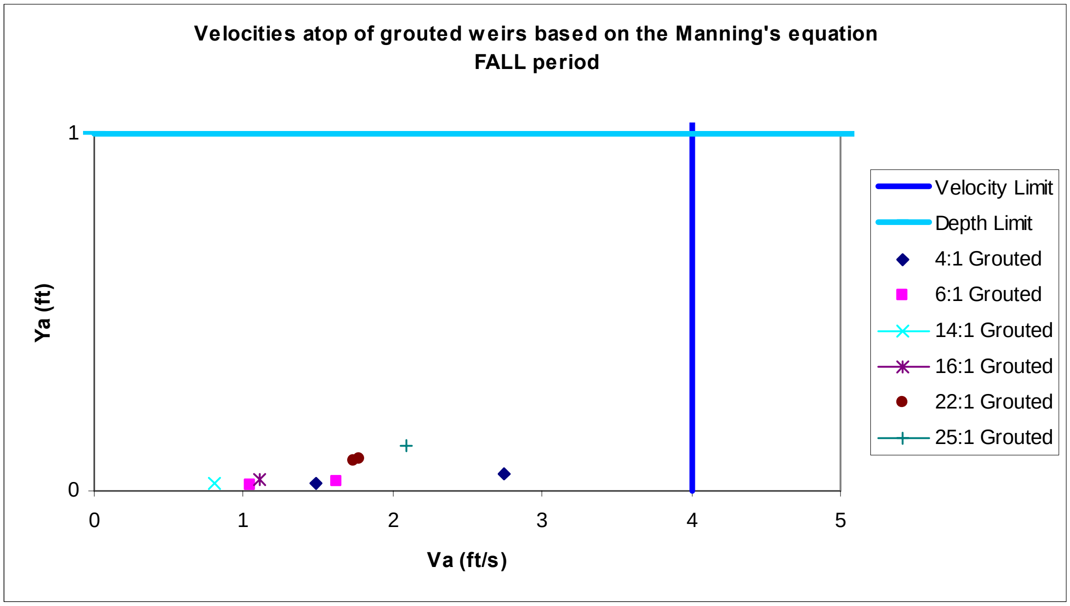


Figure 60a. Velocities atop of grouted weirs based on Manning's equation

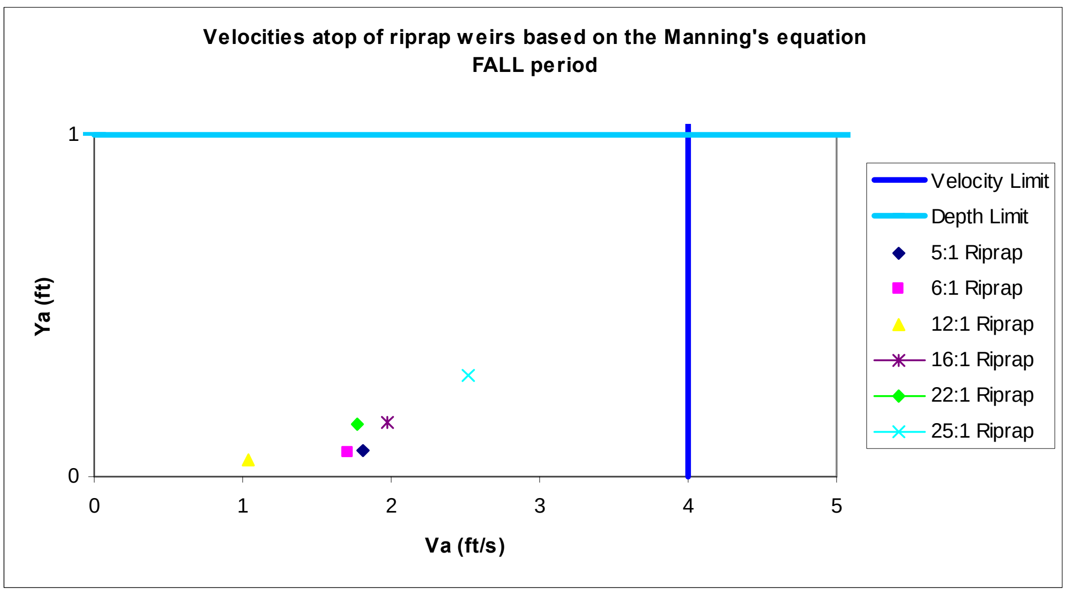


Figure 60b. Velocities atop of riprap weirs based on Manning's equation

3.2 Summary tables

Table 7. Overall performance when the drainage area (D.A.) is not considered

OVERALL PERFORMANCE WHEN THE DRAINAGE AREA IS NOT CONSIDERED						
Weir Slope	**Structure**	**Recurrence Interval**	**Flow Patterns**	**Depth Requirement**	**Velocity Requirement**	**Turbulence**
HIGH GRADIENT (4:1, 5:1, 6:1)	Grouted Weirs	**G**	**P**	**P**	**A**	**-**
	Riprap Weirs	**P**	**G**	**P**	**G**	**-**
MEDIUM GRADIENT (12:1, 14:1, 16:1)	Grouted Weirs	**G**	**A**	**P**	**G**	**-**
	Riprap Weirs	**A-G**	**G**	**A**	**G**	**-**
LOW GRADIENT (20:1, 22:1, 25:1)	Grouted Weirs	**G**	**G**	**G**	**A-G**	**-**
	Riprap Weirs	**G**	**G**	**G**	**A**	**G**
FISH LADDERS (without baffles)		**G**	**G**	**P**	**P**	**-** **-**
FISH LADDERS (with baffles)		**G**	**G**	**A**	**G**	**A-G**

Table 8. Overall performance when the drainage area (D.A.) is considered

OVERALL PERFORMANCE WHEN THE DRAINAGE AREA IS CONSIDERED						
Drainage Area (D.A.) in miles^2	**Structure**	**Gradient**	**Depth Requirement**	**Velocity Requirement**	**Critical**	**Recommendation**
D.A.≤ 20 (5 structures)	3 Grouted Weirs	High	**P**	**G**	Y_{min}	**Low gradient structure**
		Medium	**P**	**G**		
	1 Riprap Weir	High	**P-A**	**A**		
	1 Fish Ladder (without baffles)	Medium	**P**	**P**		
20 < D.A.< 100 (10 structures)	3 Grouted Weirs	High	**P**	**P-A**	V_{max} and Y_{min}	**Low to medium gradient structure**
		Medium	**P**	**A-G**		
	5 Riprap Weirs	High	**P**	**G**		
		Medium	**P**	**P-A**		
		Low	**A-G**	**P-A**		
	2 Fish Ladders (with baffles)	Low	**P-A**	**G**		
D.A.≥ 100 (5 structures)	2 Grouted Weirs	Low	**A-G**	**P**	V_{max}	**Medium gradient structure**
	2 Riprap Weirs	Medium	**P**	**G**		
		Low	**P-A**	**P**		
	1 Fish Ladder (with baffles)	Low	**G**	**G**		

Criteria

	Recurrence Interval (R.I.)	Flow Patterns	Depth (Y)	Velocity (V)	Turbulence
P	**R.I.** $\leq$ 2 years	Flow underneath the structure	$\mathbf{Y} < Y_{min} - 20\% \, Y_{min}$	$\mathbf{V} > V_{max} + 25\% \, V_{max}$	High level
A	2 < **R.I.** $\leq$ 5 years	Preferential flow paths	$Y_{min} - 20\% \, Y_{min} \leq \mathbf{Y} < Y_{min}$	$V_{max} \leq \mathbf{V} \leq V_{max} + 25\% \, V_{max}$	Medium level
G	**R.I.** > 5 years	Flow evenly distributed atop of structure	$\mathbf{Y} \geq Y_{min}$	$\mathbf{V} \leq V_{max}$	Low level

Notation
P = Poor
A = Average
G = Good
V_{max} = 4ft/s
Y_{min} = 1ft

Table 9. Ranking of the structures

RANKING OF THE DIFFERENT STRUCTURES BASED ON HYDRAULIC AND ECONOMIC MEASUREMENTS		
Drainage Area (D.A.) in miles^2	**Ranking**	
D.A. $\leq$ 20	20:1 riprap	**Better**
	20:1 grouted	
	Fish ladder with baffles	
	15:1 riprap	
	10:1 riprap	**Worst**
20 < D.A. < 100	15:1 riprap	**Better**
	10:1 riprap	
	20:1 riprap Fish ladder with baffles	
	20:1 grouted	**Worst**
D.A. $\geq$ 100	15:1 riprap	**Better**
	20:1 riprap Fish ladder with baffles	
	20:1 grouted	
	10:1 riprap	**Worst**

Final Recommendation: The best performance, without considering the drainage areas, was exhibited by the low gradient grouted or riprap weirs or by the fish ladder with baffles. The medium gradient weirs also performed satisfactorily.
Considering also the drainage areas, it is recommended that when the drainage areas are less than 20 miles^2 the best structure is the low gradient, when the drainage areas are between 20 and 100 miles^2 the best structure is either the low or medium gradient and when the drainage areas are larger than 100 miles^2 the best ones are the medium gradient.

4. RECOMMENDATIONS

- For future studies it is recommended that continuous observations be made for a longer period of time, in order to capture higher flow events. A useful tool to facilitate such a need would be the installation of sensors for a continuous recording of basic flow characteristics related to fish passage.
- Measurements obtained only atop of the structures are sufficient for evaluating the hydraulic performance of the structures.

APPENDIX A: STREAM VELOCITY ESTIMATIONS FOR DISCHARGES WITH DIFFERENT RECURRENCE PERIODS

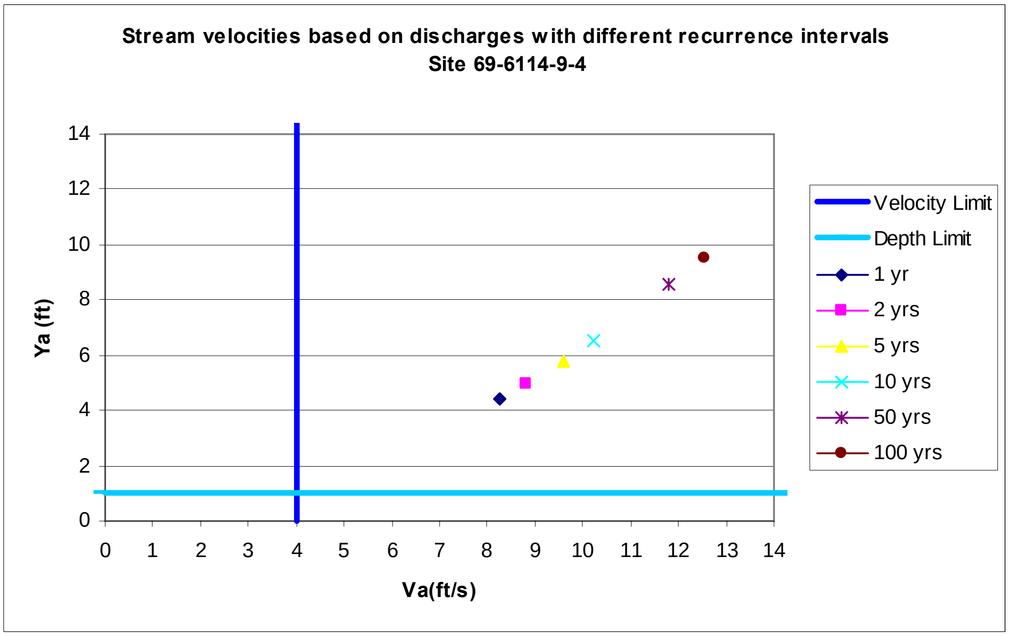


Figure 2. Velocities for discharges with different recurrence periods for Long Br. Cr.

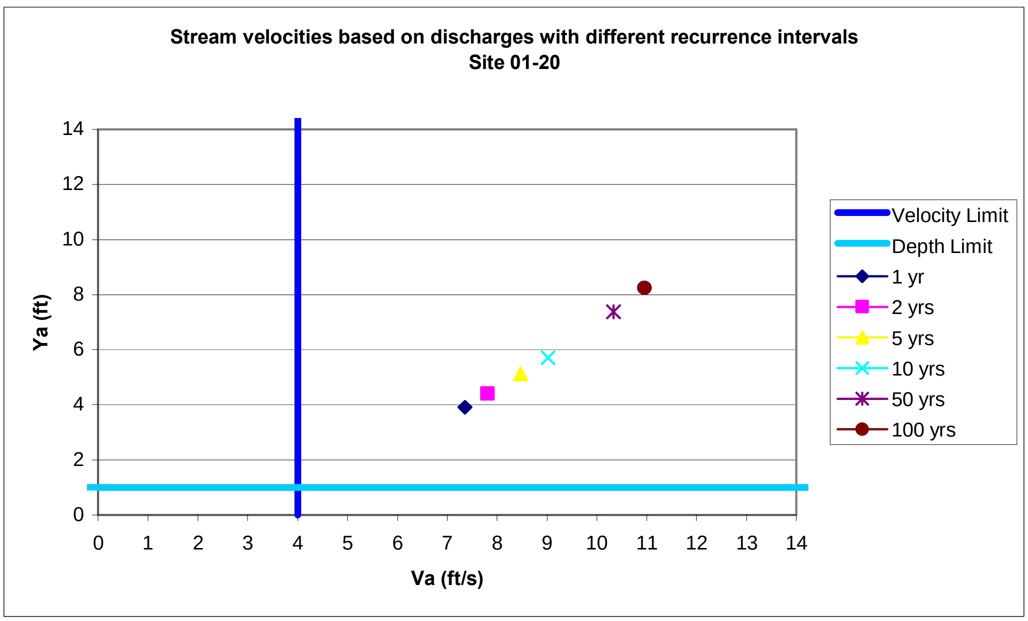


Figure 3. Velocities for discharges with different recurrence periods for Miller Cr.

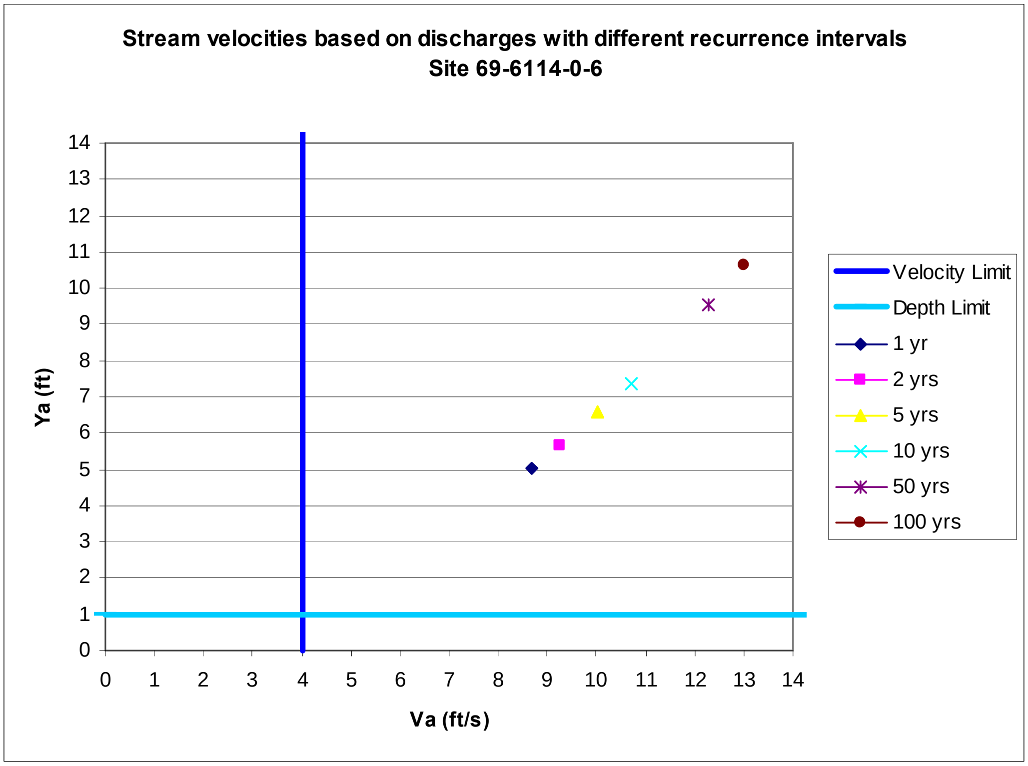


Figure 4. Velocities for discharges with different recurrence periods for Indian Cr.

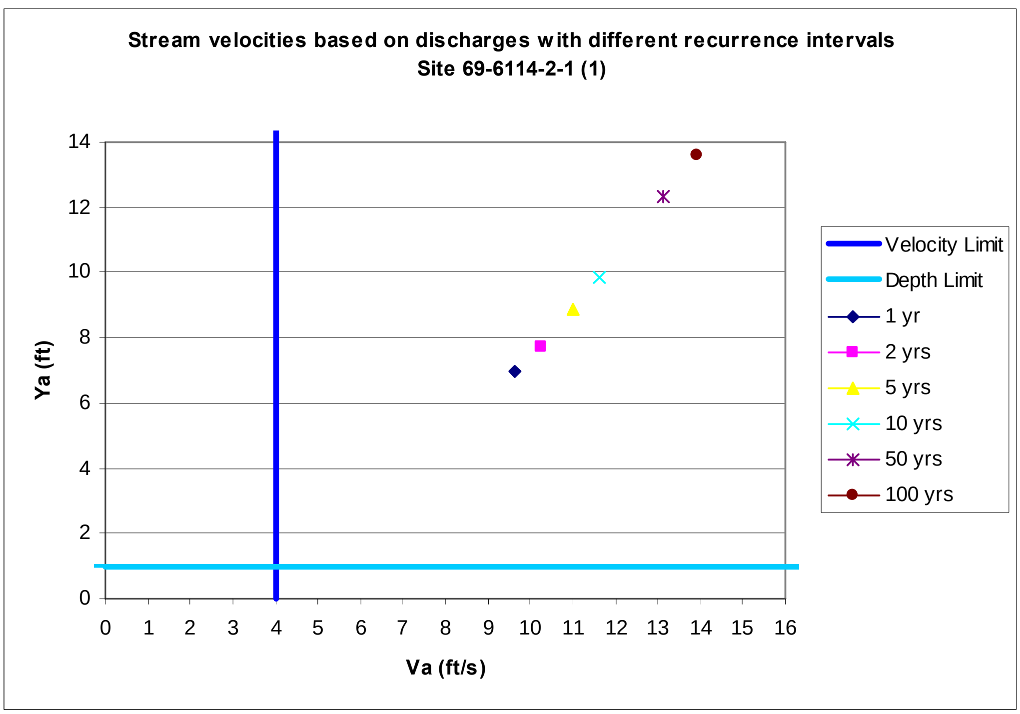


Figure 5. Velocities for discharges with different recurrence periods for Walnut Cr.

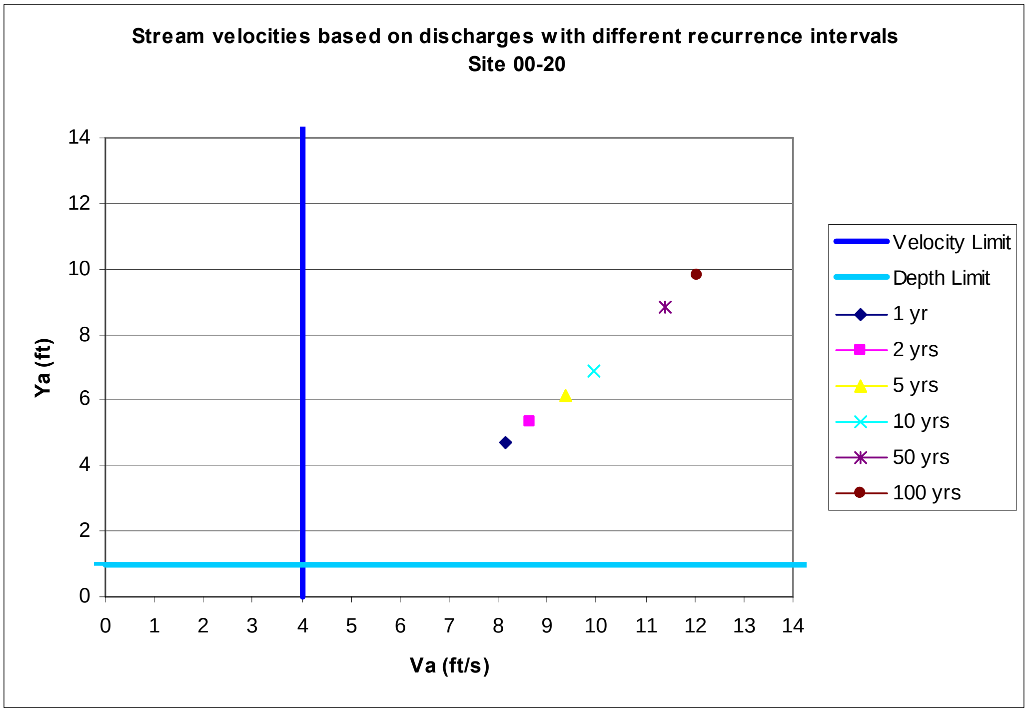


Figure 6. Velocities for discharges with different recurrence periods for Coon Cr.

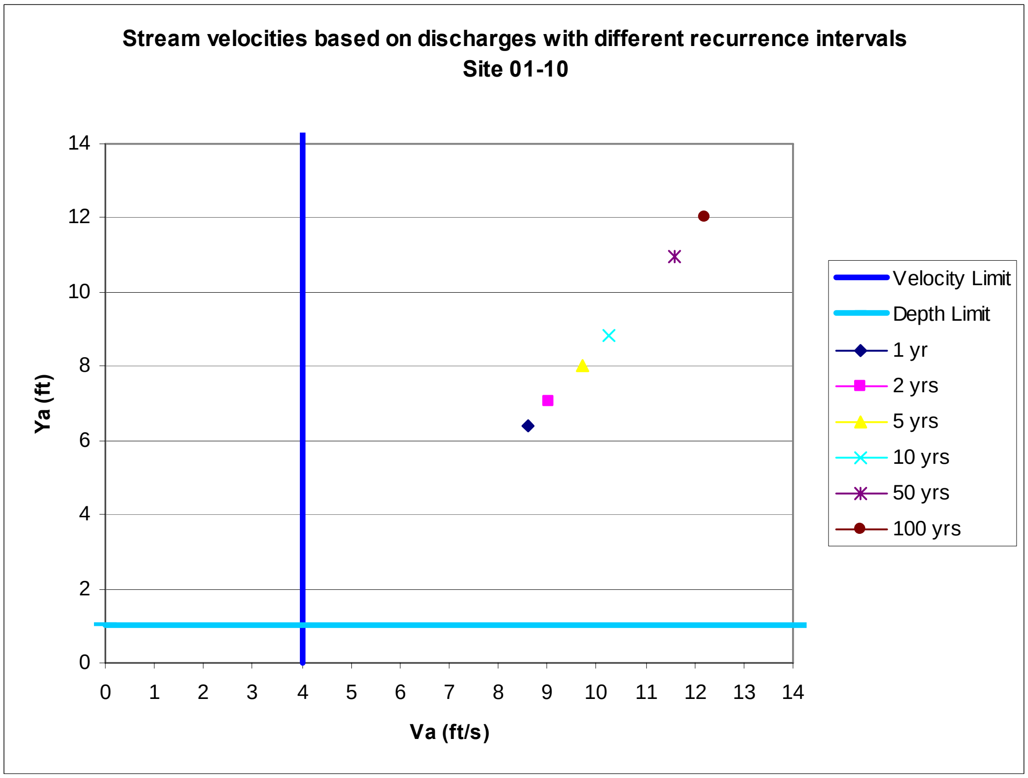


Figure 7. Velocities for discharges with different recurrence periods for Indian Cr.

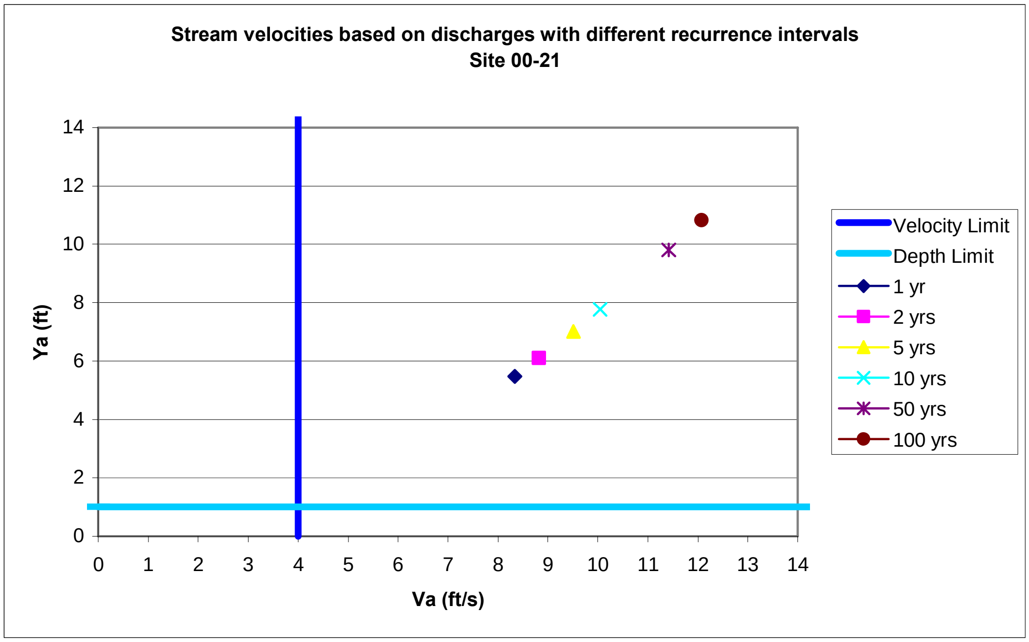


Figure 8. Velocities for discharges with different recurrence periods for Beaver Cr.

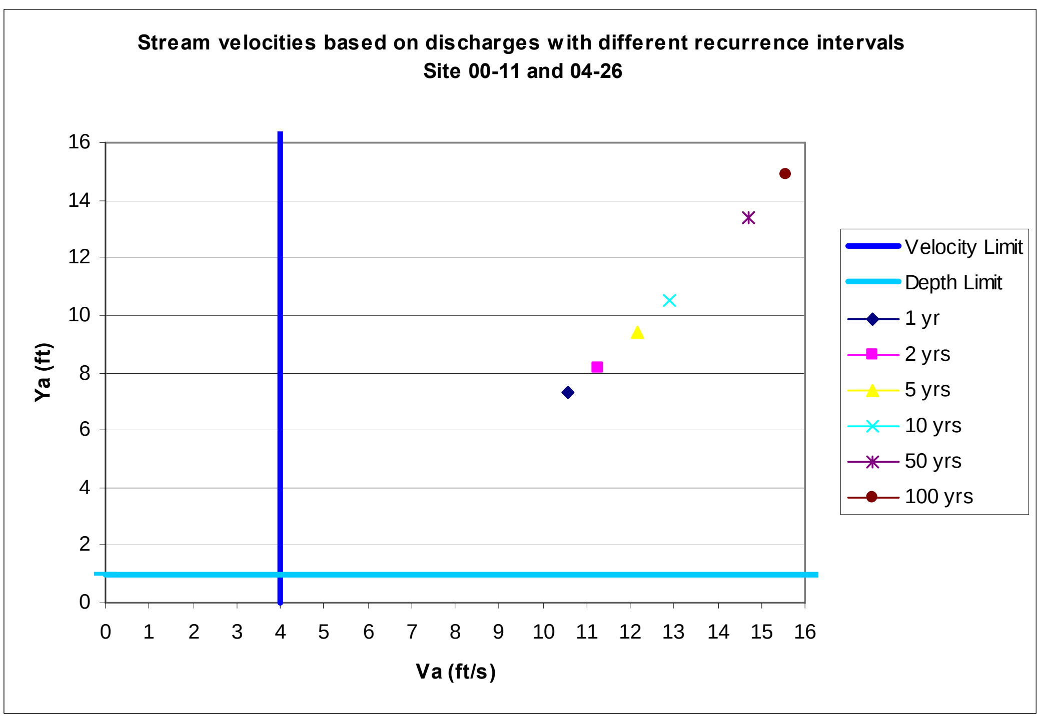


Figure 9. Velocities for discharges with different recurrence periods for Turkey Cr.

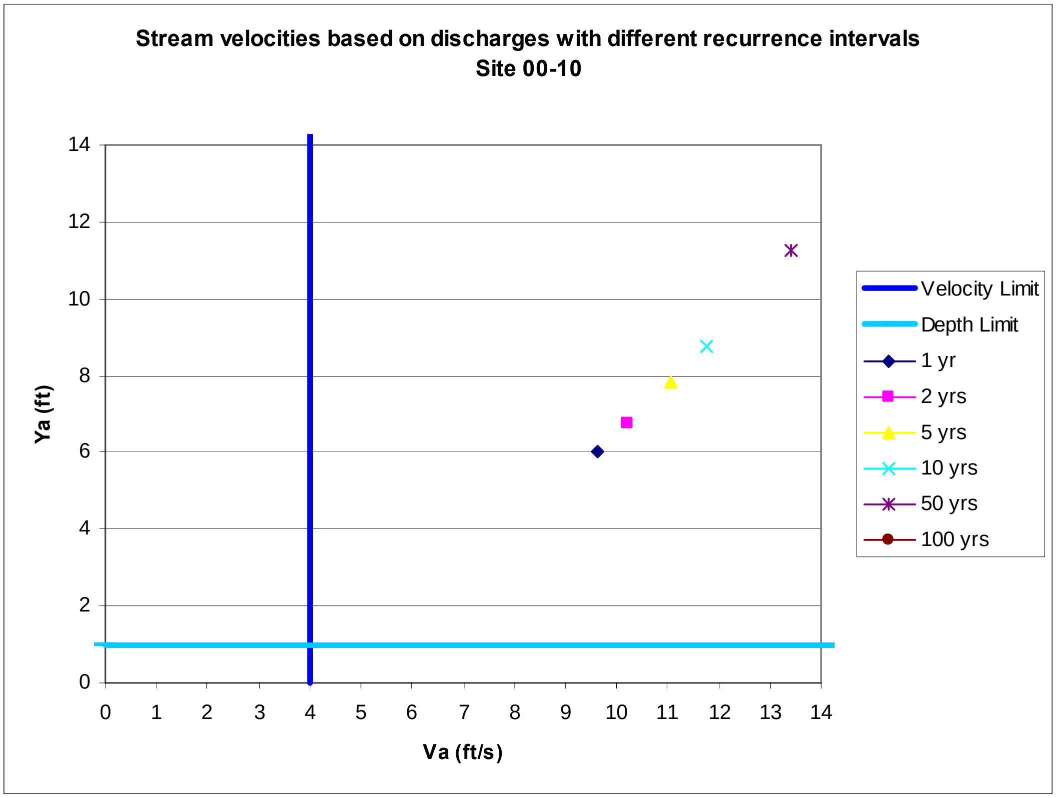


Figure 10. Velocities for discharges with different recurrence periods for Turkey Cr.

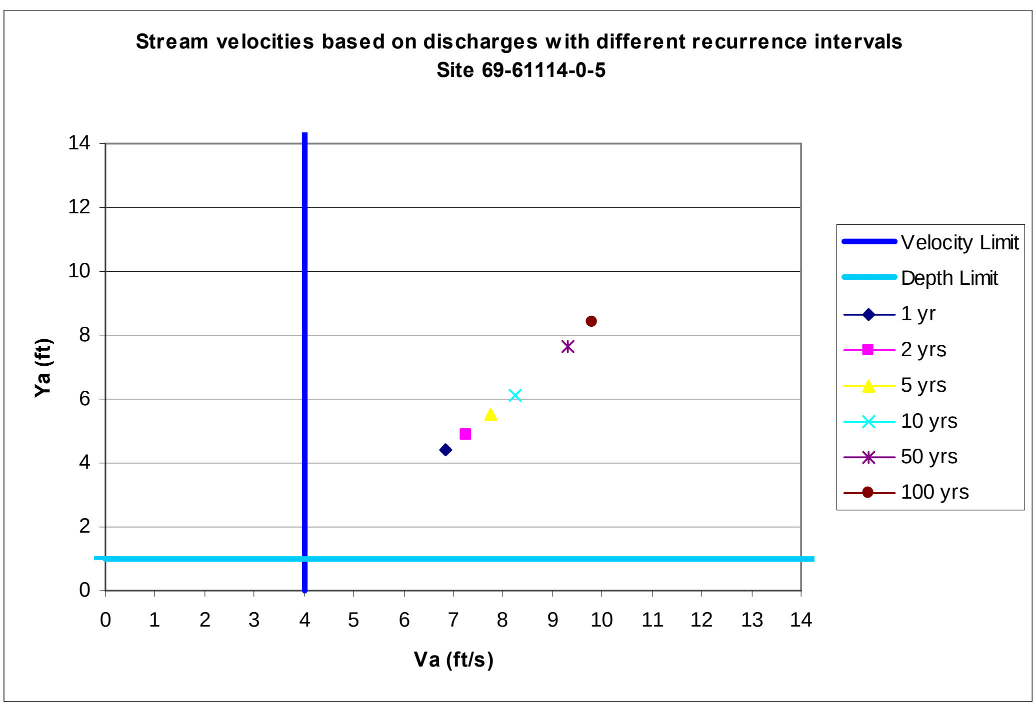


Figure 11. Velocities for discharges with different recurrence periods for Silver Cr. Trib.

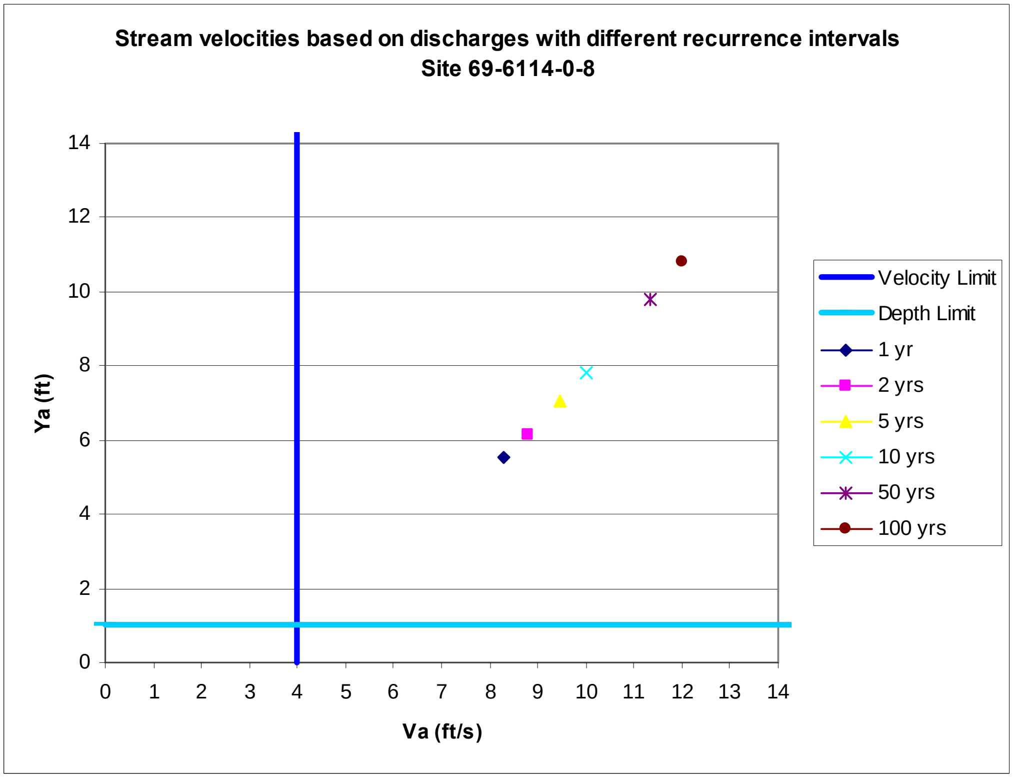


Figure 12. Velocities for discharges with different recurrence periods for Snake Cr.

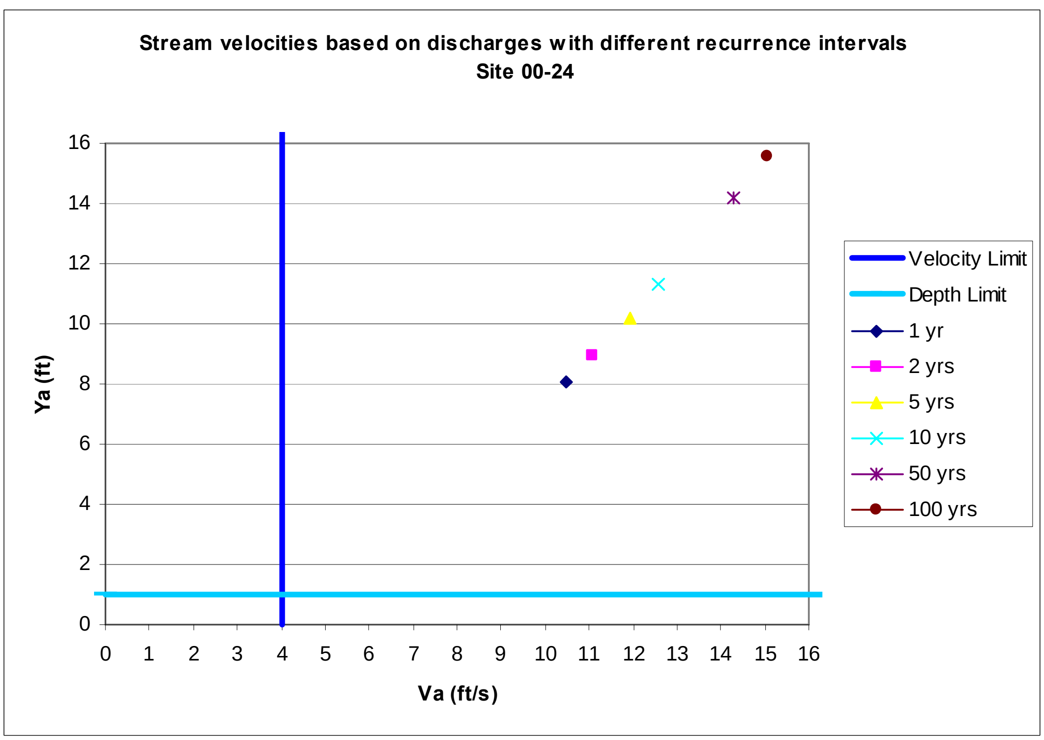


Figure 13. Velocities for discharges with different recurrence periods for Tarkio R.

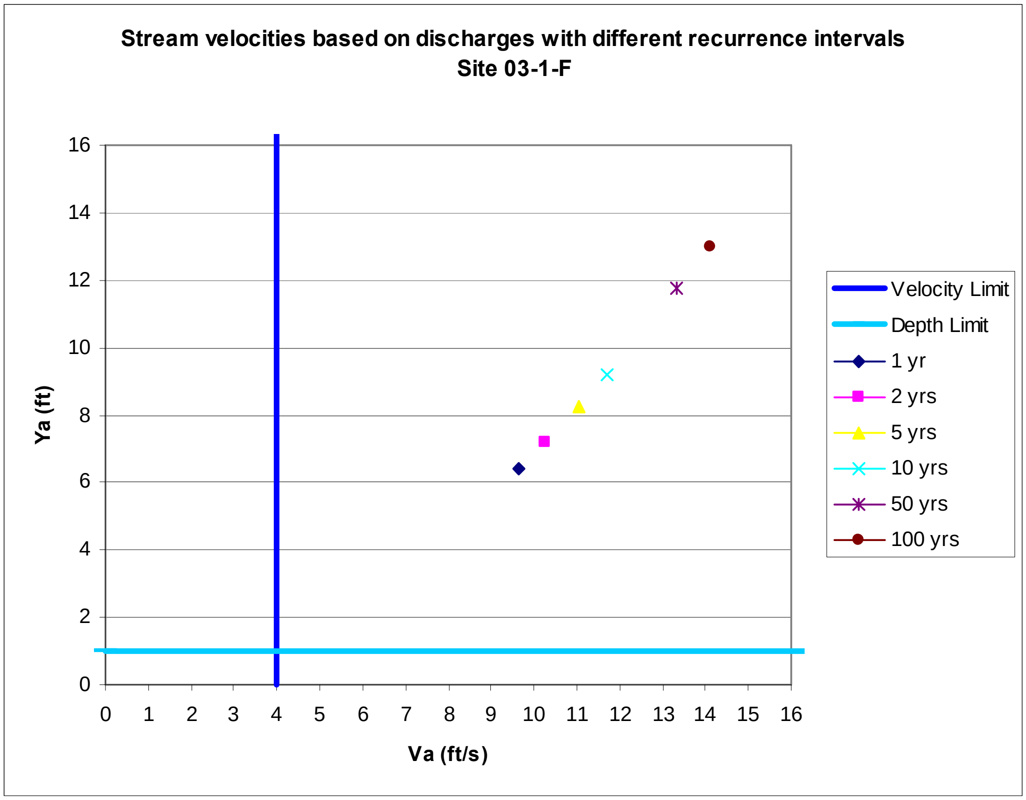


Figure 14. Velocities for discharges with different recurrence periods for Mosquito Cr.

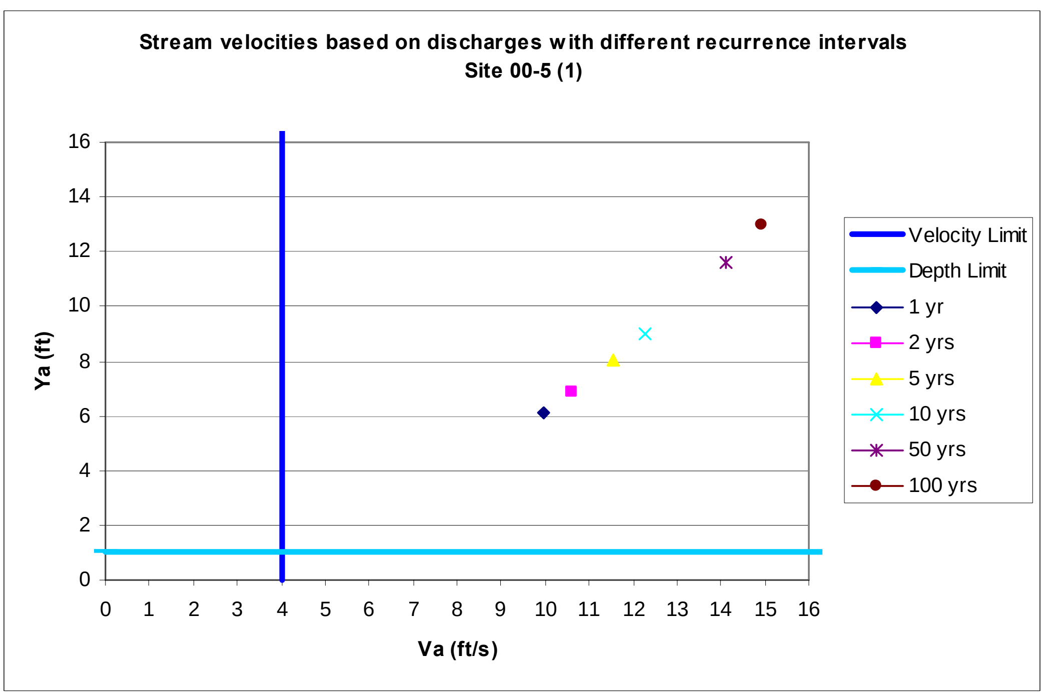


Figure 15. Velocities for discharges with different recurrence periods for Walnut Cr.

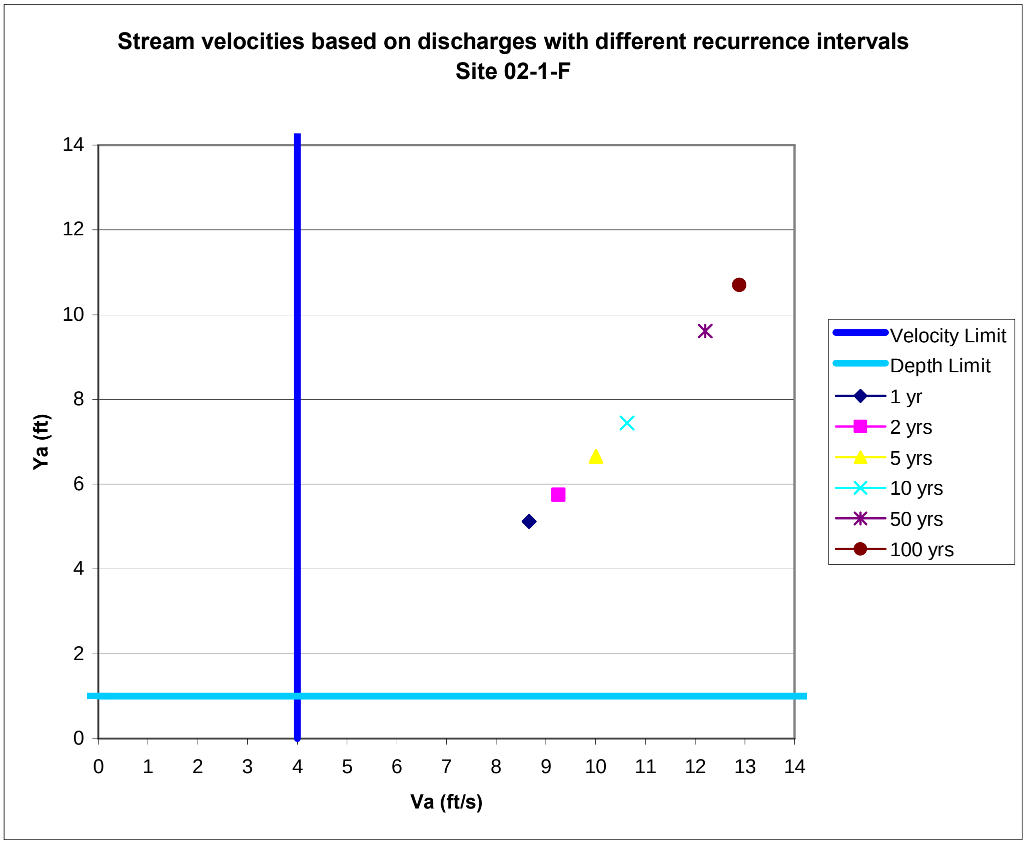


Figure 16. Velocities for discharges with different recurrence periods for David's Cr.

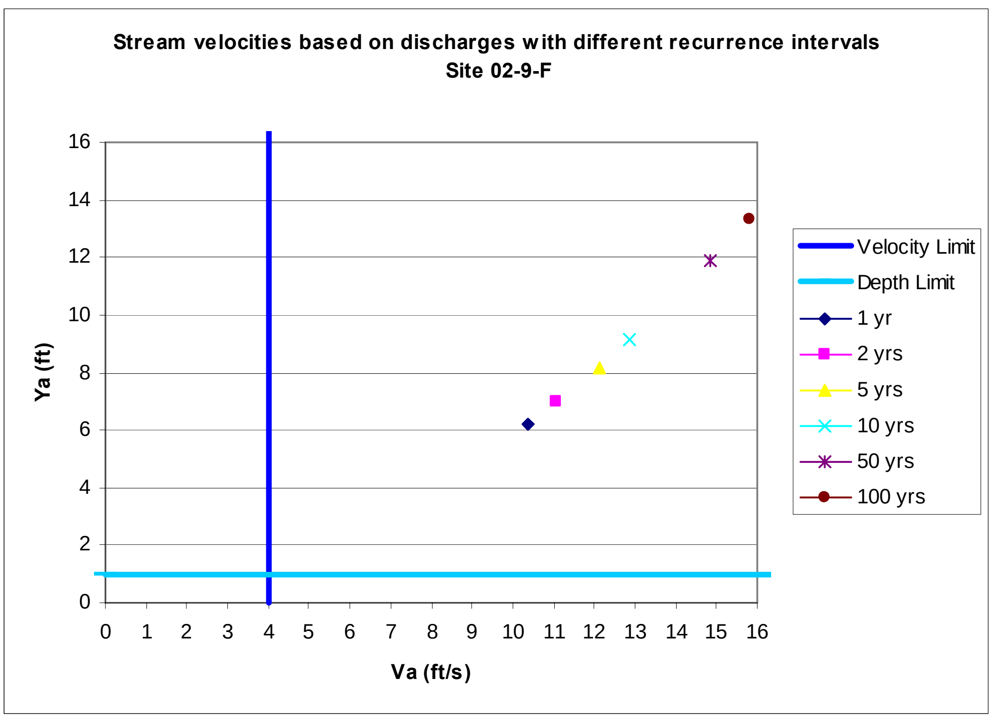


Figure 17. Velocities for discharges with different recurrence periods for Tarkio R.

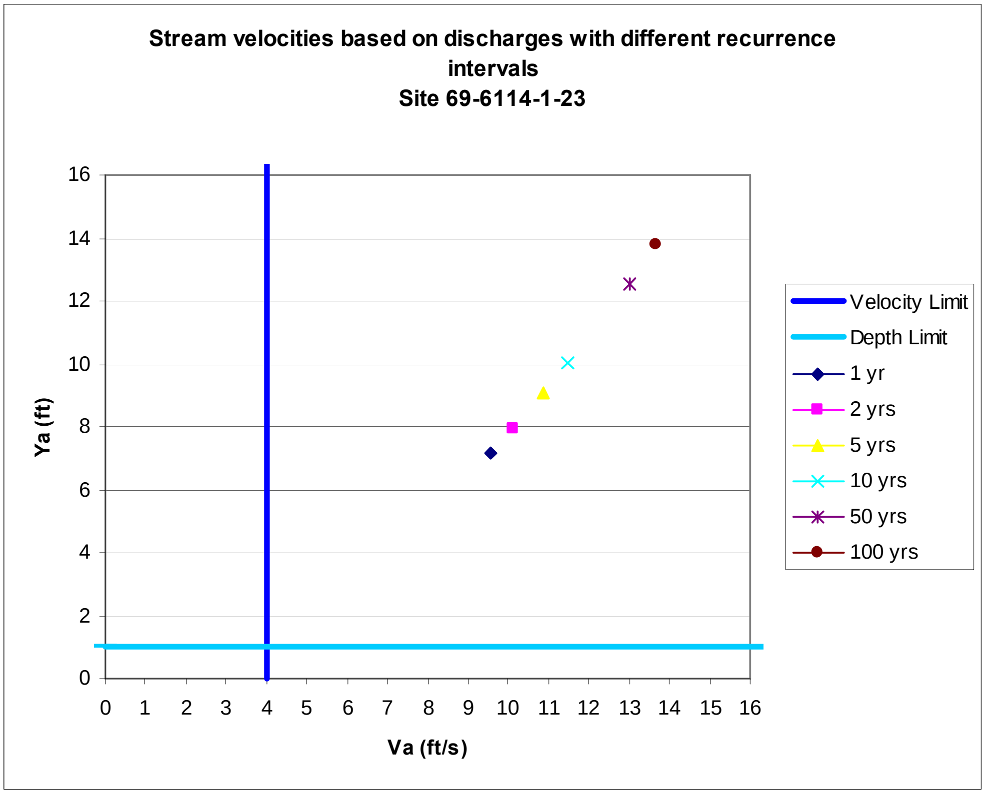


Figure 18. Velocities for discharges with different recurrence periods for E. Tarkio R.

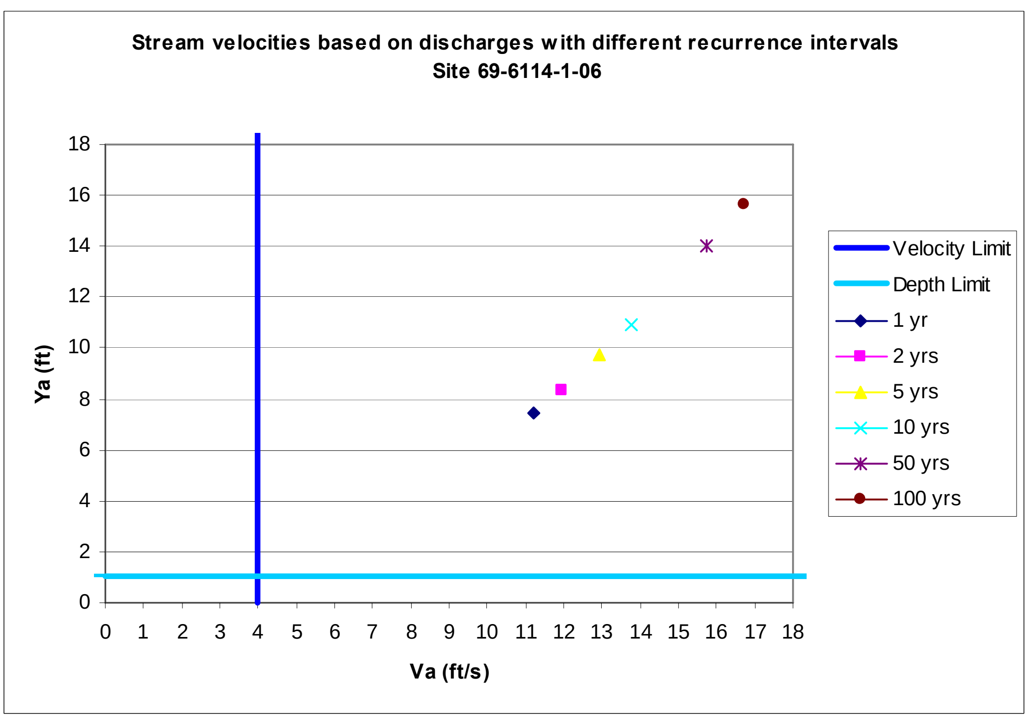


Figure 19. Velocities for discharges with different recurrence periods for Boyer R.

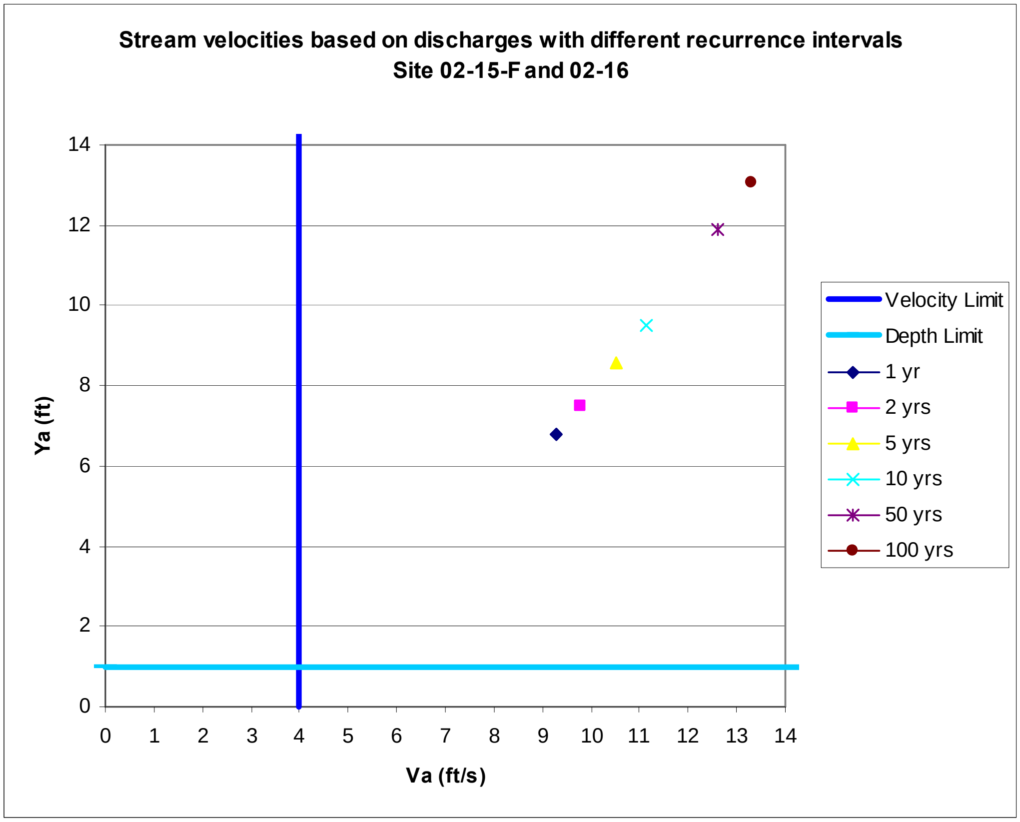


Figure 20. Velocities for discharges with different recurrence periods for Otter Cr.

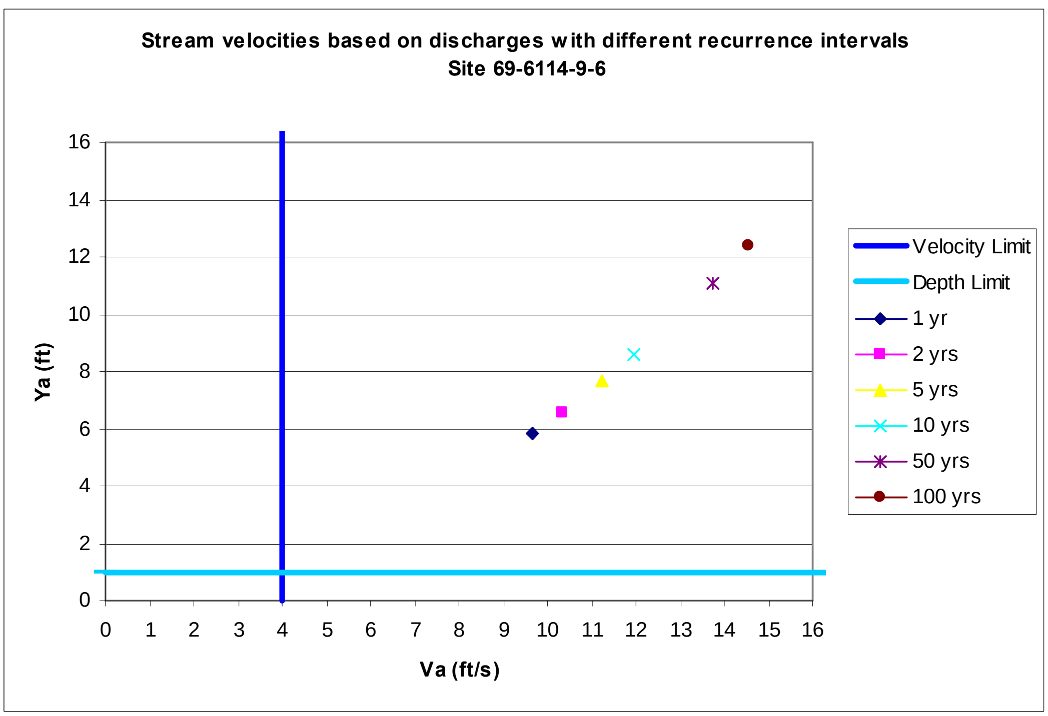


Figure 21. Velocities for discharges with different recurrence periods for Walnut Cr.

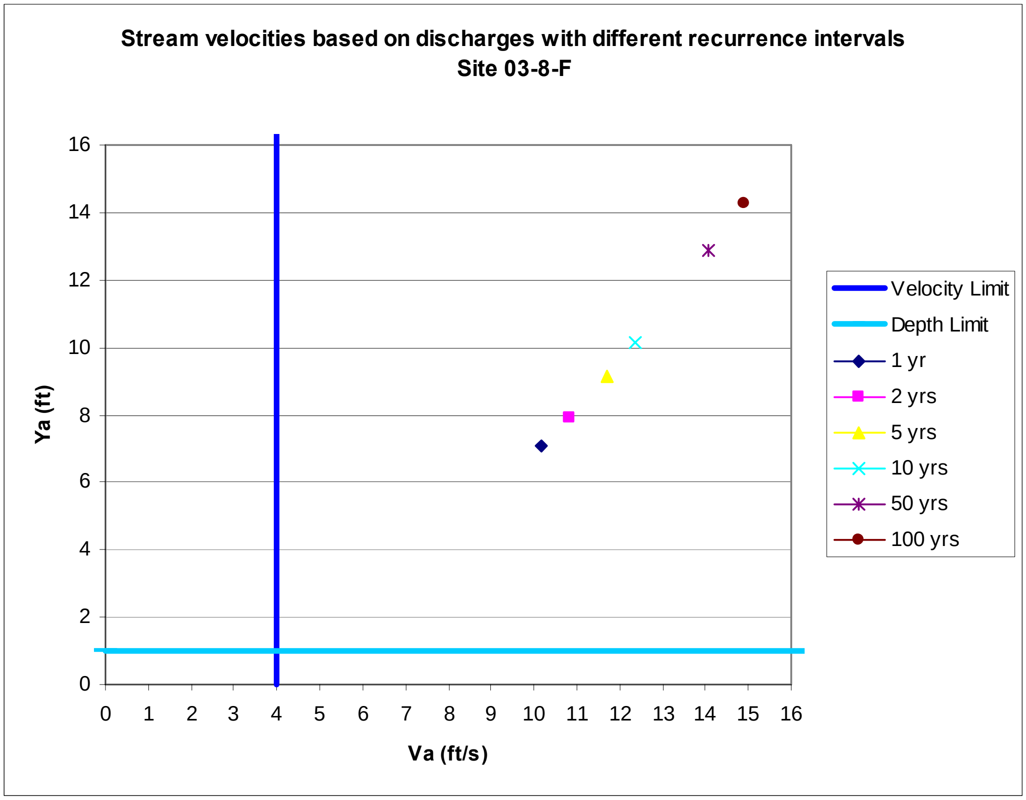


Figure 22. Velocities for discharges with different recurrence periods for Keg Cr.

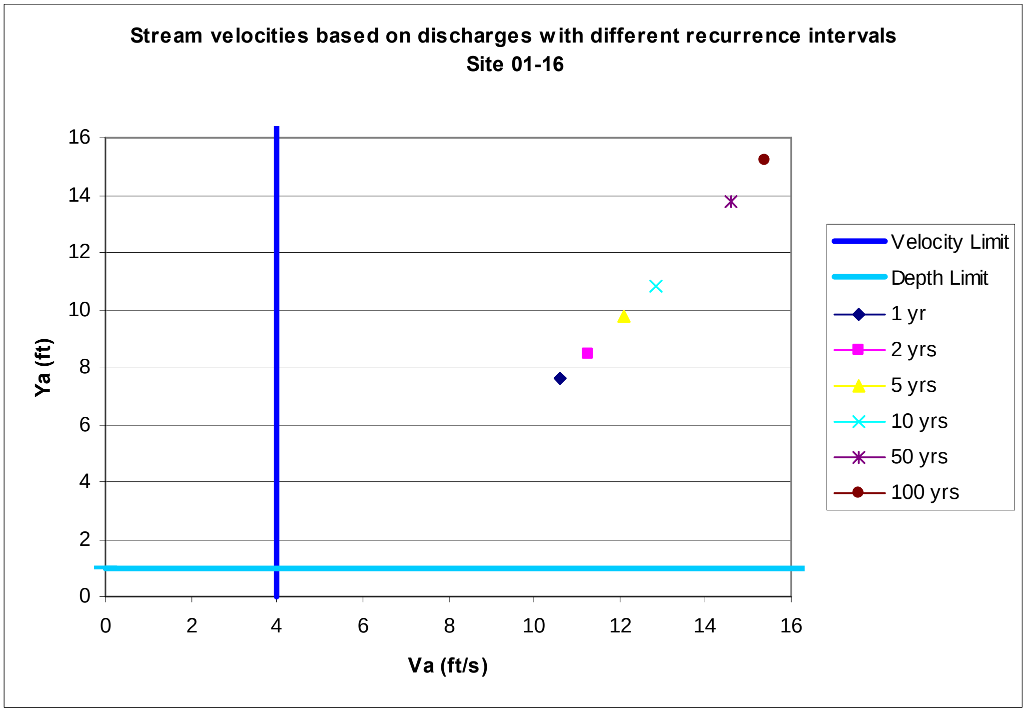


Figure 23. Velocities for discharges with different recurrence periods for W Nodaway R.

APPENDIX B: FIGURES OF THE DIFFERENT SITES

Fall Period

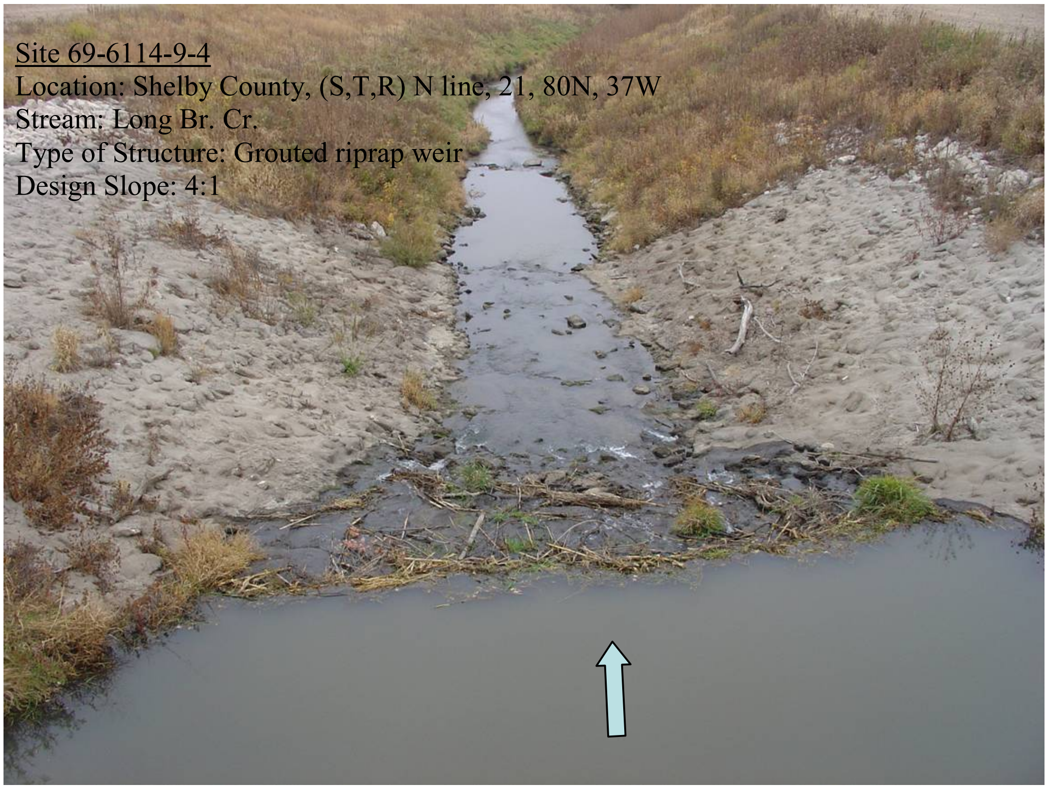


Figure 24a. Description of site 69-6114-9-4

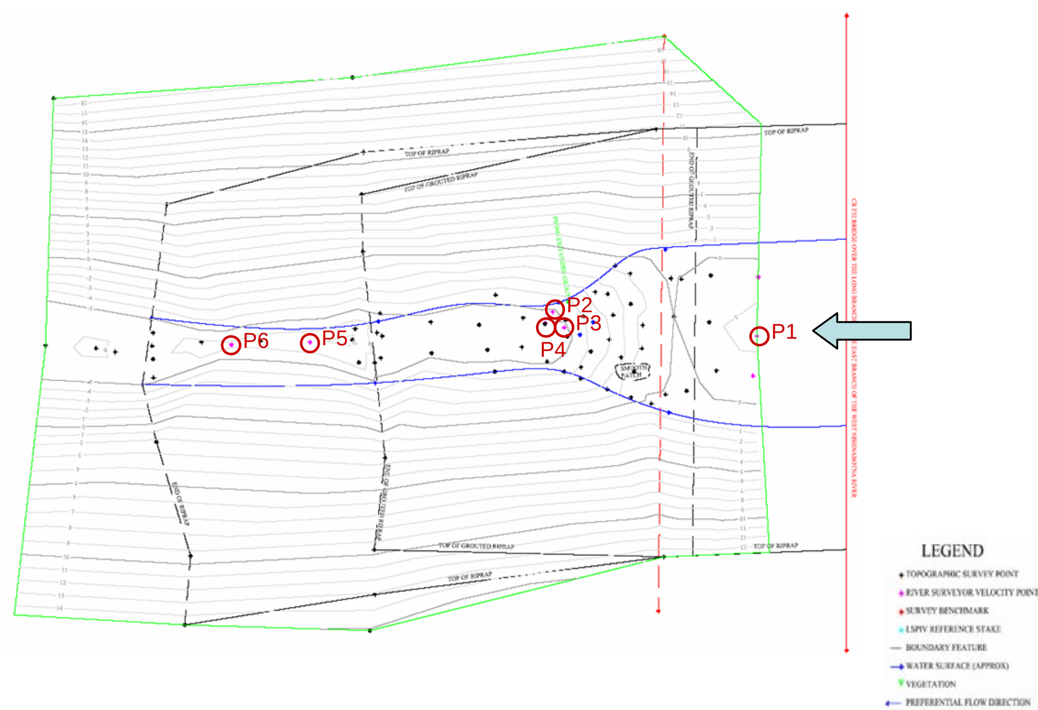


Figure 24b. Topographic plot

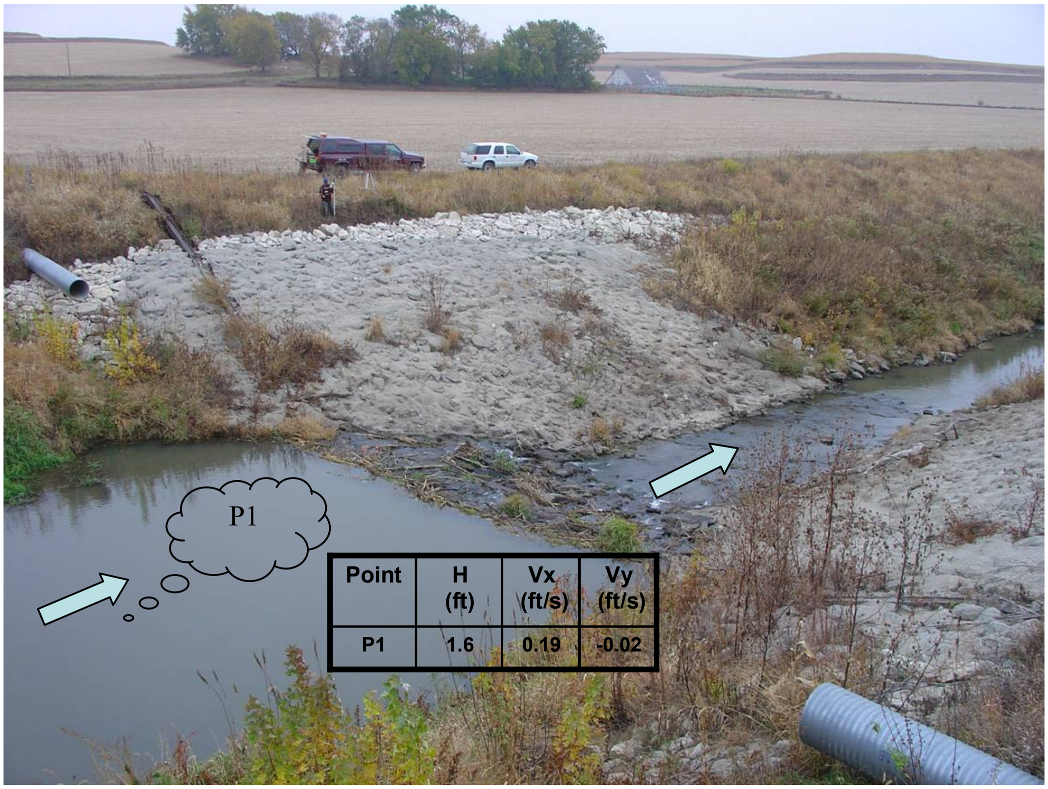


Figure 24c. Flowtracker measurements

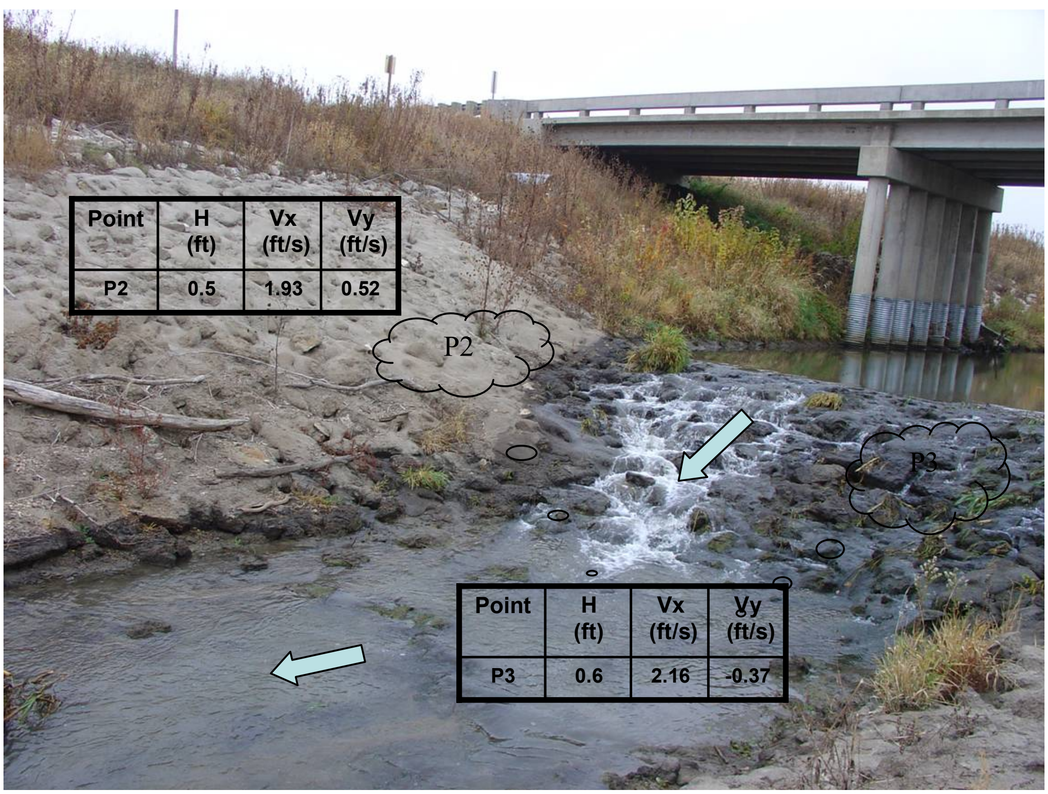
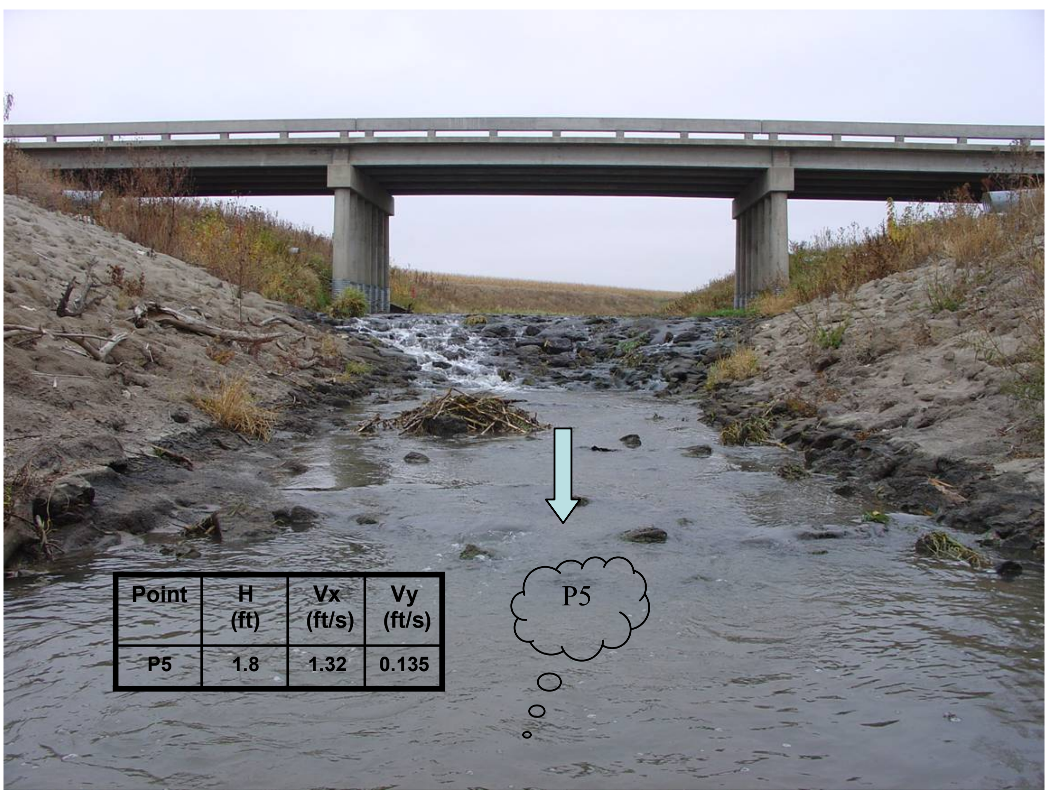


Figure 24d. Flowtracker measurements

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P4	1	4.2	0.26

Figure 24e. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P5	1.8	1.32	0.135

Figure 24f. Flowtracker measurements

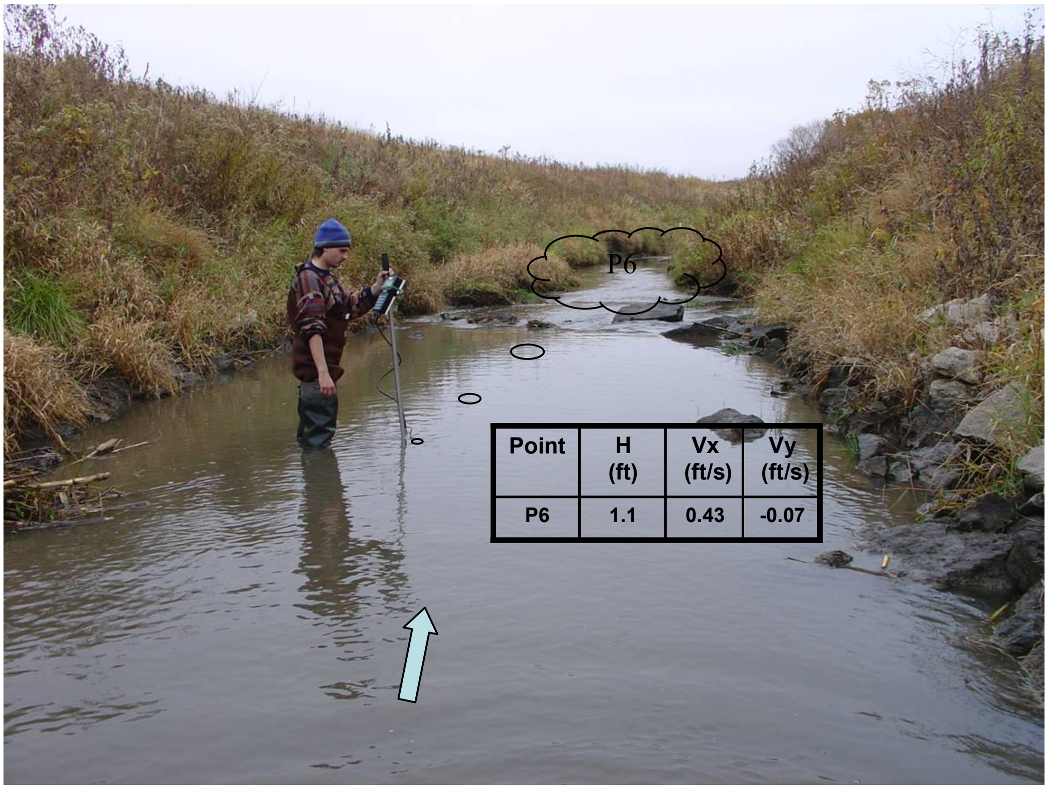


Figure 24g. Flowtracker measurements

Figure 24h. Riprap size

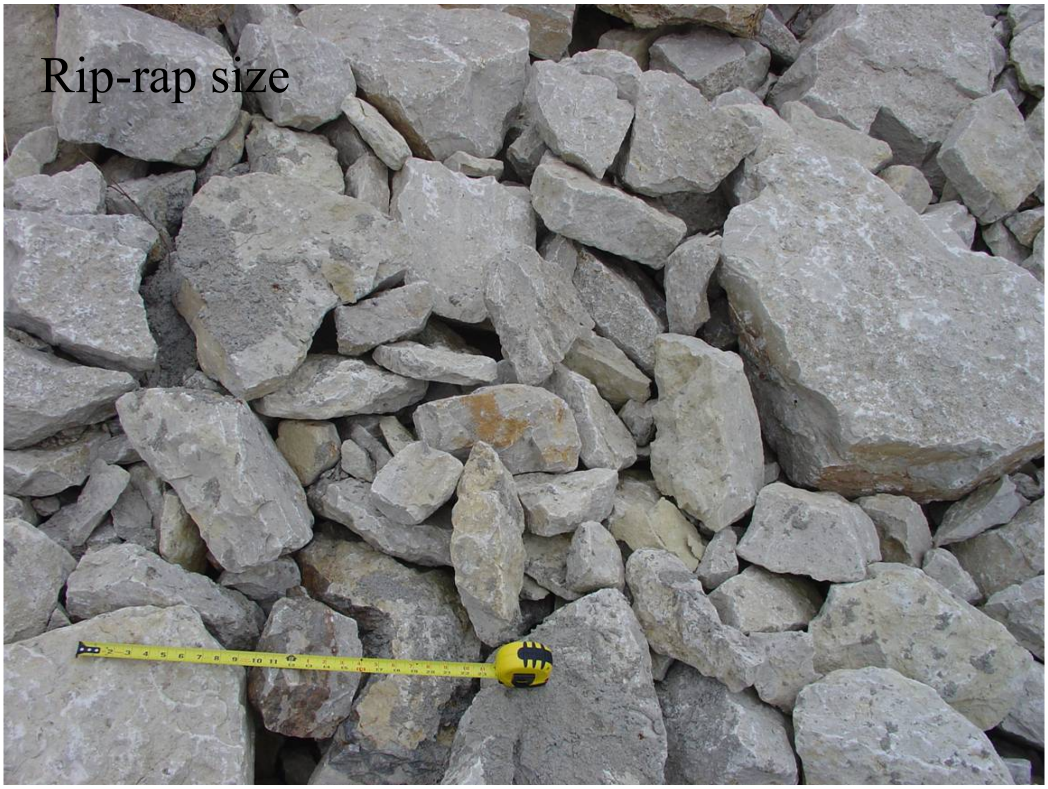


Figure 24i. Riprap size

Figure 24j. General picture

Figure 24k. General picture

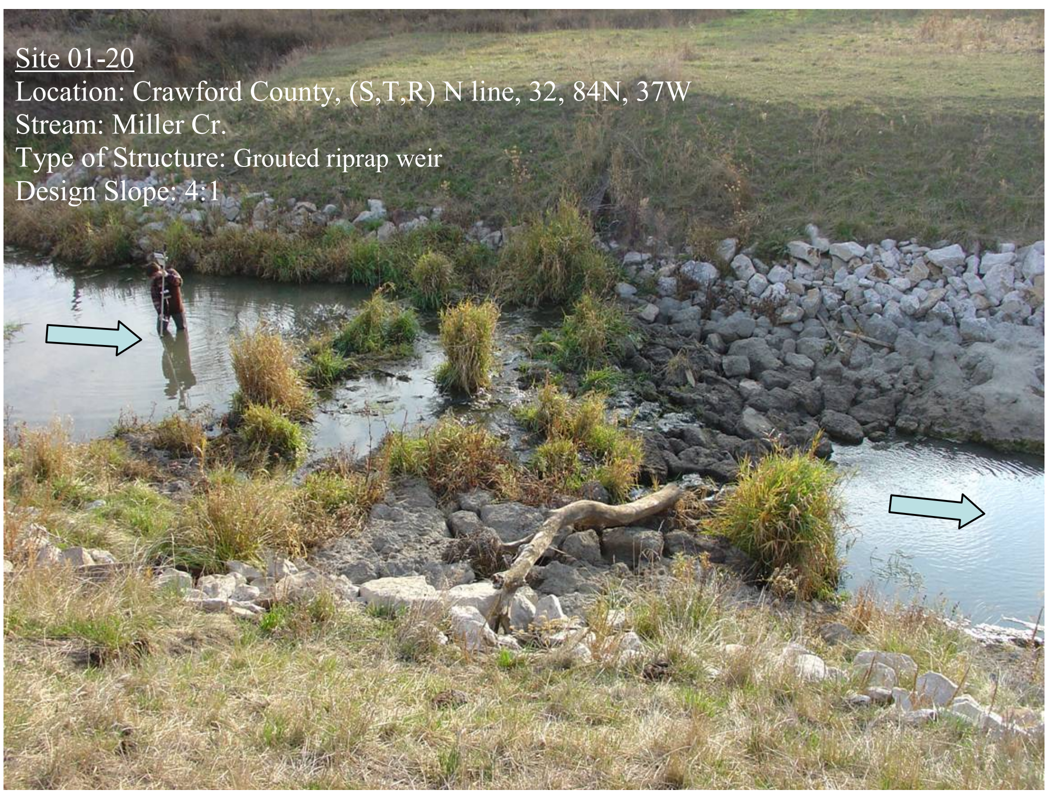


Figure 25a. Description of site 01-20

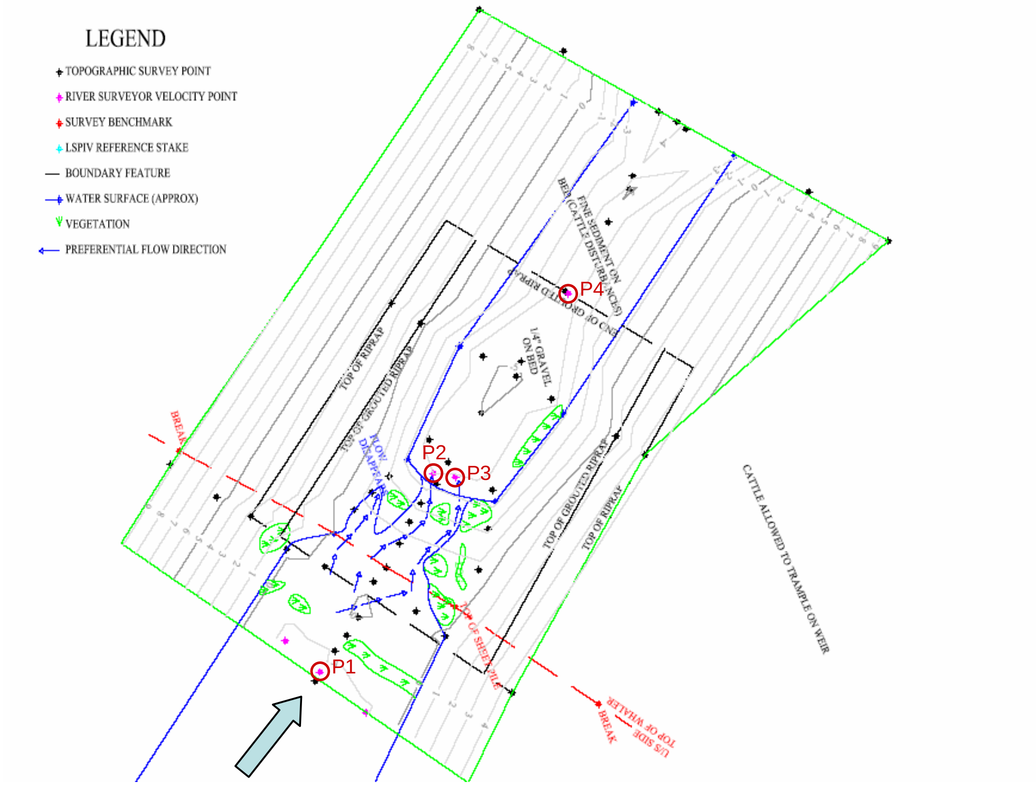


Figure 25b. Topographic plot

Figure 25c. Flowtracker measurements

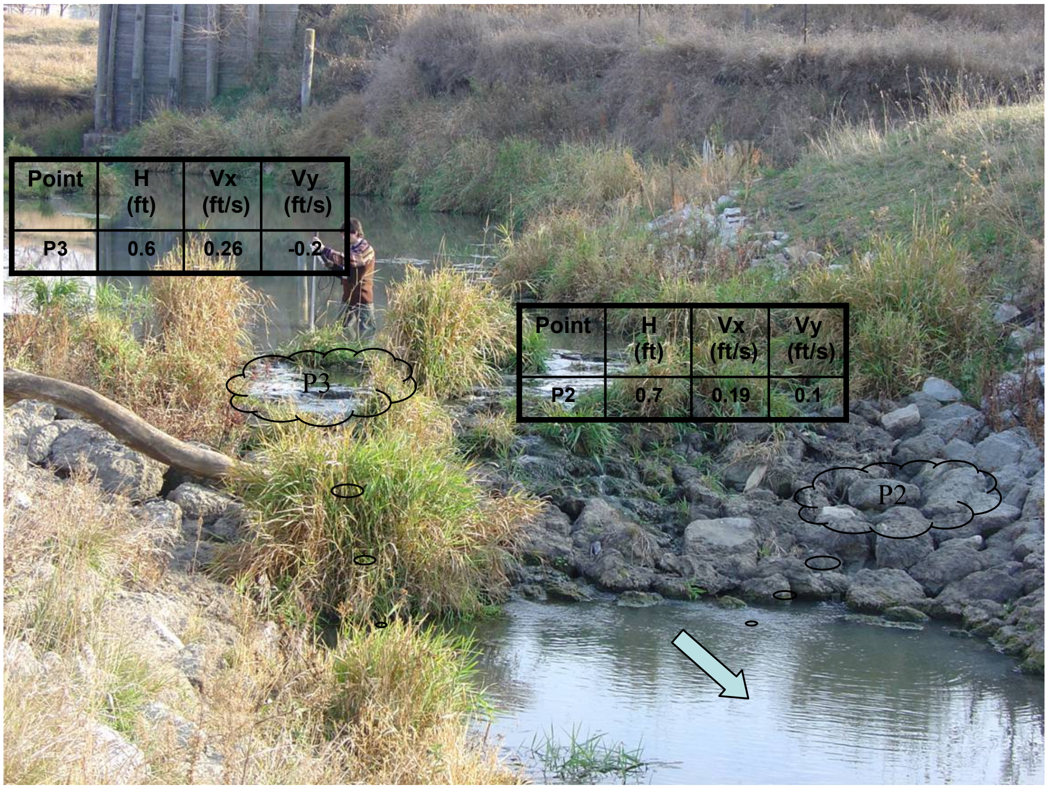


Figure 25d. Flowtracker measurements

Figure 25e. Flowtracker measurements

Figure 25f. Riprap size

Figure 25g. Riprap size

Figure 25h. Riprap size

Figure 25i. General picture

Figure 25j. General picture

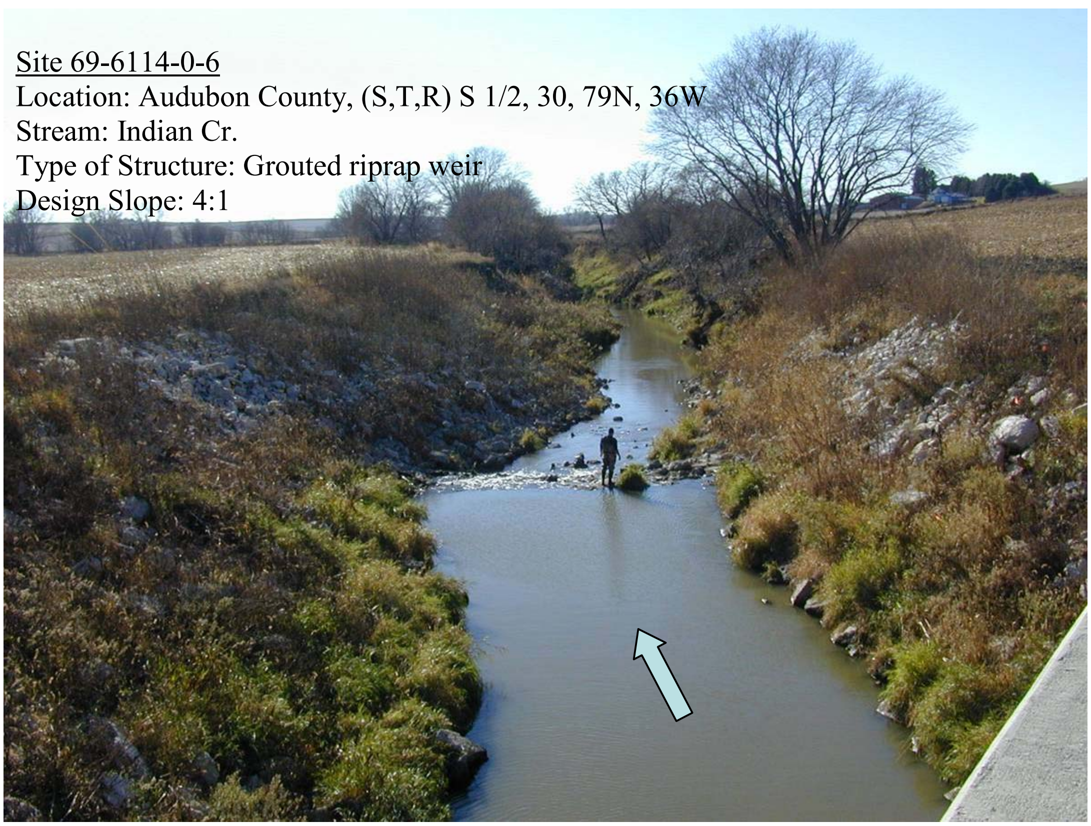


Figure 26a. Description of site 69-6114-0-6

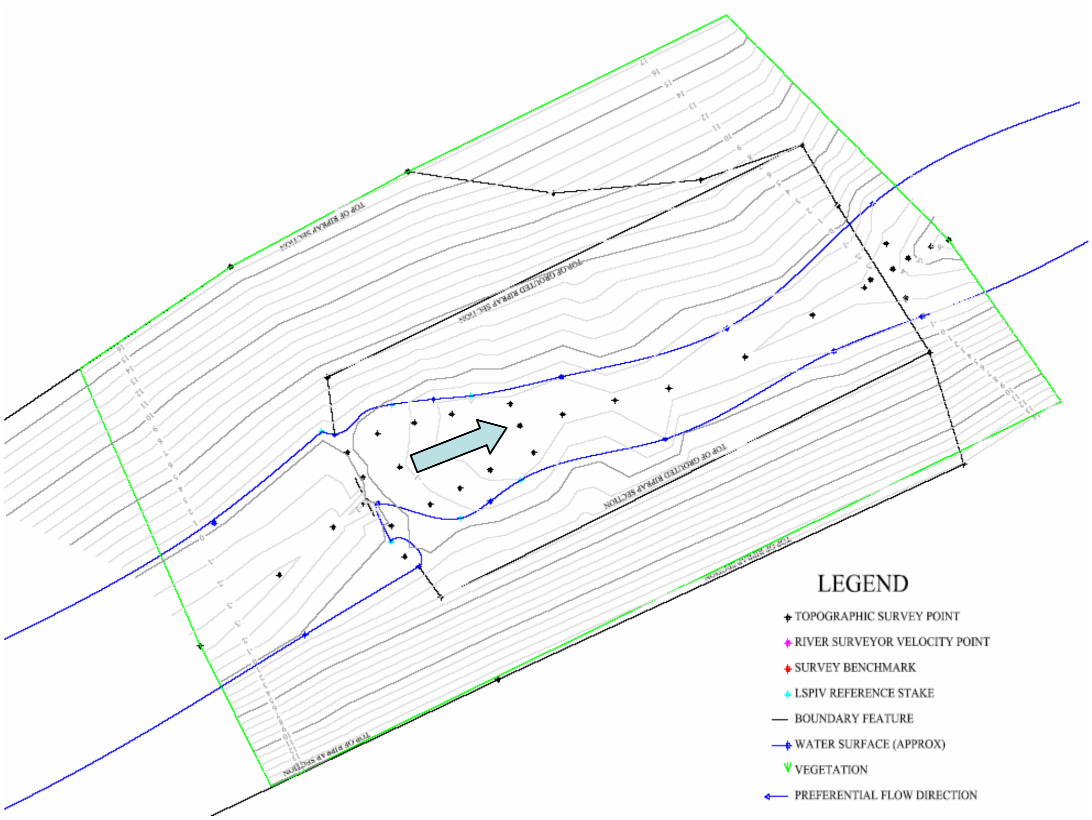


Figure 26b. Topographic plot

Figure 26c. LSPIV image

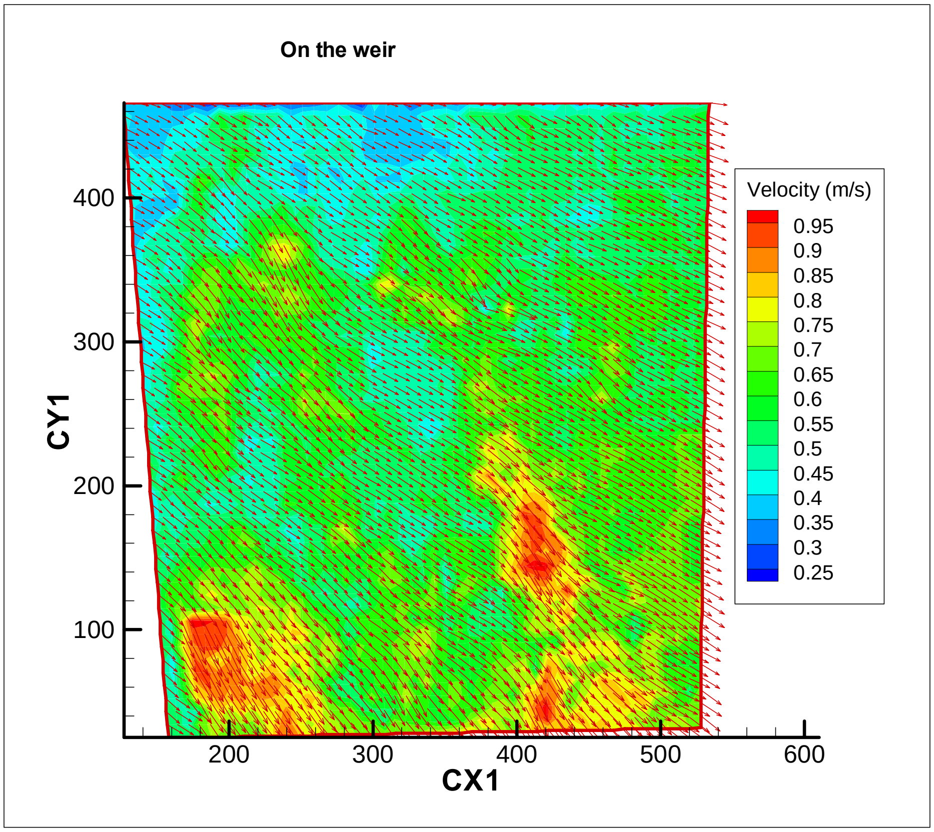


Figure 26d. LSPIV result (atop)

Figure 26e. Riprap size

Figure 26f. Riprap size

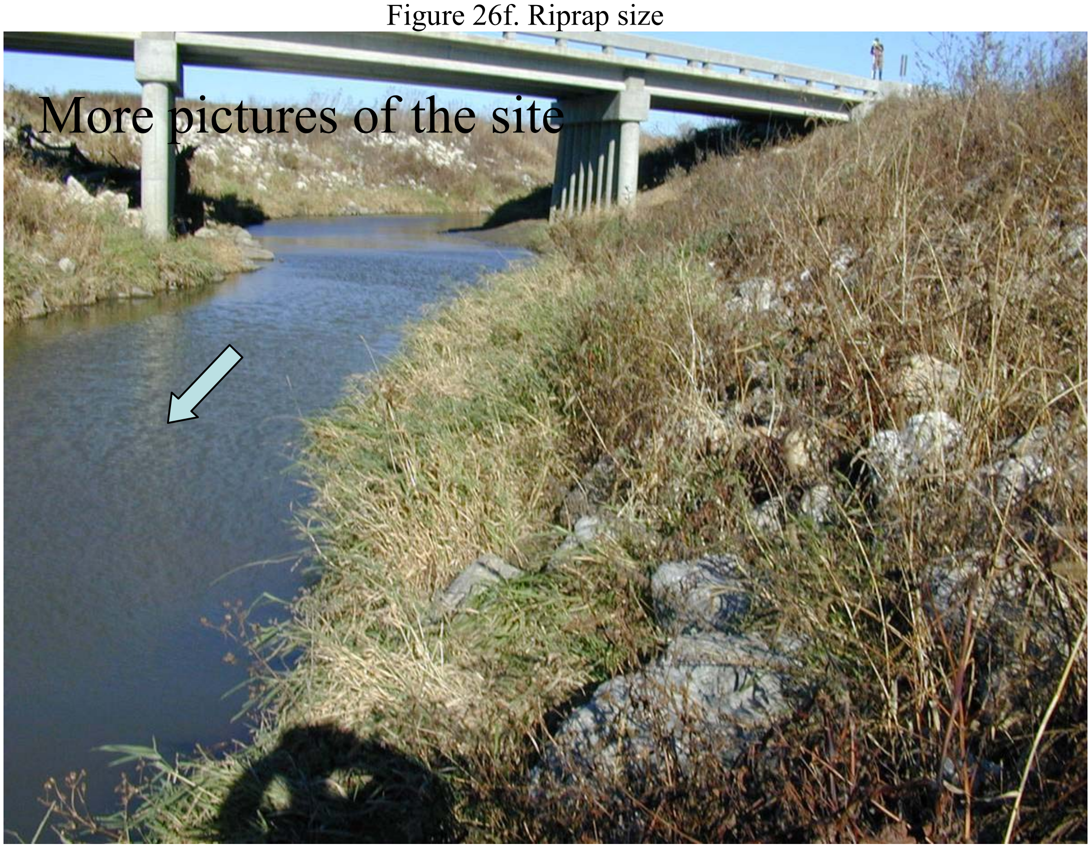


Figure 26g. General picture

Figure 26h. General picture

Figure 26i. General picture

Figure 26j. General picture

Figure 27a. Description of site 69-6114-2-1 (1)

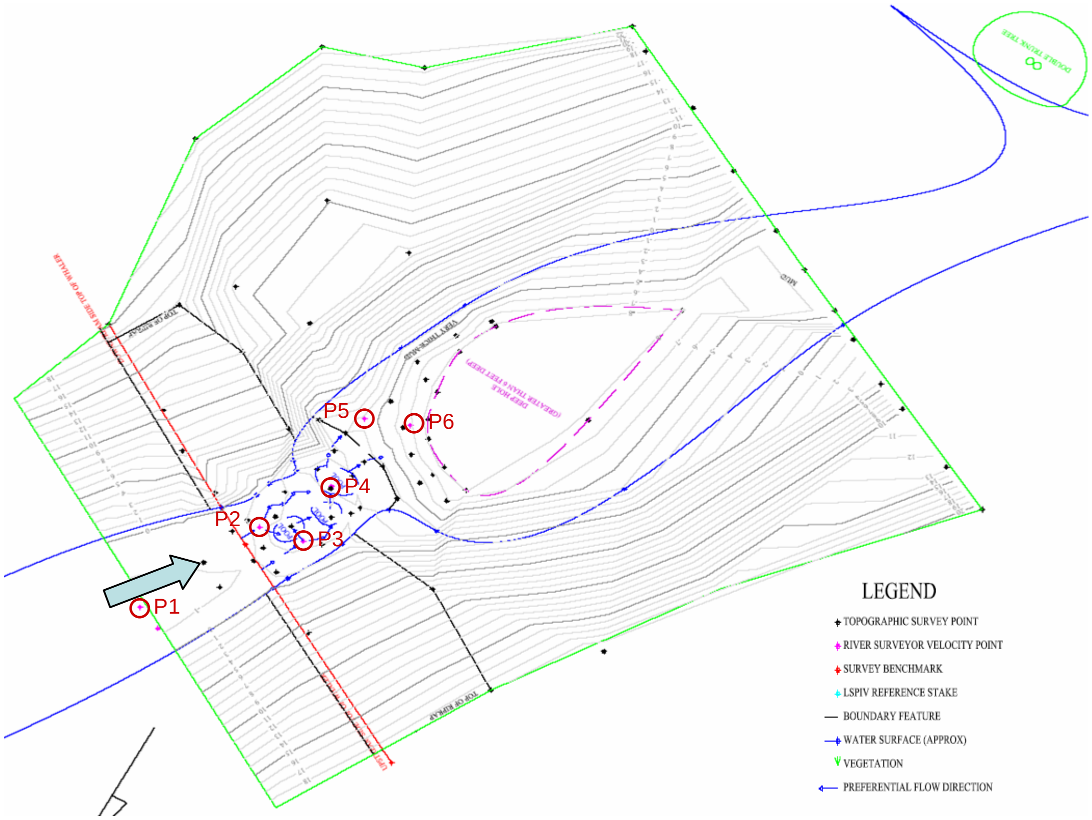


Figure 27b. Topographic plot

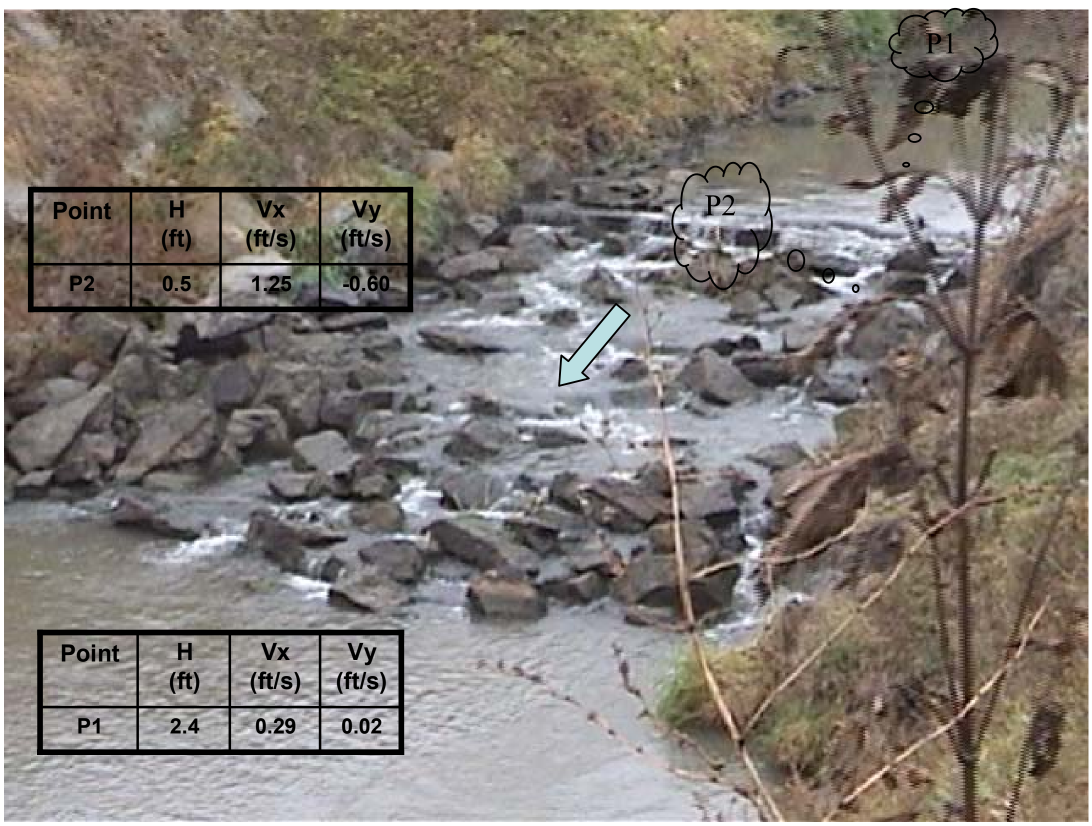


Figure 27c. Flowtracker measurements

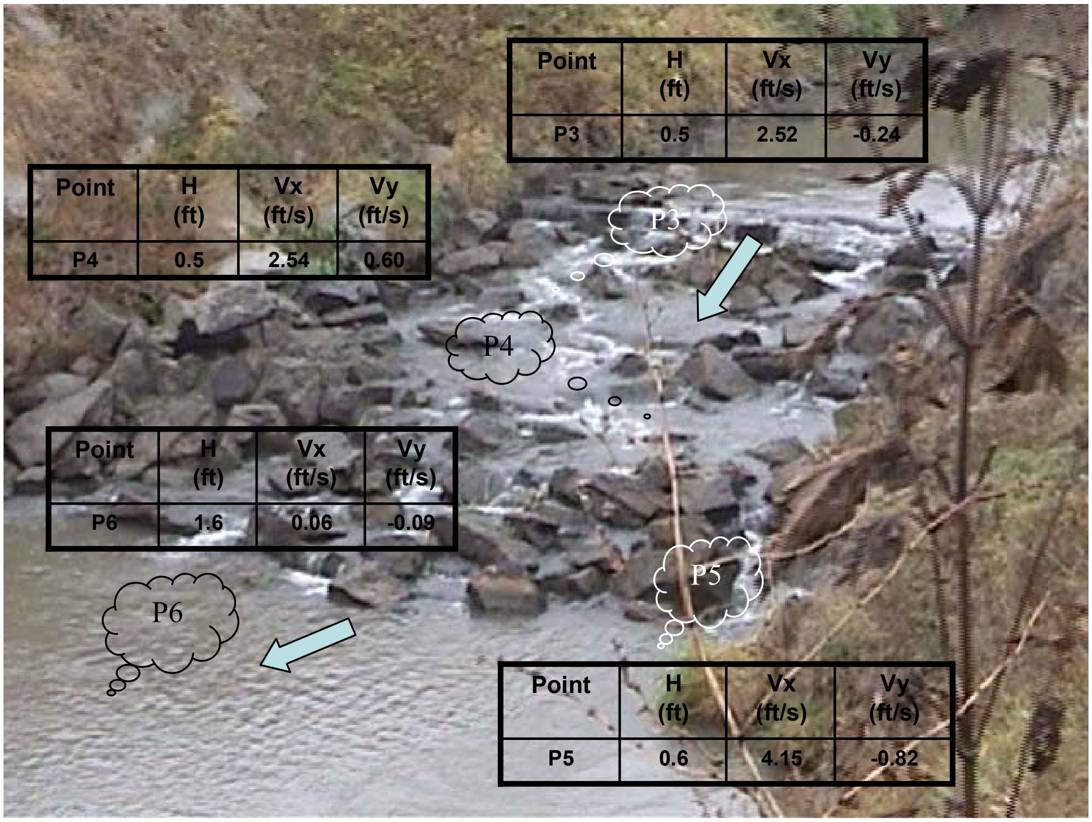


Figure 27d. Flowtracker measurements

Figure 27e. Riprap size

Figure 27f. Riprap size

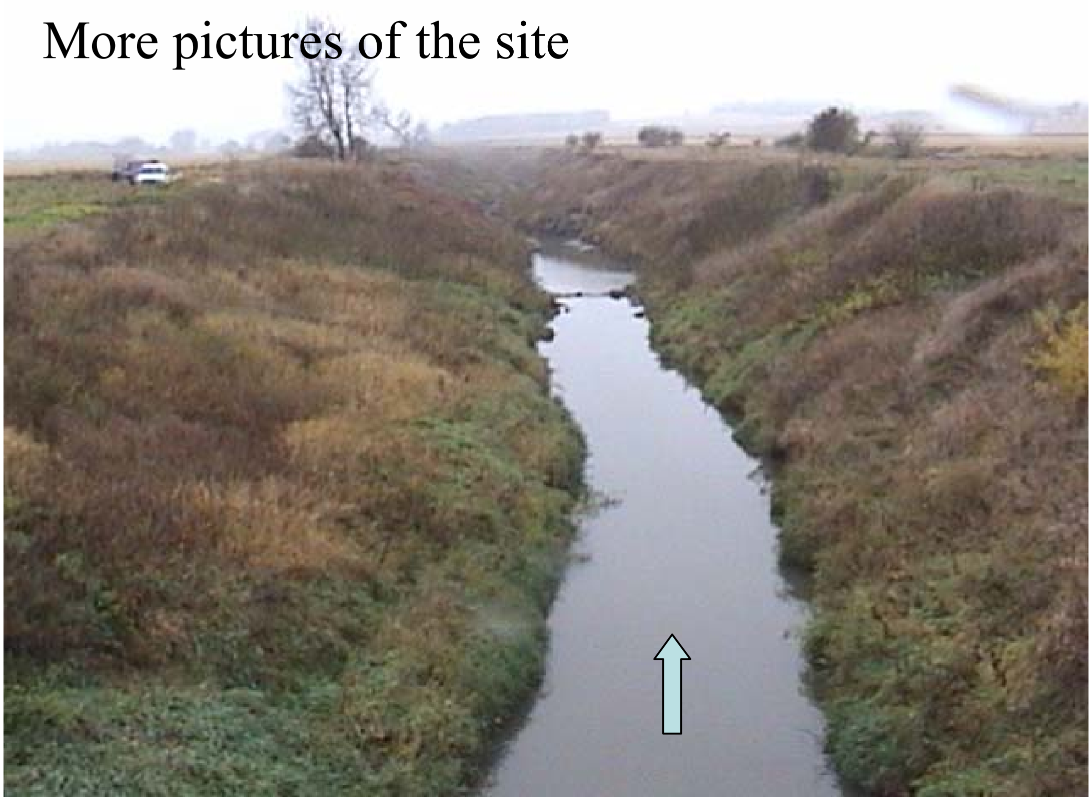


Figure 27g. General picture

Figure 27h. General picture

Figure 28a. Description of site 00-20

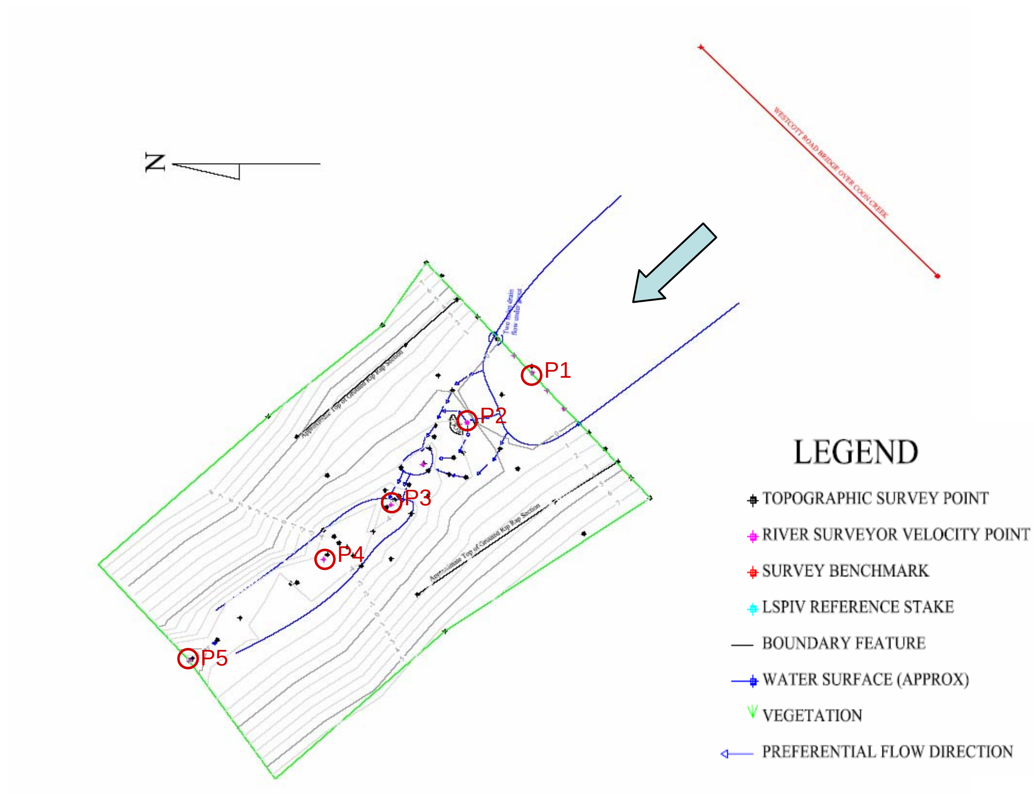


Figure 28b. Topographic plot

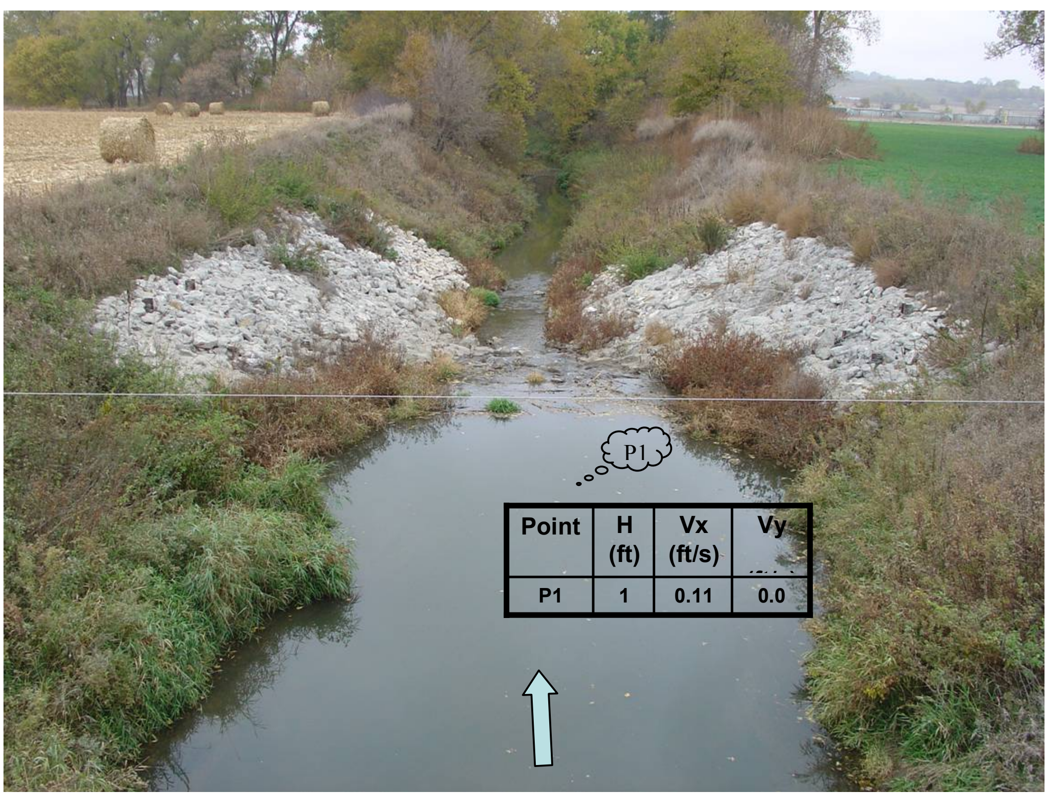
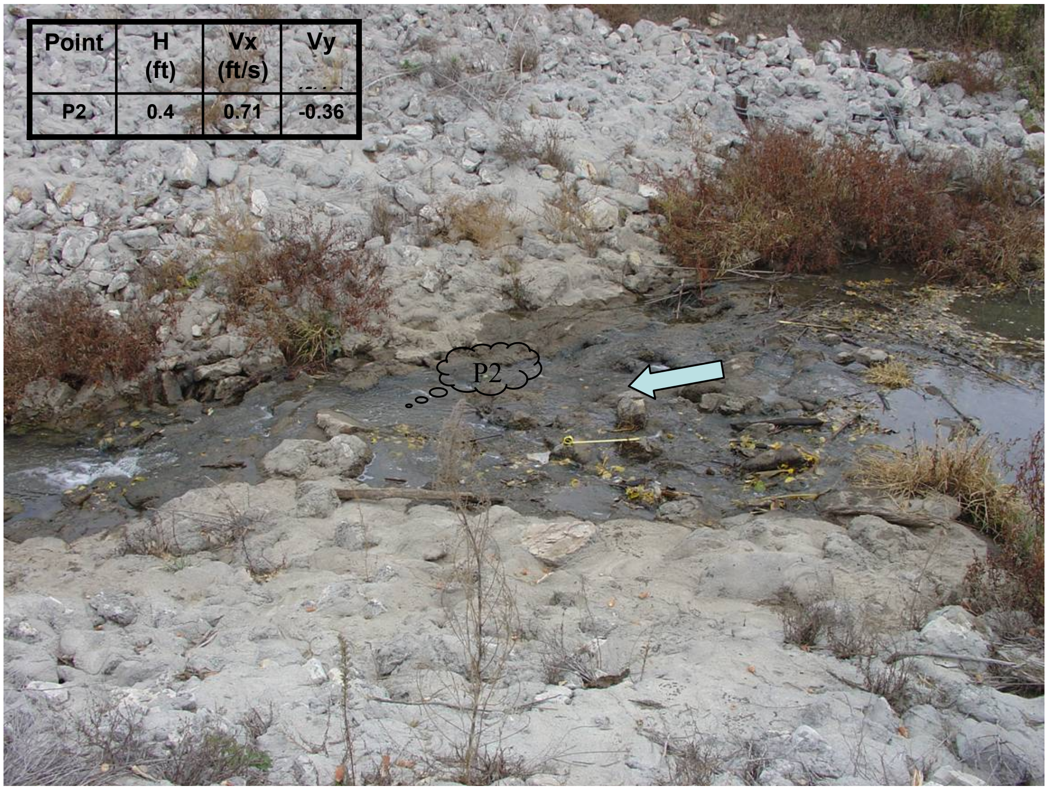
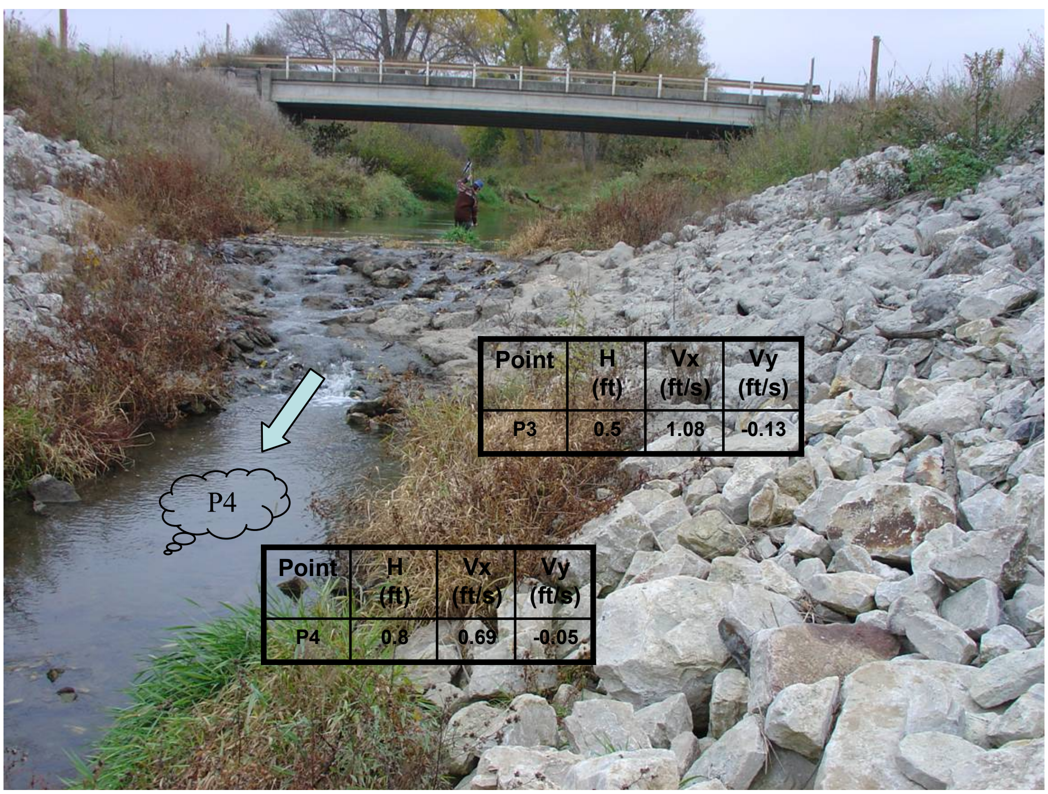


Figure 28c. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy
P2	0.4	0.71	-0.36

Figure 28d. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P3	0.5	1.08	-0.13

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P4	0.8	0.69	-0.05

Figure 28e. Flowtracker measurements

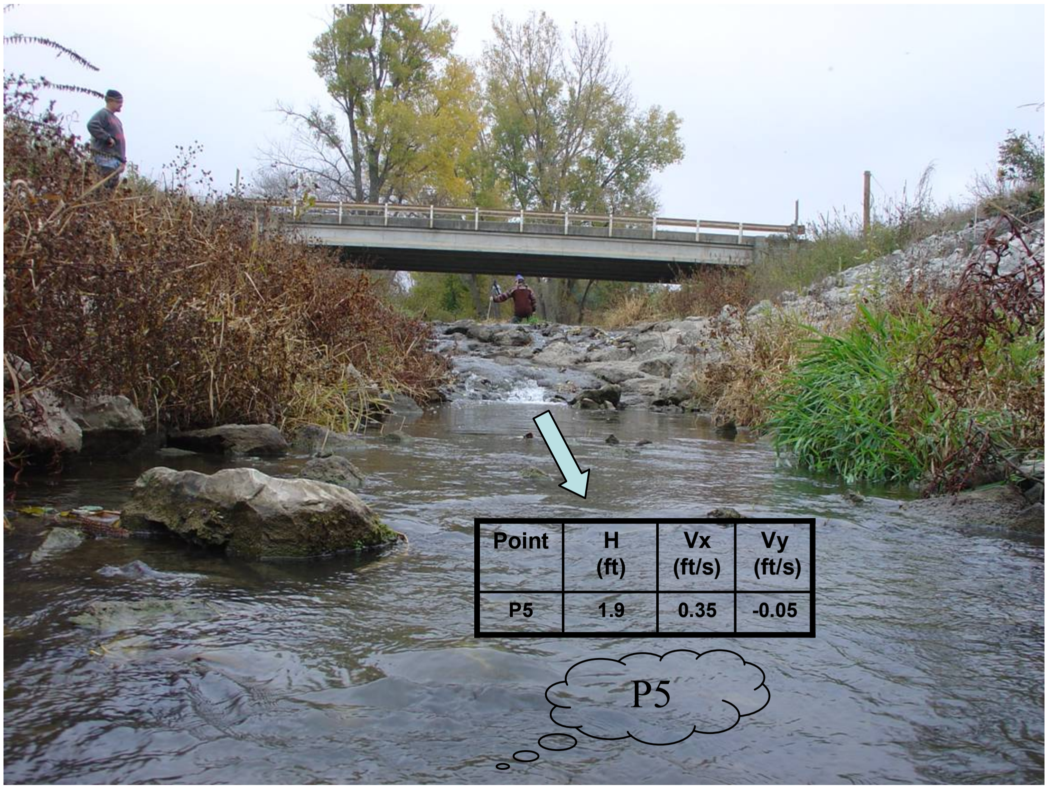


Figure 28f. Flowtracker measurements

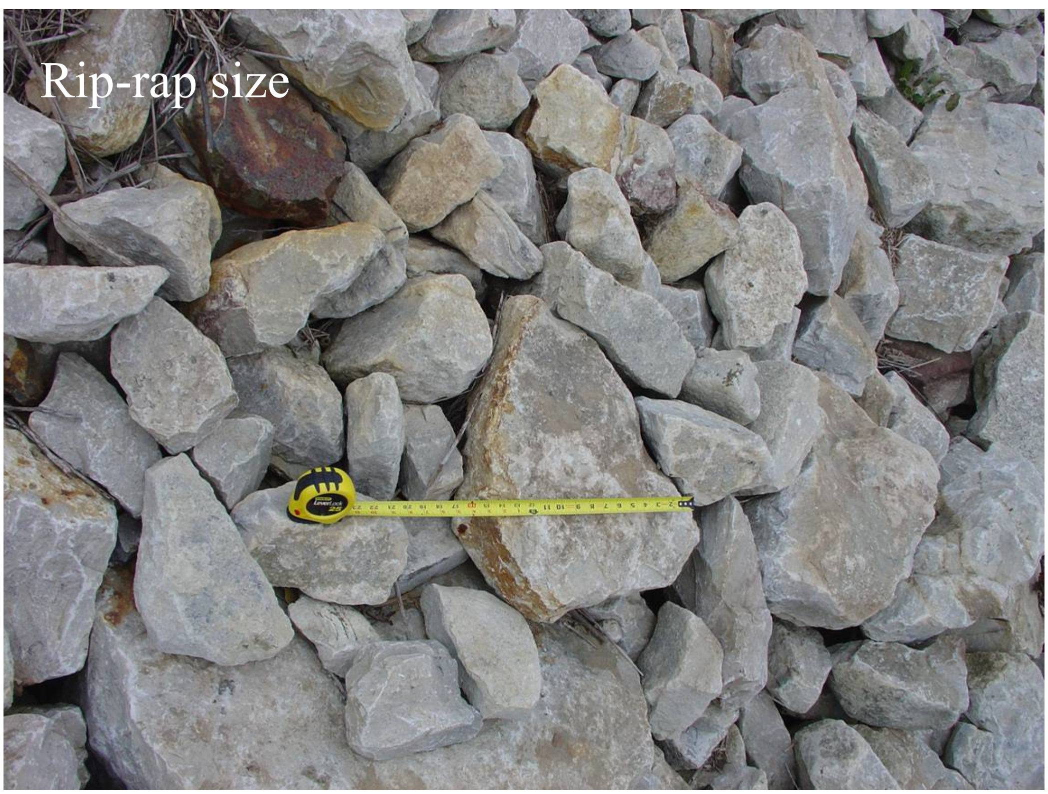


Figure 28g. Riprap size

Figure 29a. Description of site 01-10

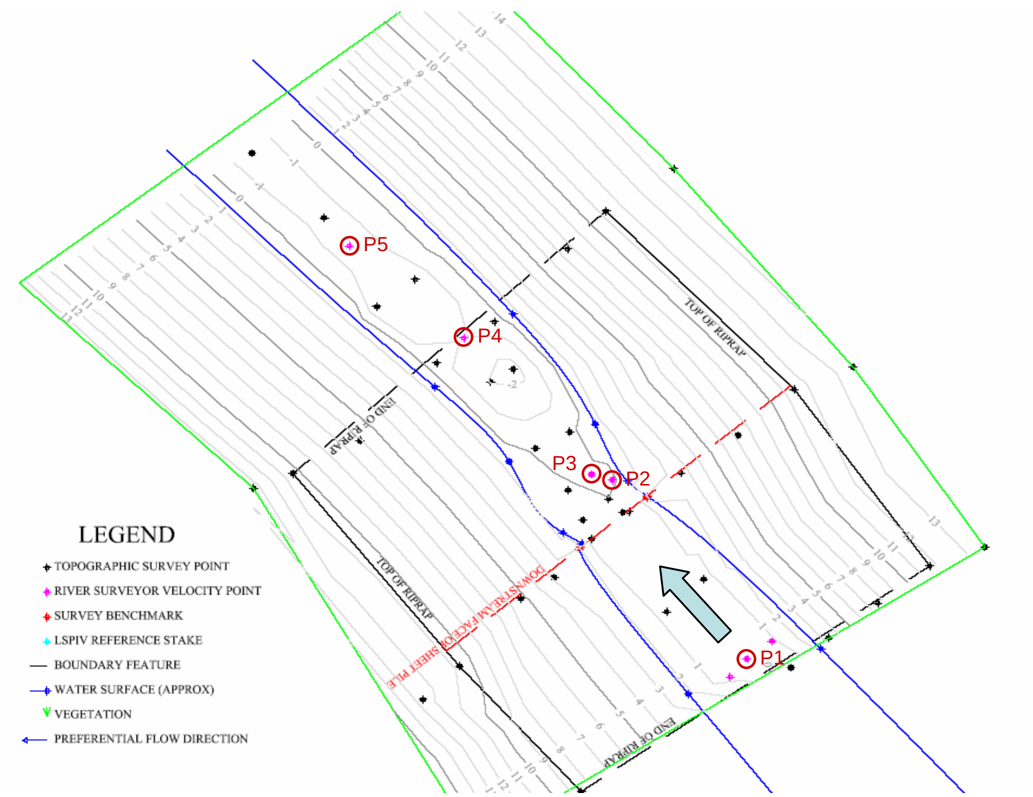


Figure 29b. Topographic plot

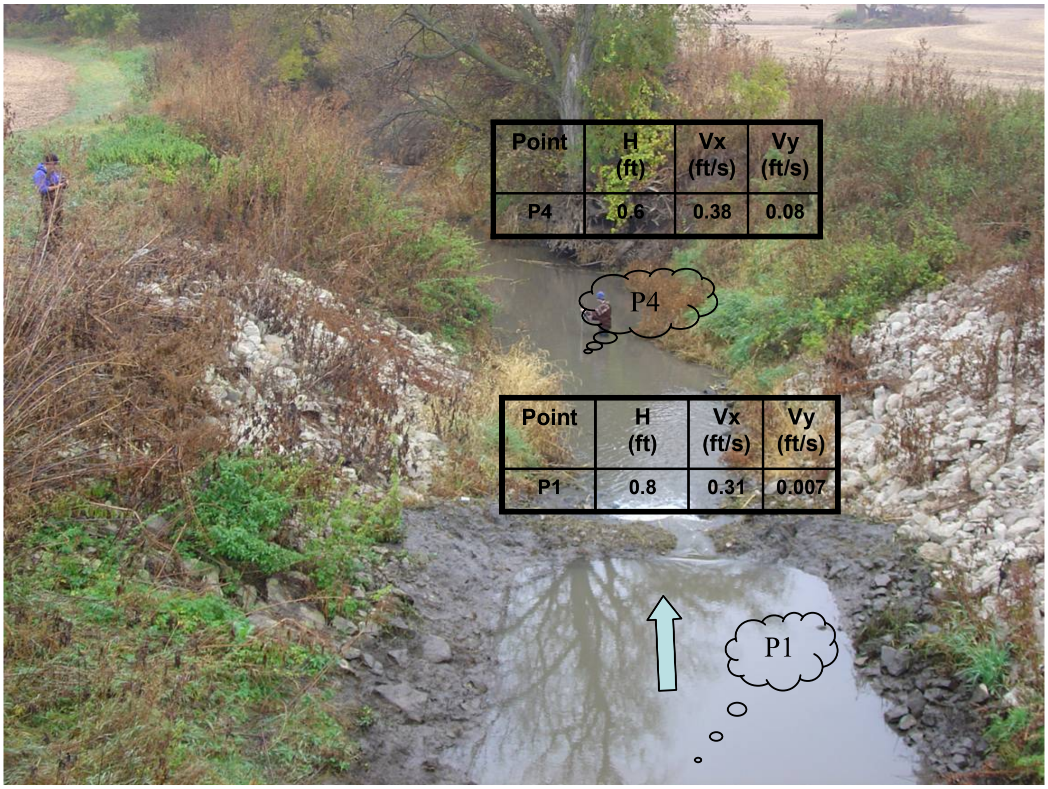


Figure 29c. Flowtracker measurements

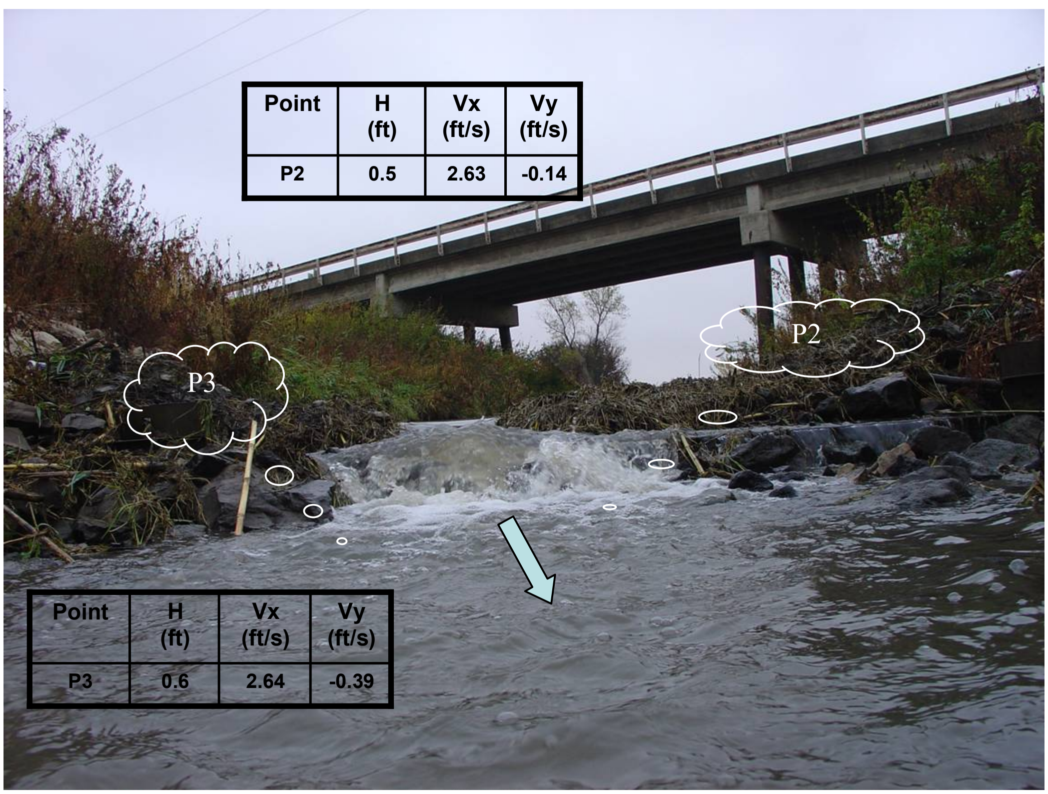
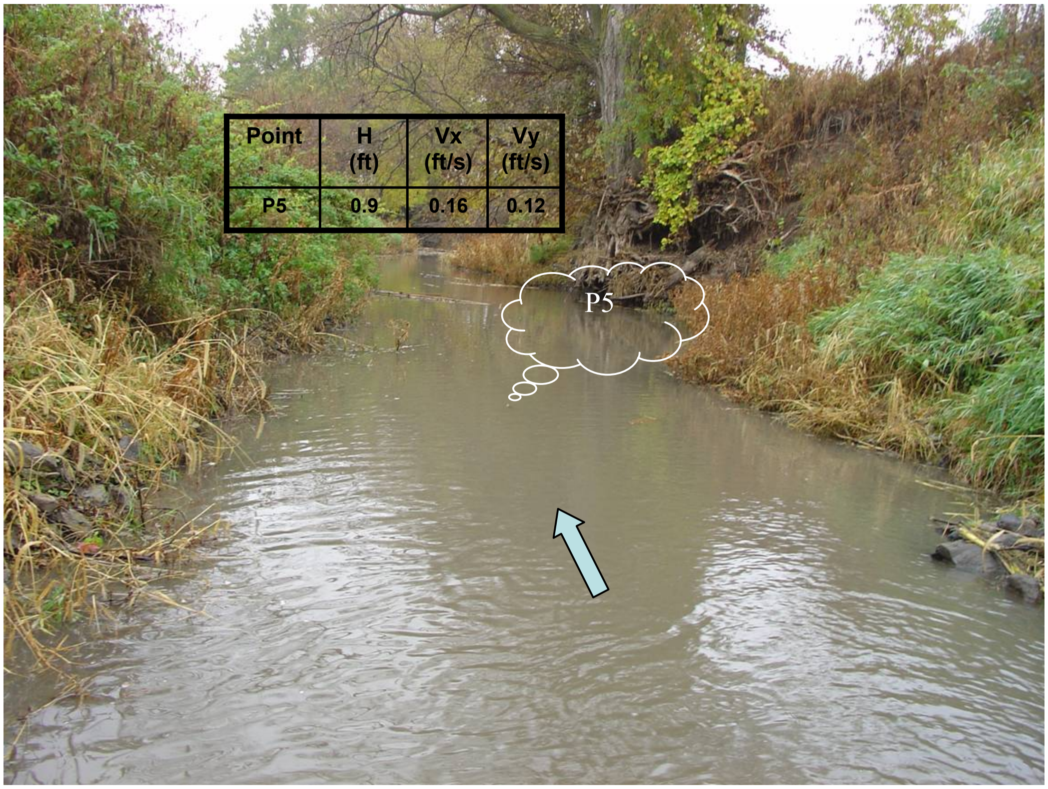


Figure 29d. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P5	0.9	0.16	0.12

Figure 29e. Flowtracker measurements

Figure 29f. Riprap size

Figure 29g. Riprap size

Figure 29h. General picture

Figure 29i. General picture

Figure 29j. General picture

Figure 30a. Description of site 00-21

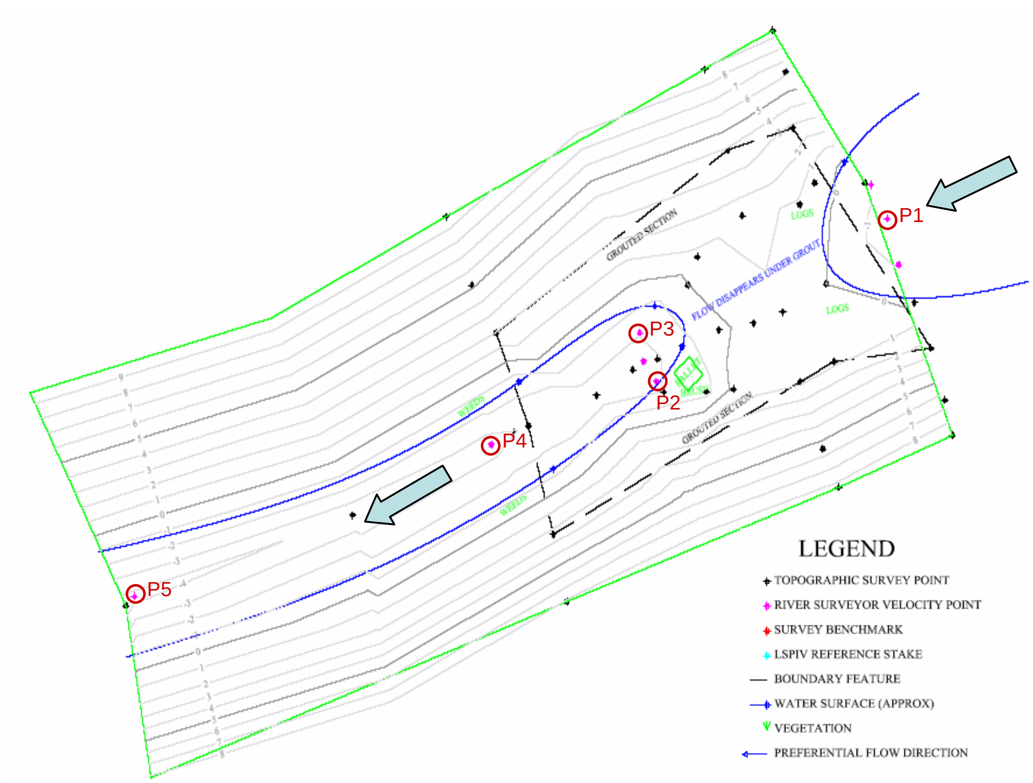


Figure 30b. Topographic plot

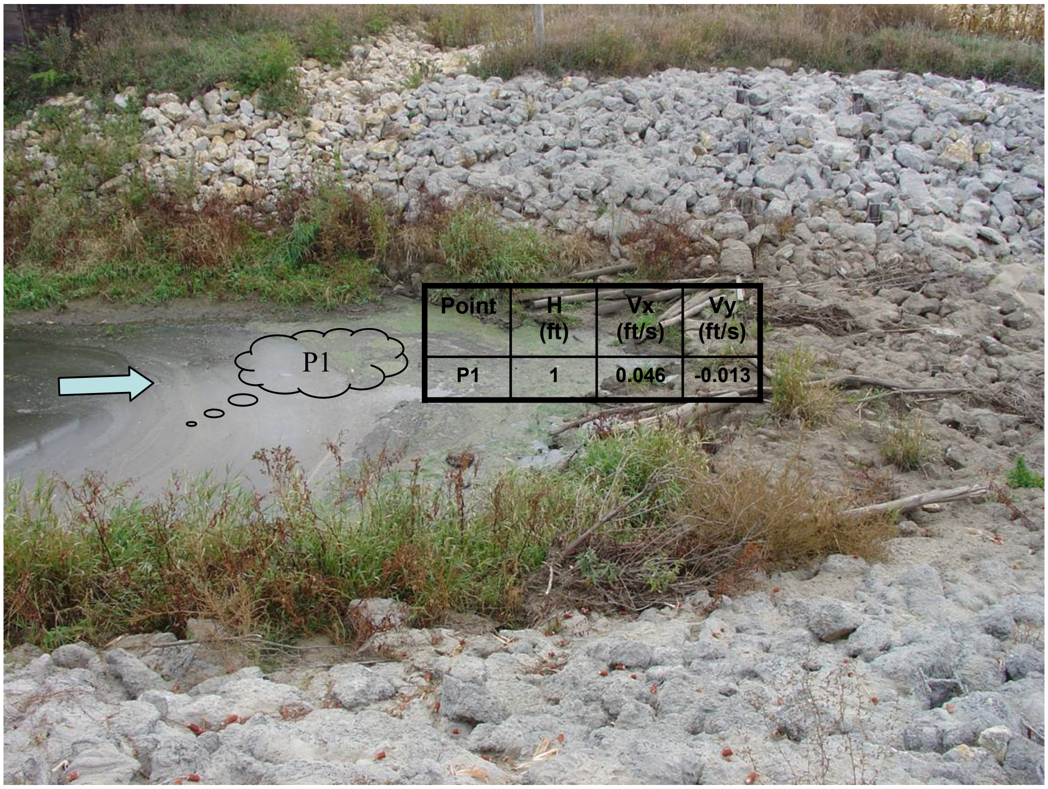


Figure 30c. Flowtracker measurements

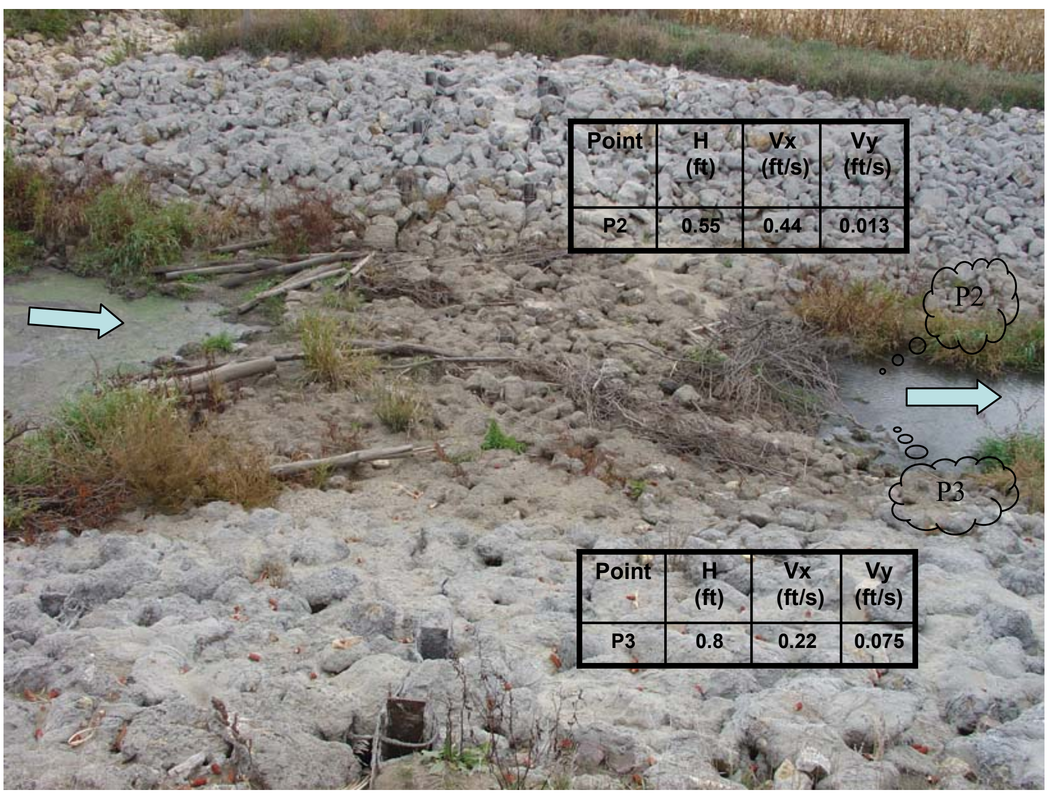


Figure 30d. Flowtracker measurements

Figure 30e. Flowtracker measurements

Figure 30f. Flowtracker measurements

Figure 30g. Riprap size

Figure 30h. Riprap size

Figure 30i. General picture

Figure 31a. Description of site 00-11 and 04-26

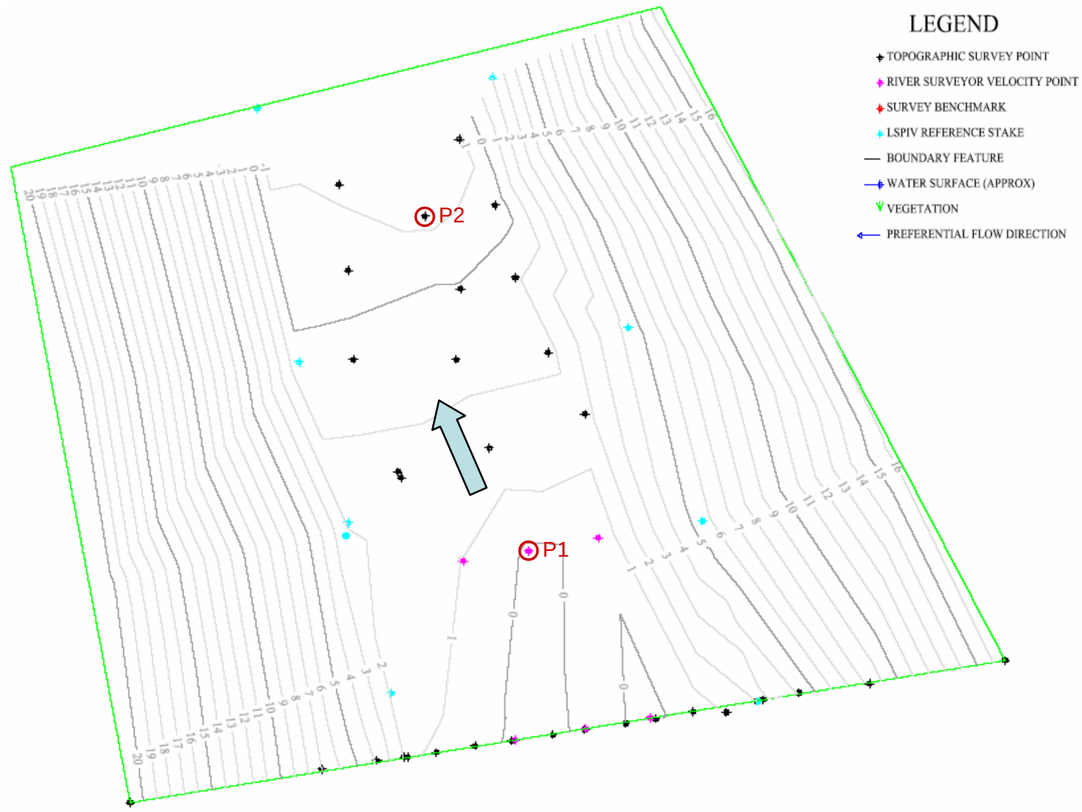


Figure 31b. Topographic plot

Figure 31c. Flowtracker measurements

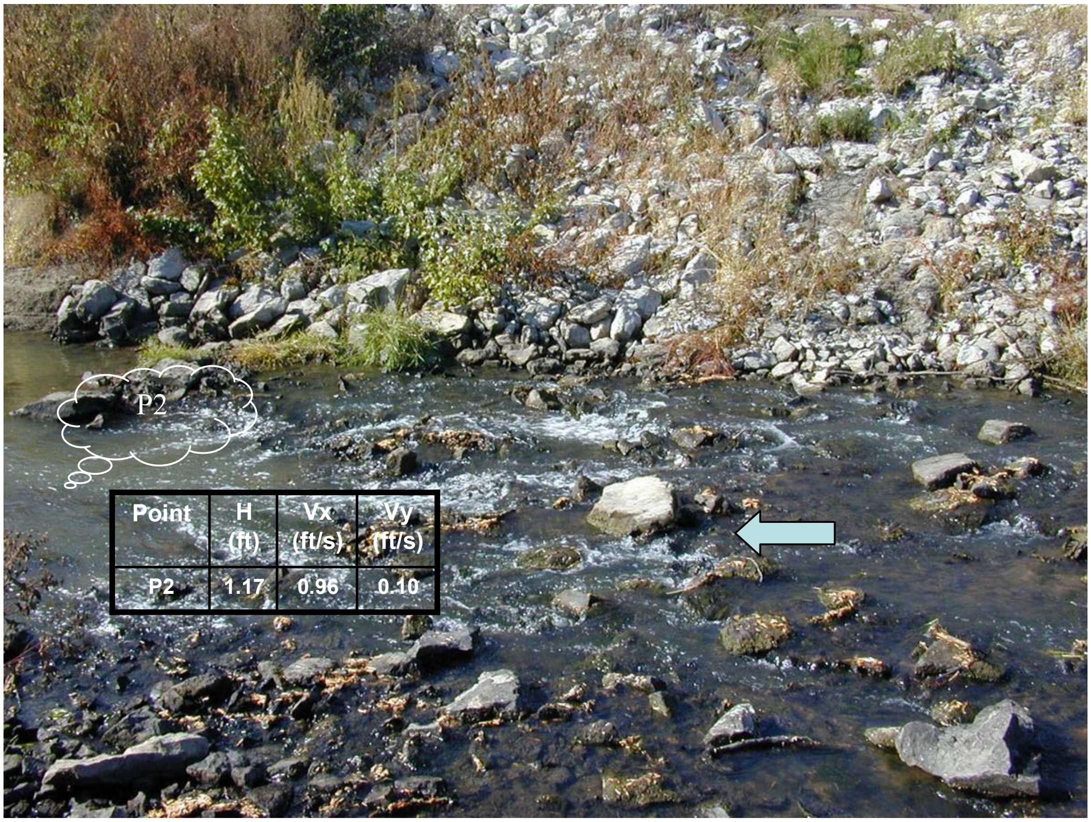


Figure 31d. Flowtracker measurements

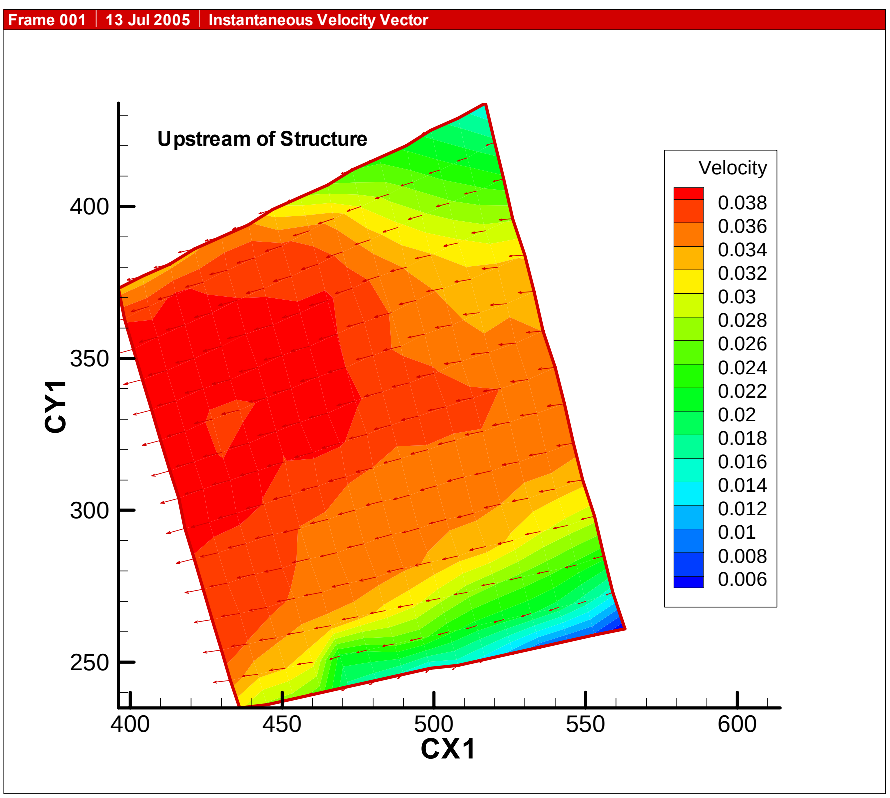


Figure 31e. LSPIV result (upstream)

Figure 32a. Description of site 00-10

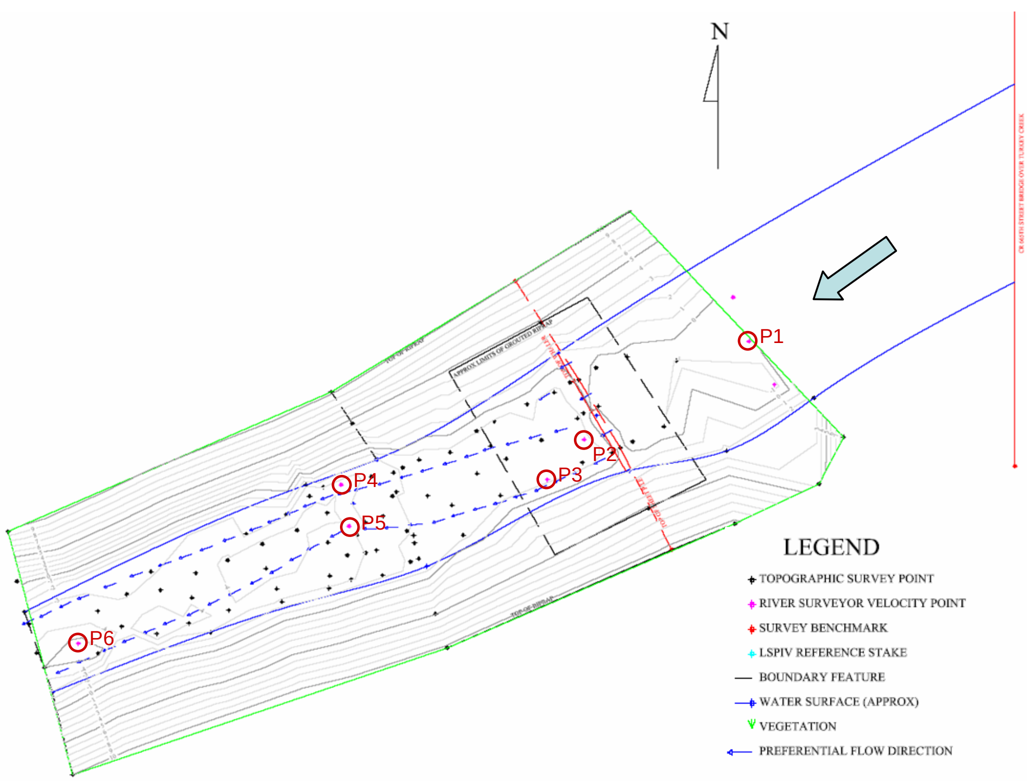


Figure 32b. Topographic plot

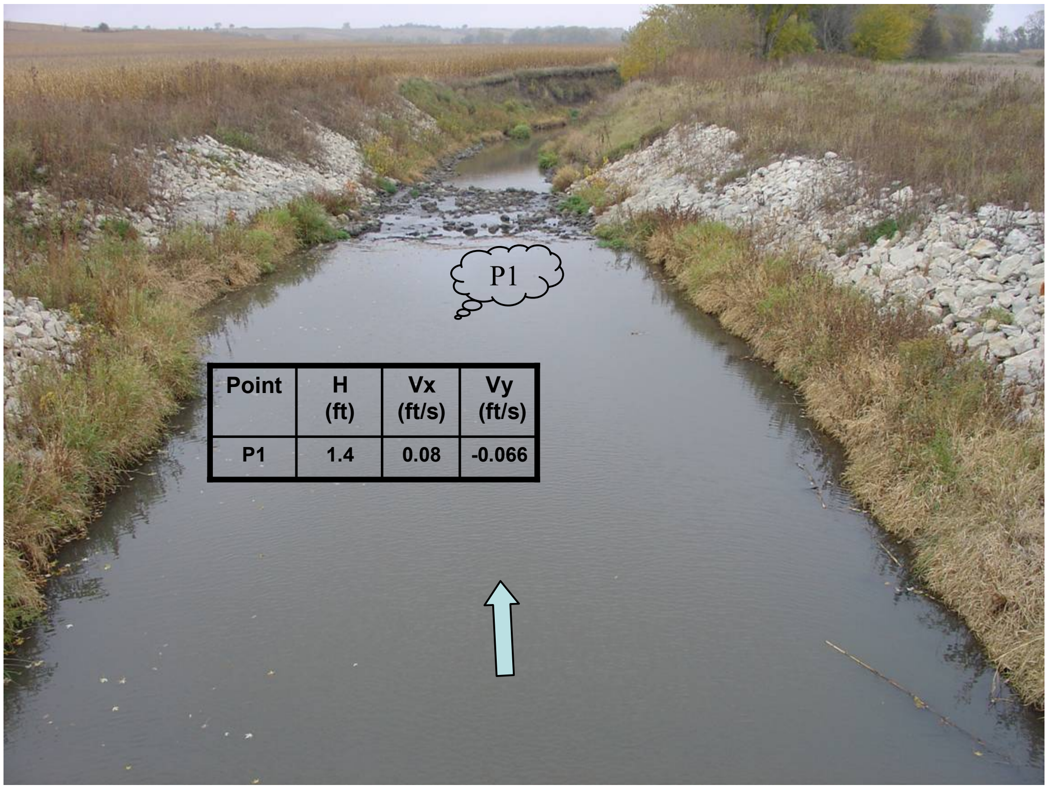


Figure 32c. Flowtracker measurements

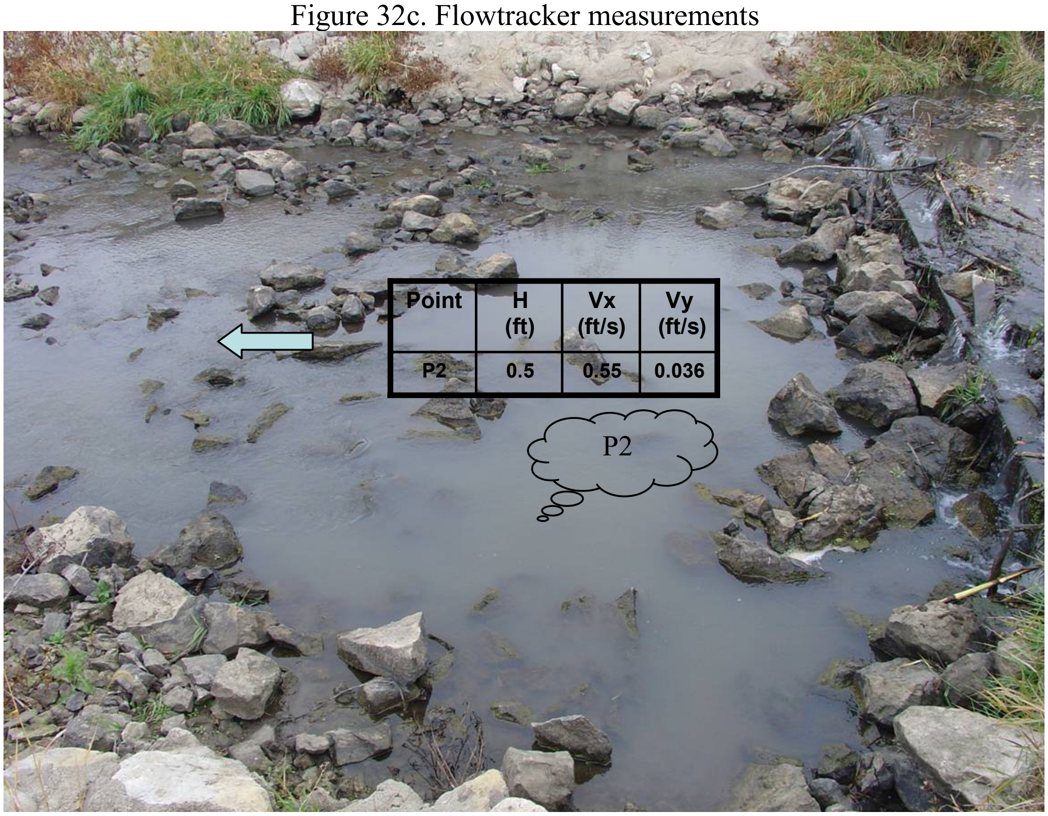


Figure 32d. Flowtracker measurements

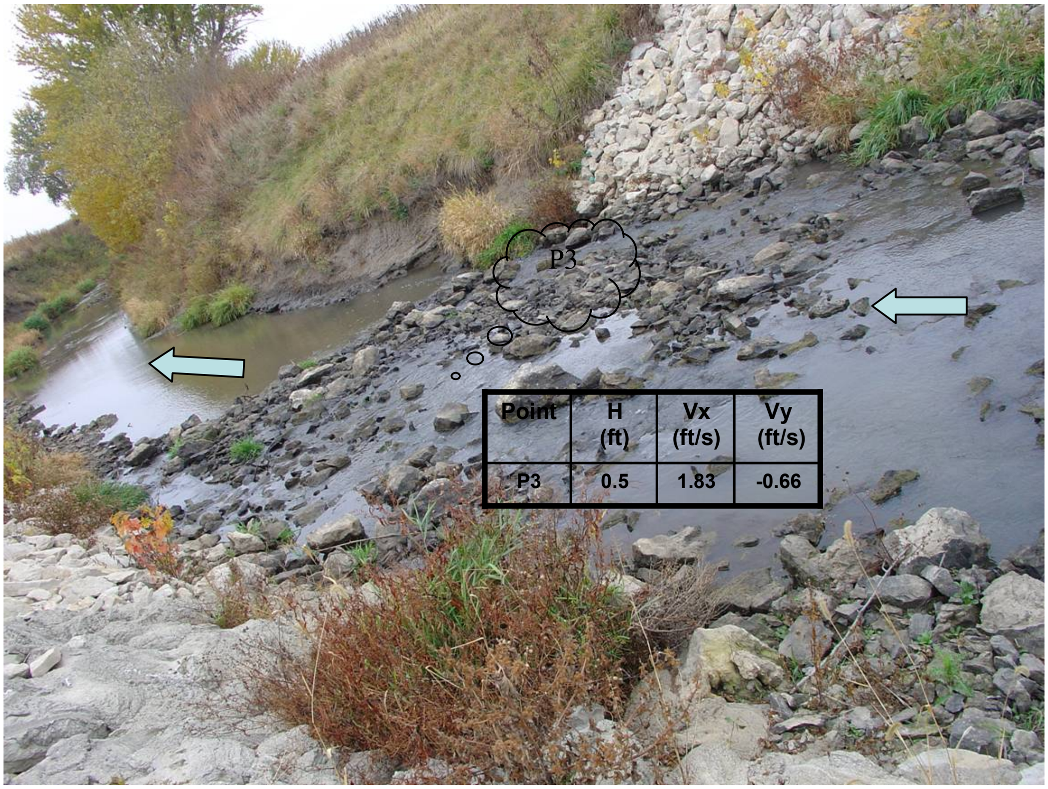


Figure 32e. Flowtracker measurements

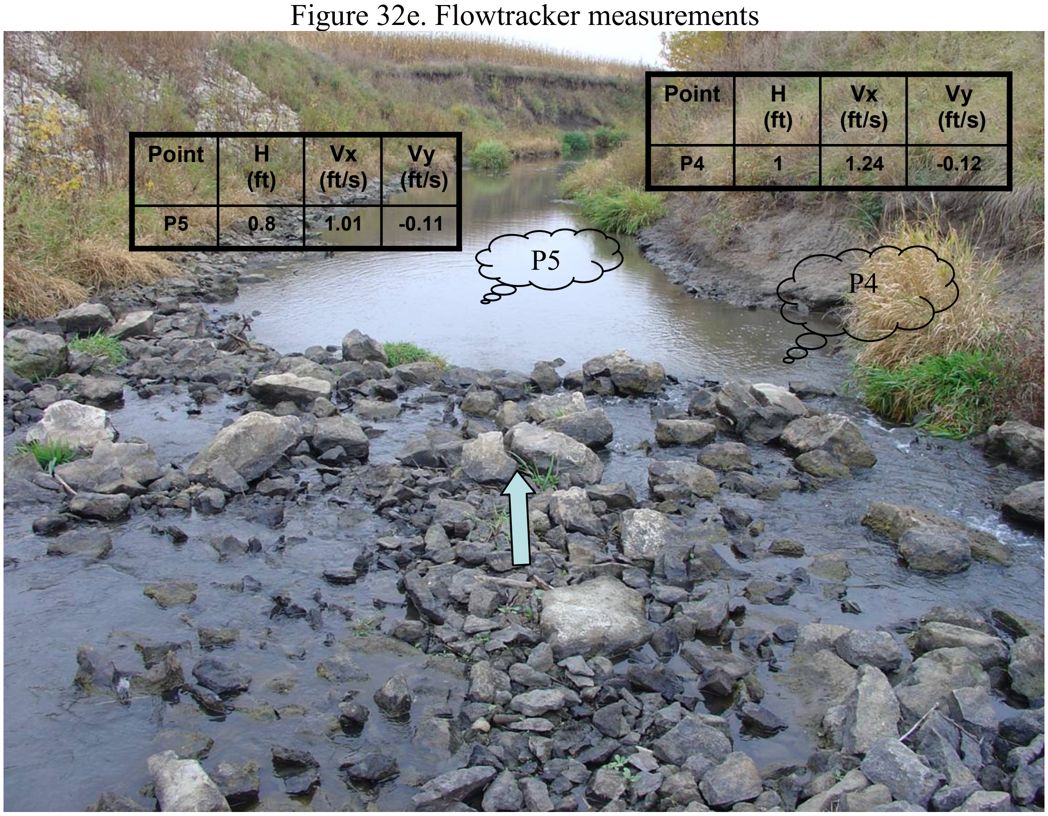


Figure 32f. Flowtracker measurements

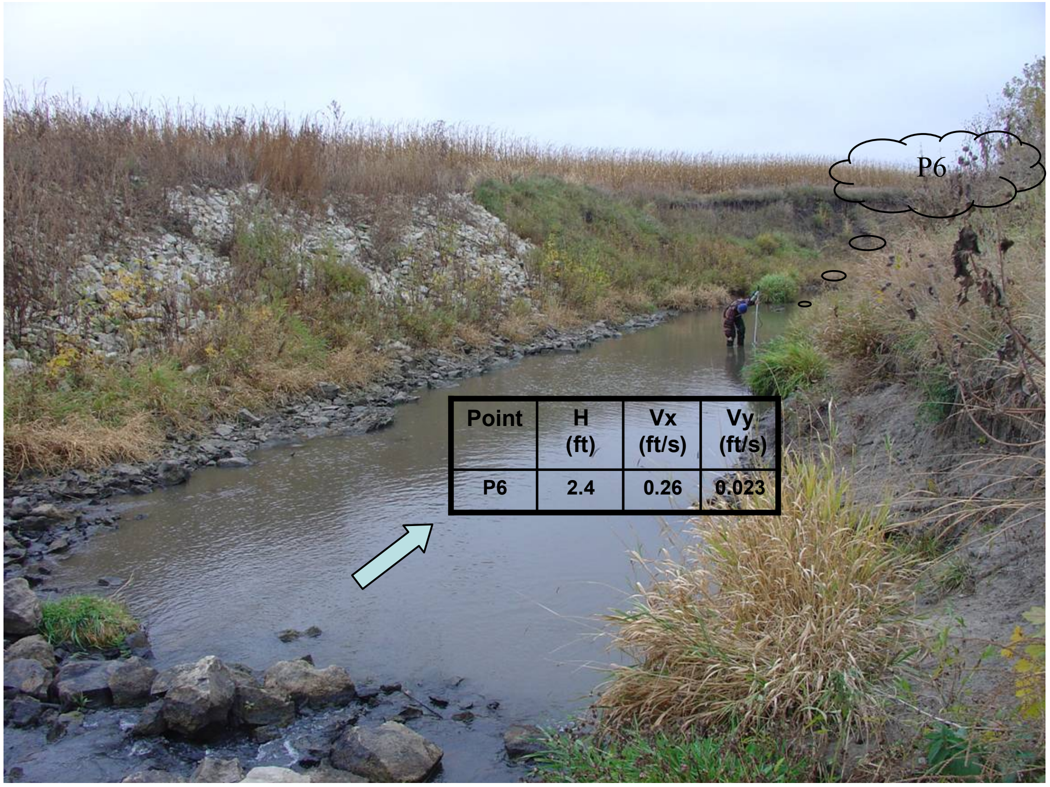


Figure 32g. Flowtracker measurements

Figure 32h. Riprap size

Figure 32i. Riprap size

Figure 32j. Riprap size

Figure 32k. General picture

Figure 32l. General picture

Figure 33a. Description of site 69-6114-0-5

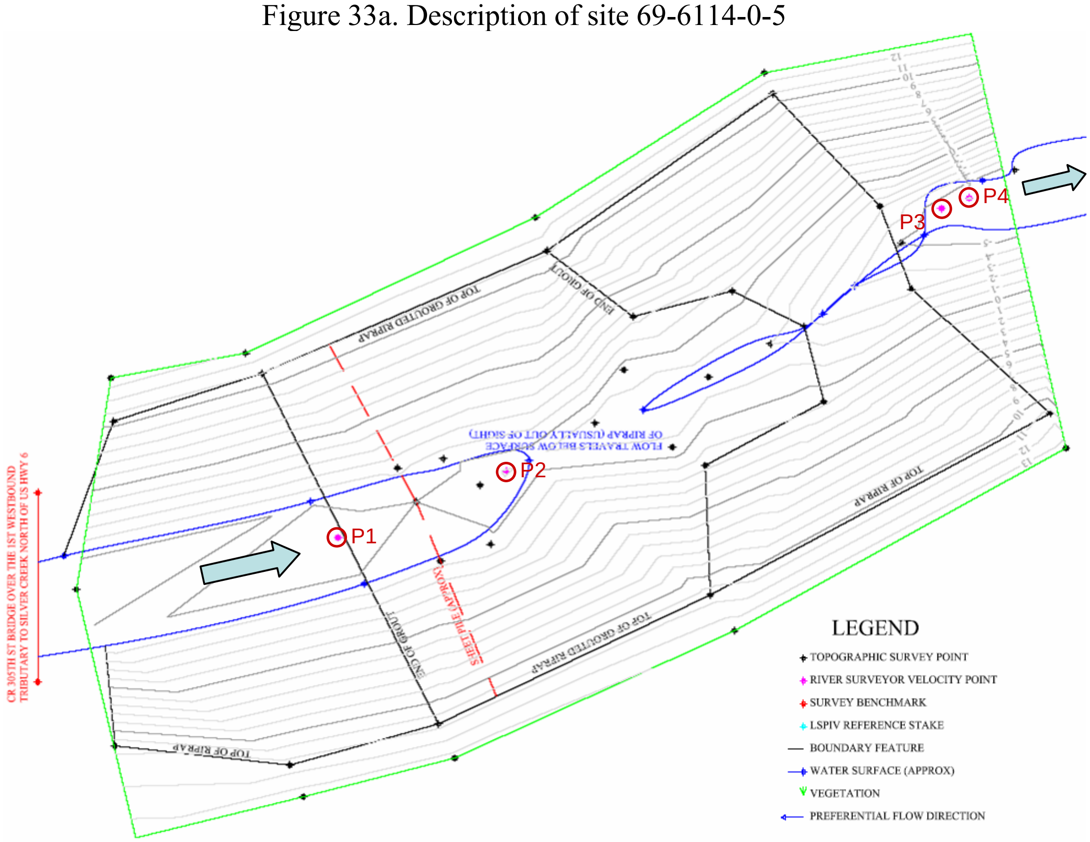


Figure 33b. Topographic plot

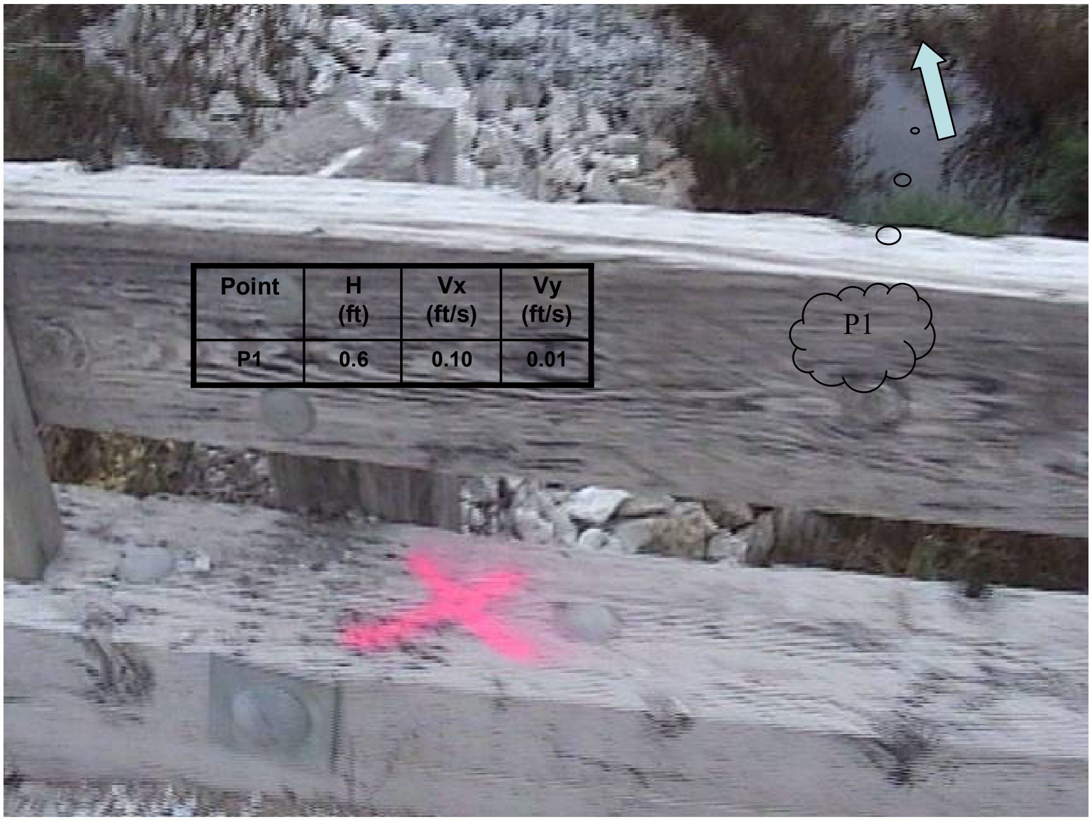


Figure 33c. Flowtracker measurements

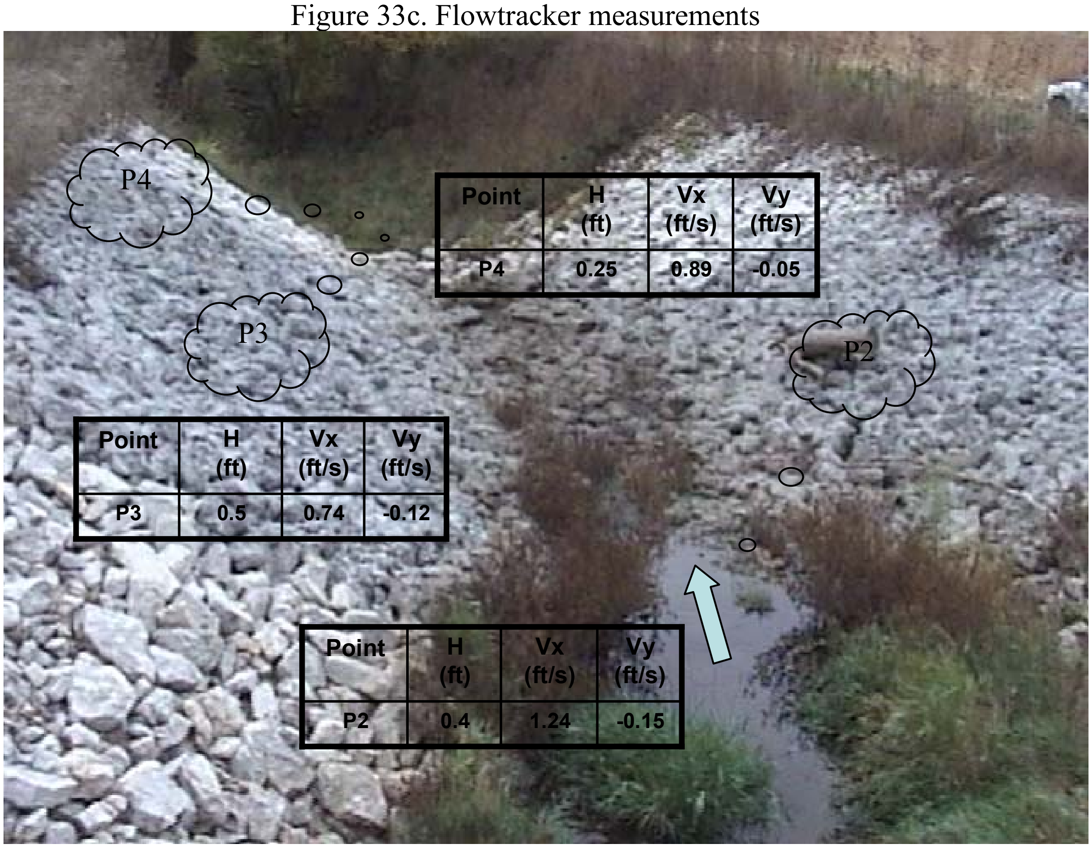


Figure 33d. Flowtracker measurements

Figure 33e. Riprap size

Figure 33f. Riprap size

Figure 33g. General picture

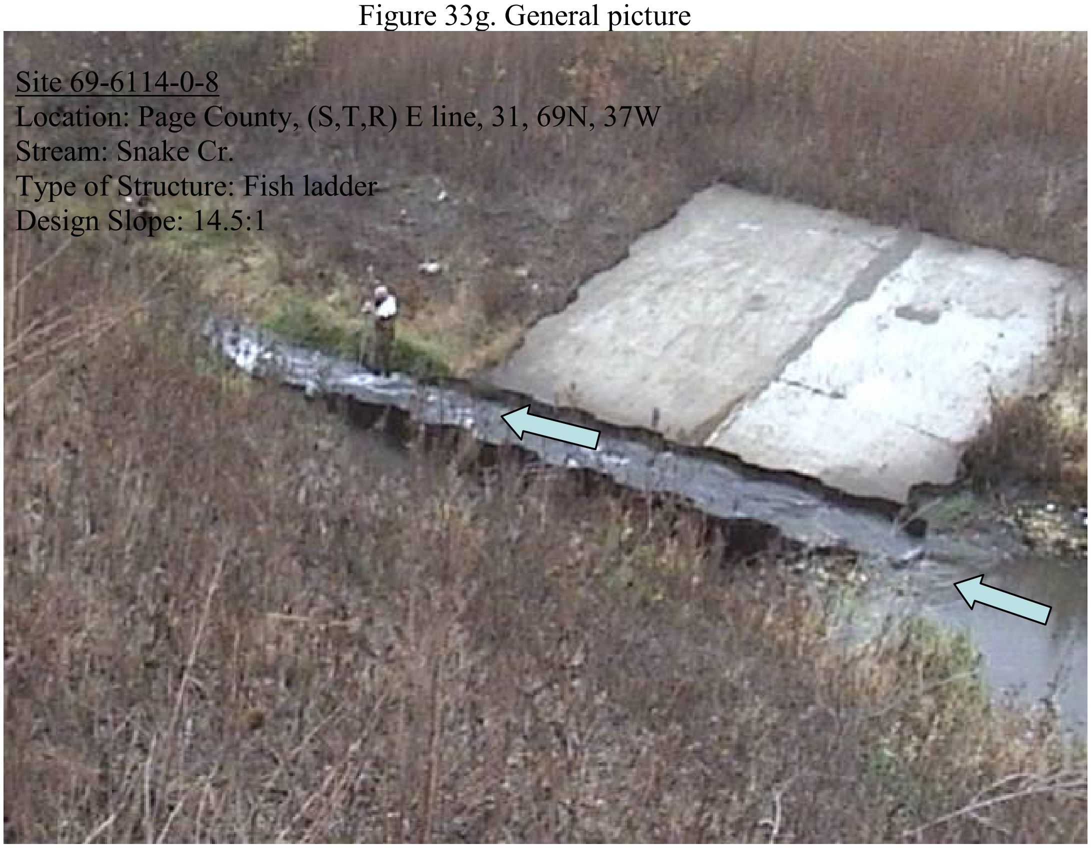


Figure 34a. Description of site 69-6114-0-8

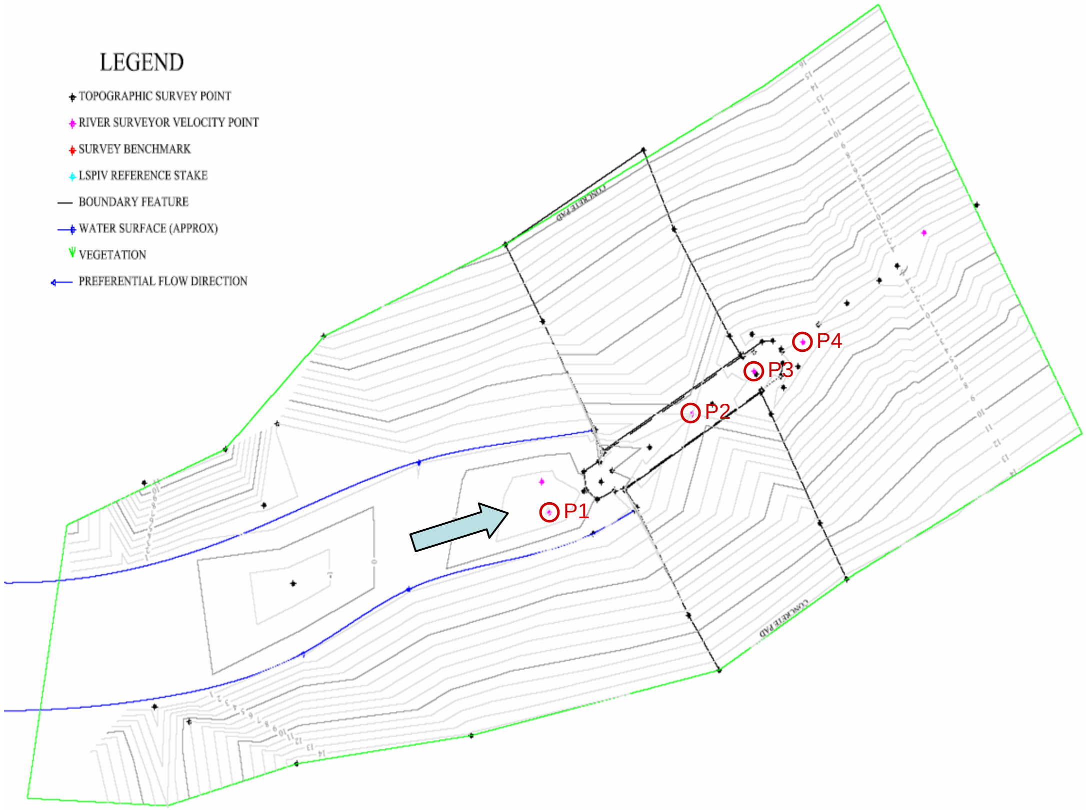
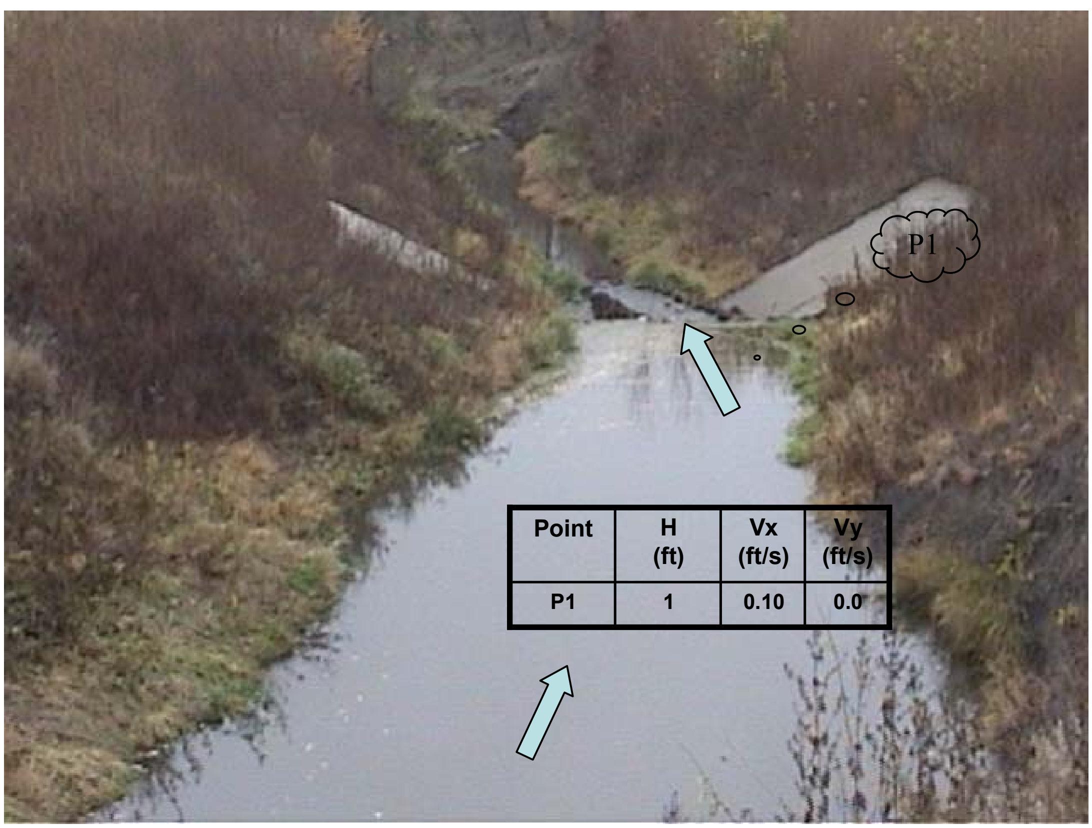


Figure 34b. Topographic plot



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P1	1	0.10	0.0

Figure 34c. Flowtracker measurements

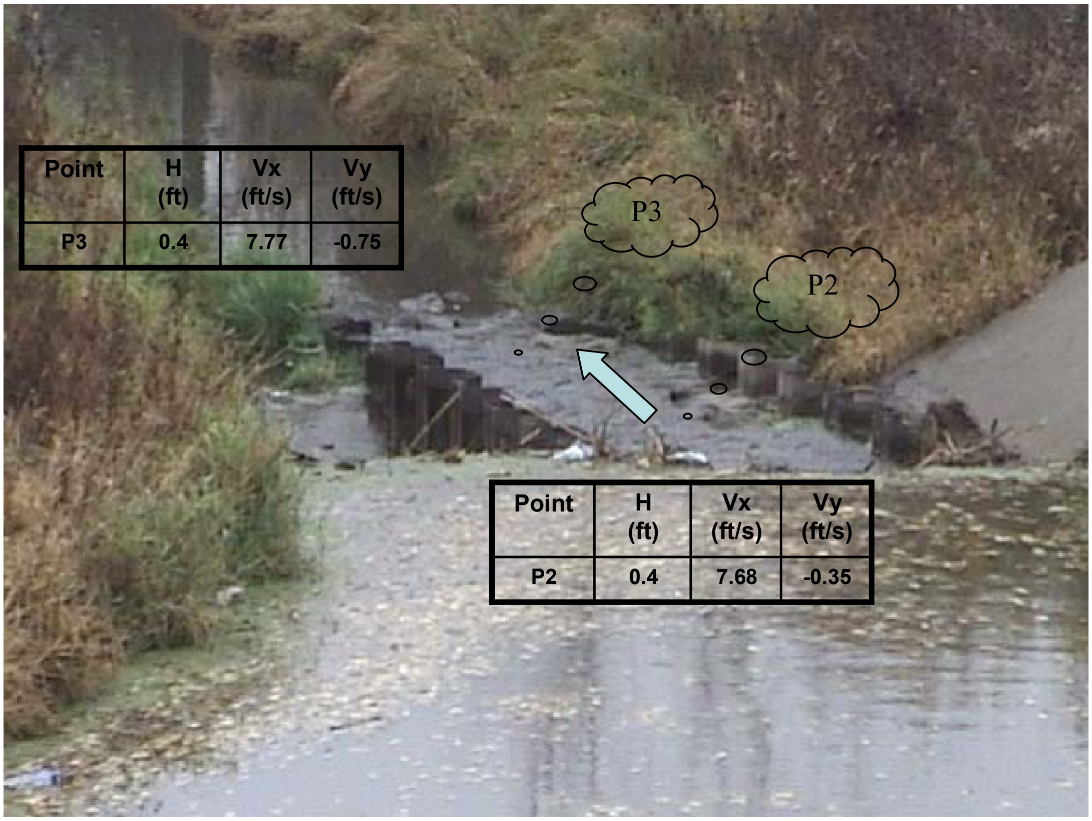


Figure 34d. Flowtracker measurements

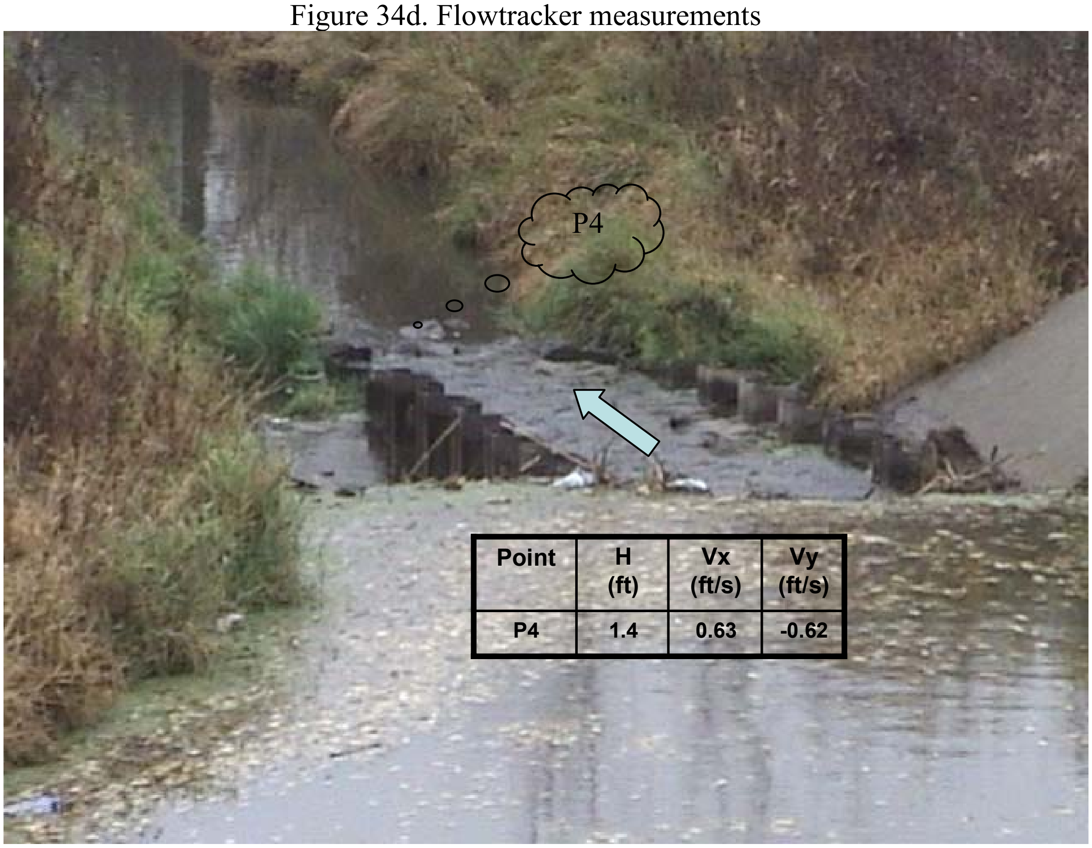


Figure 34e. Flowtracker measurements

Figure 35a. Description of site 00-24

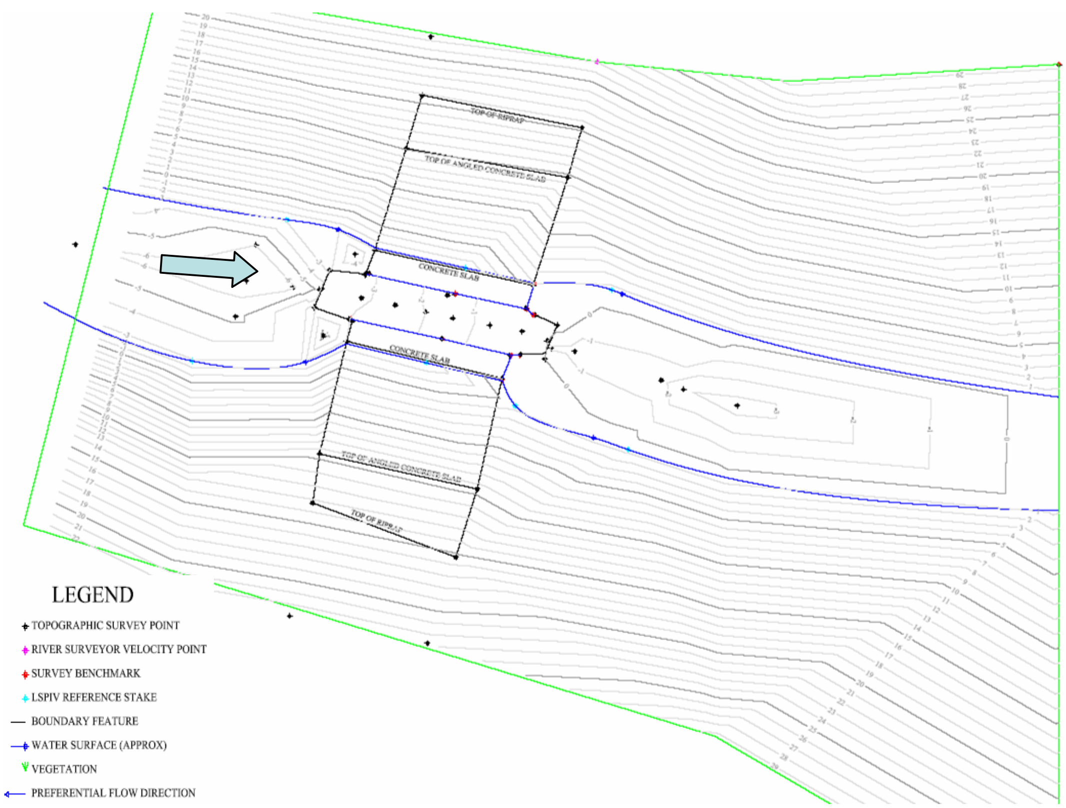


Figure 35b. Topographic plot

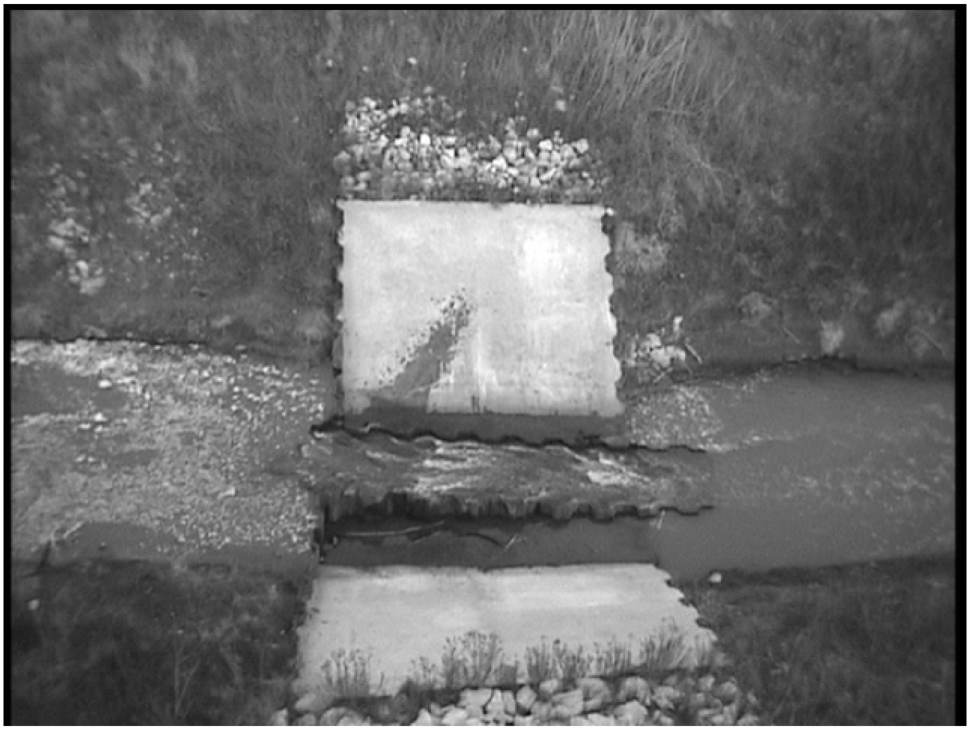


Figure 35c. LSPIV image

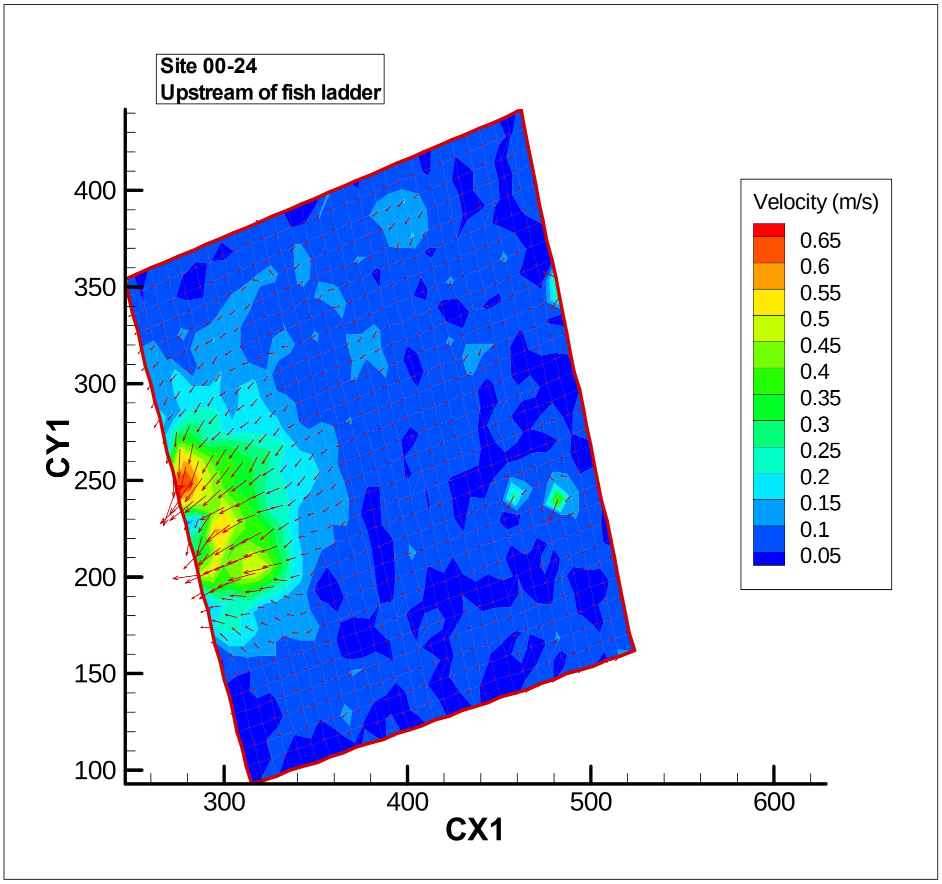


Figure 35d. LSPIV result (upstream)

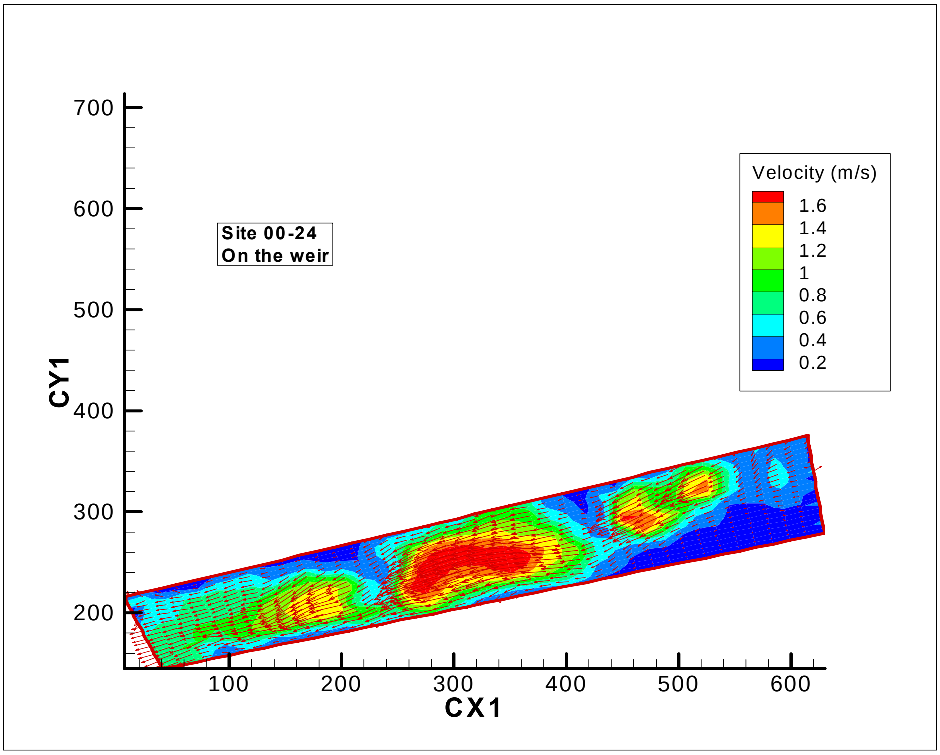


Figure 35e. LSPIV result (atop)

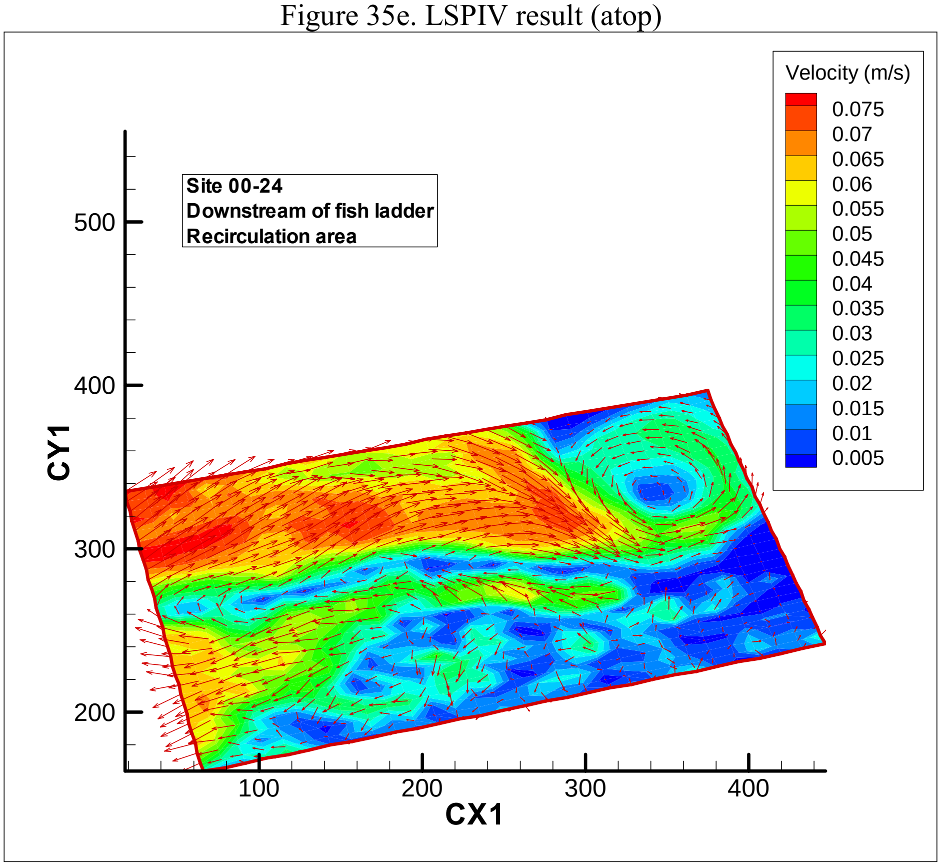


Figure 35f. LSPIV result (downstream)

Figure 35g. Riprap size

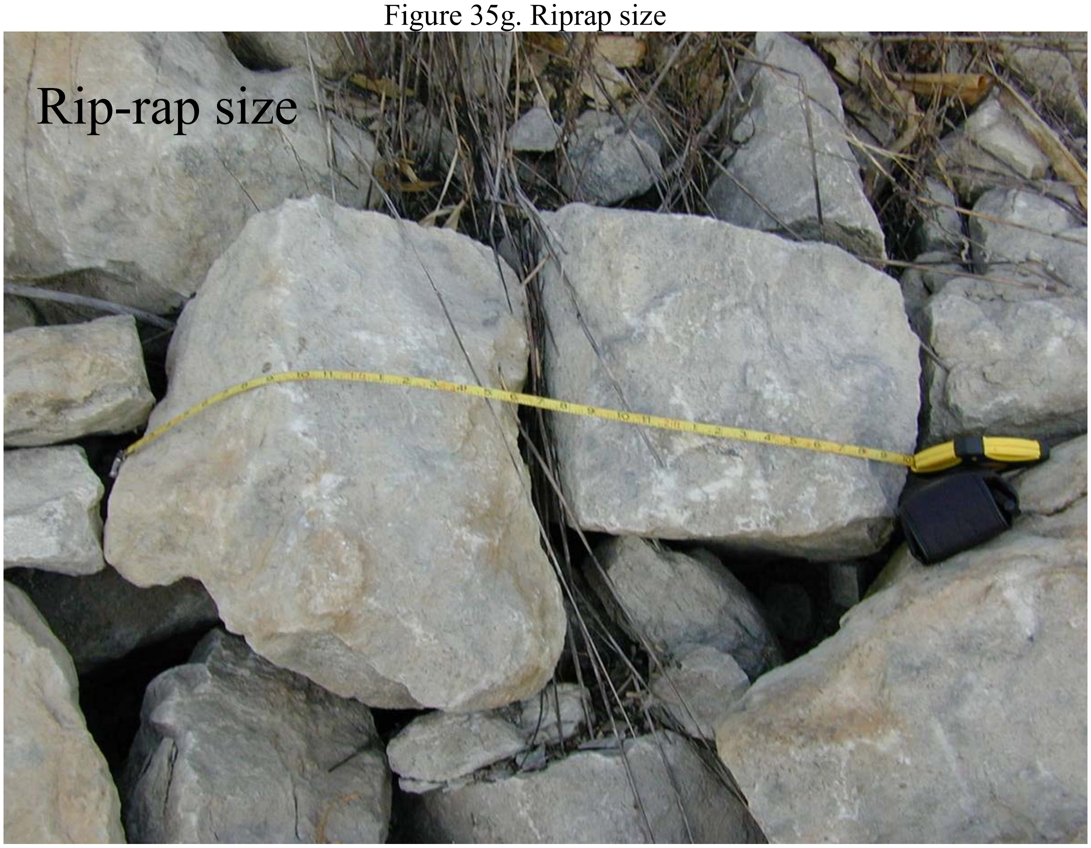


Figure 35h. Riprap size

Figure 35i. Riprap size

Figure 35j. General picture


Figure 35k. General picture


Figure 35l. General picture

Figure 36a. Description of site 03-1-F

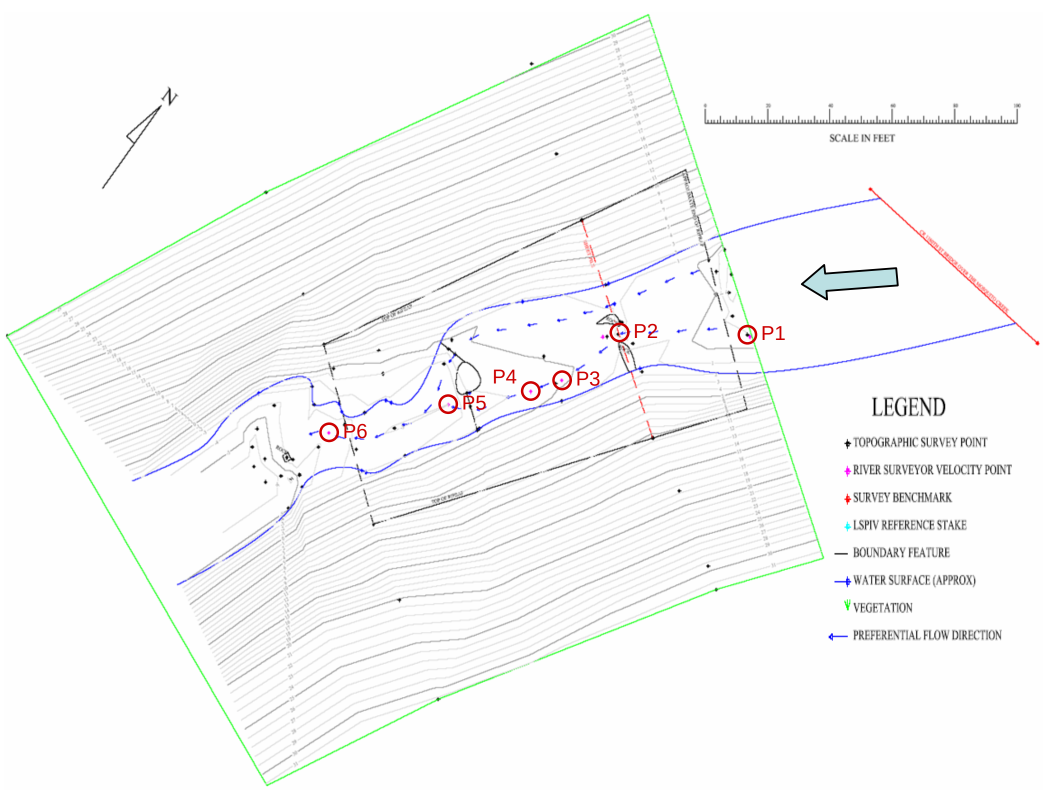


Figure 36b. Topographic plot

Figure 36c. Flowtracker measurements

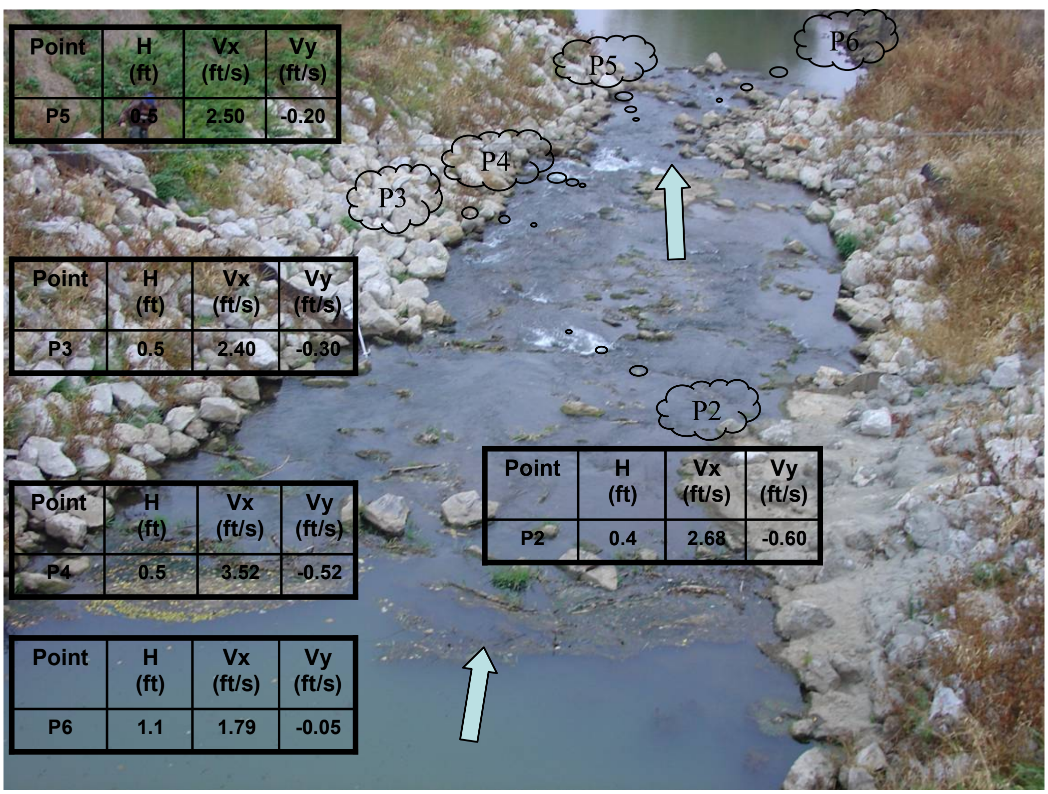


Figure 36d. Flowtracker measurements

Figure 36e. Riprap size

Figure 36f. Riprap size

Figure 36g. General picture


Figure 36h. General picture

Figure 36i. General picture

Figure 37a. Description of site 00-5 (1)

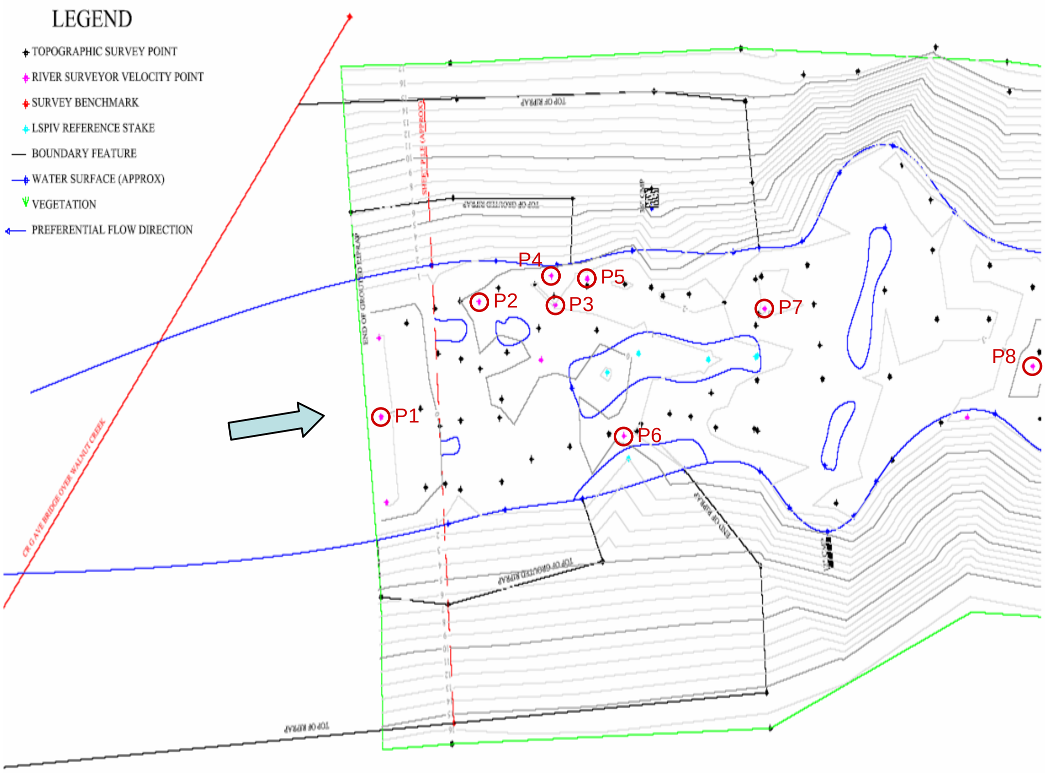


Figure 37b. Topographic plot

Left side of the river (downstream part)

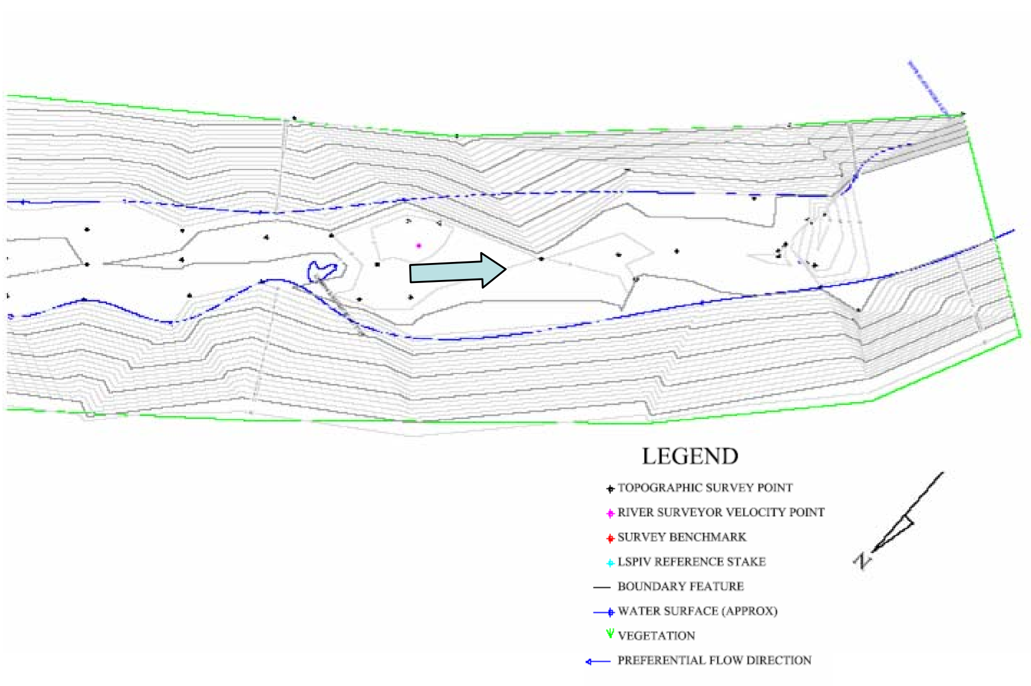


Figure 37c. Topographic plot

Figure 37d. Flowtracker measurements

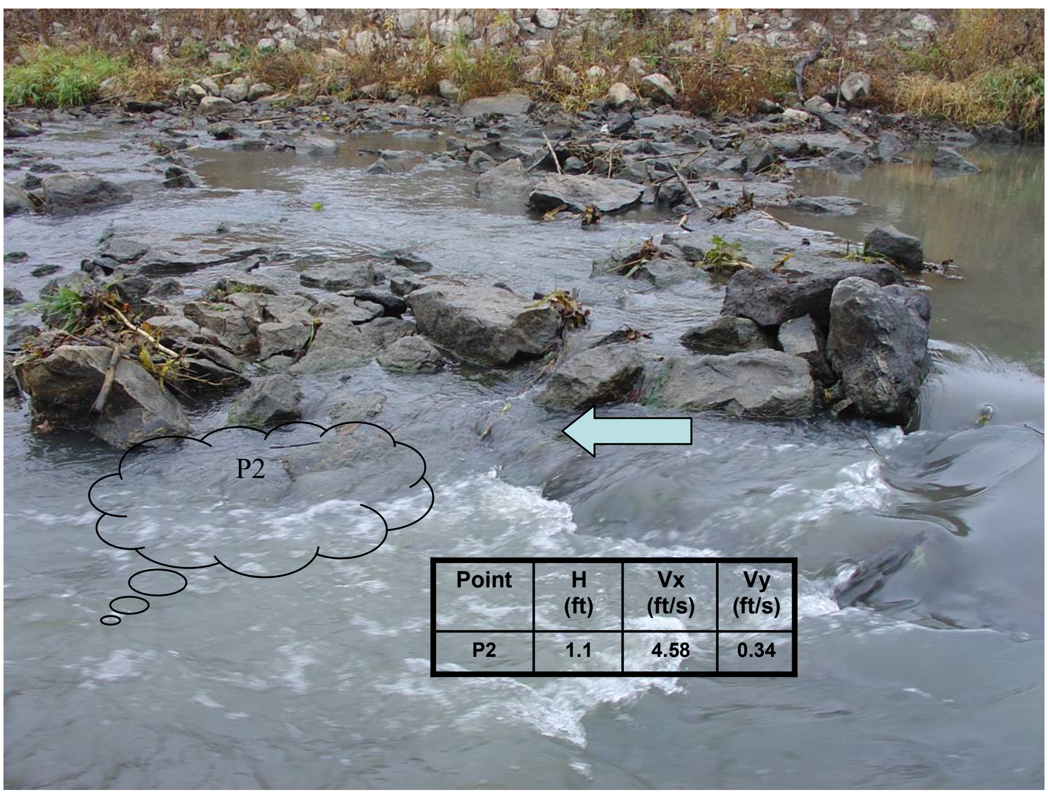


Figure 37e. Flowtracker measurements

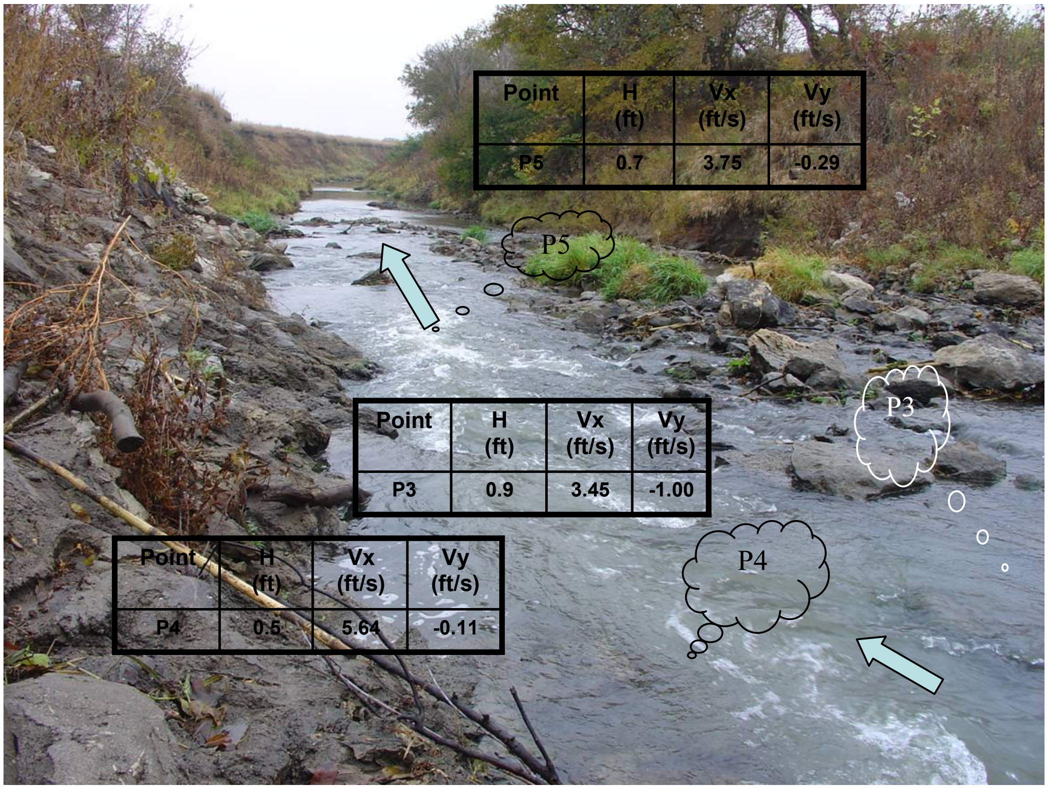


Figure 37f. Flowtracker measurements

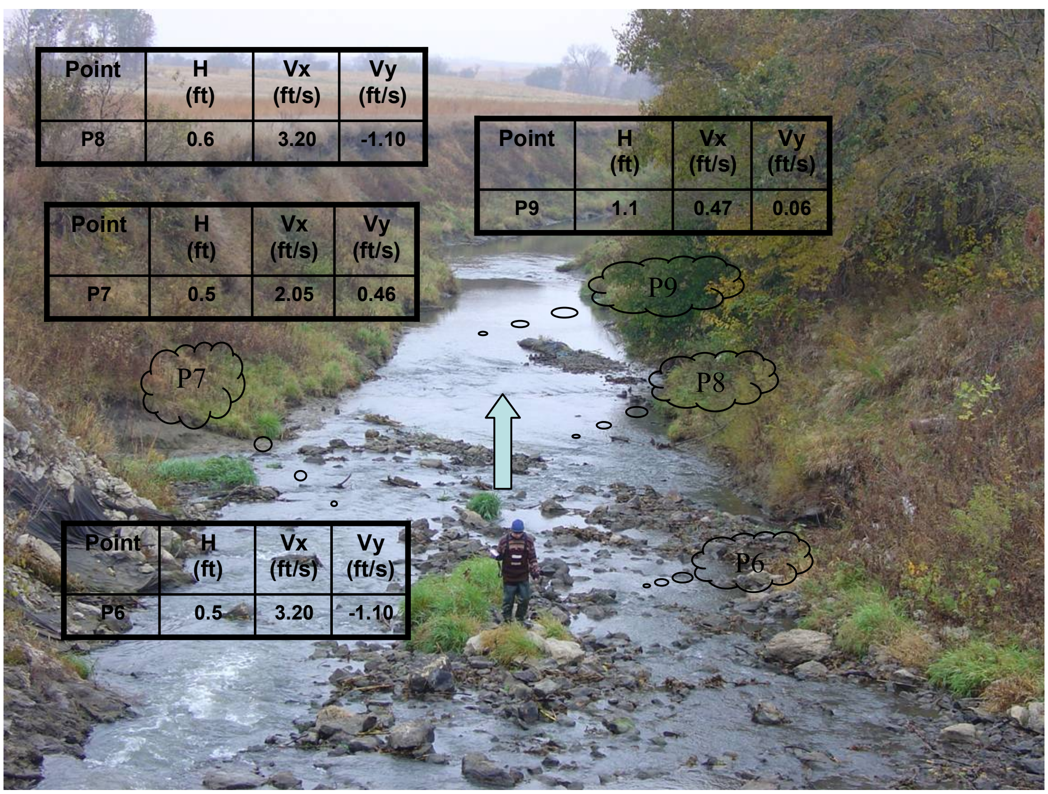


Figure 37g. Flowtracker measurements

Figure 37h. Riprap size

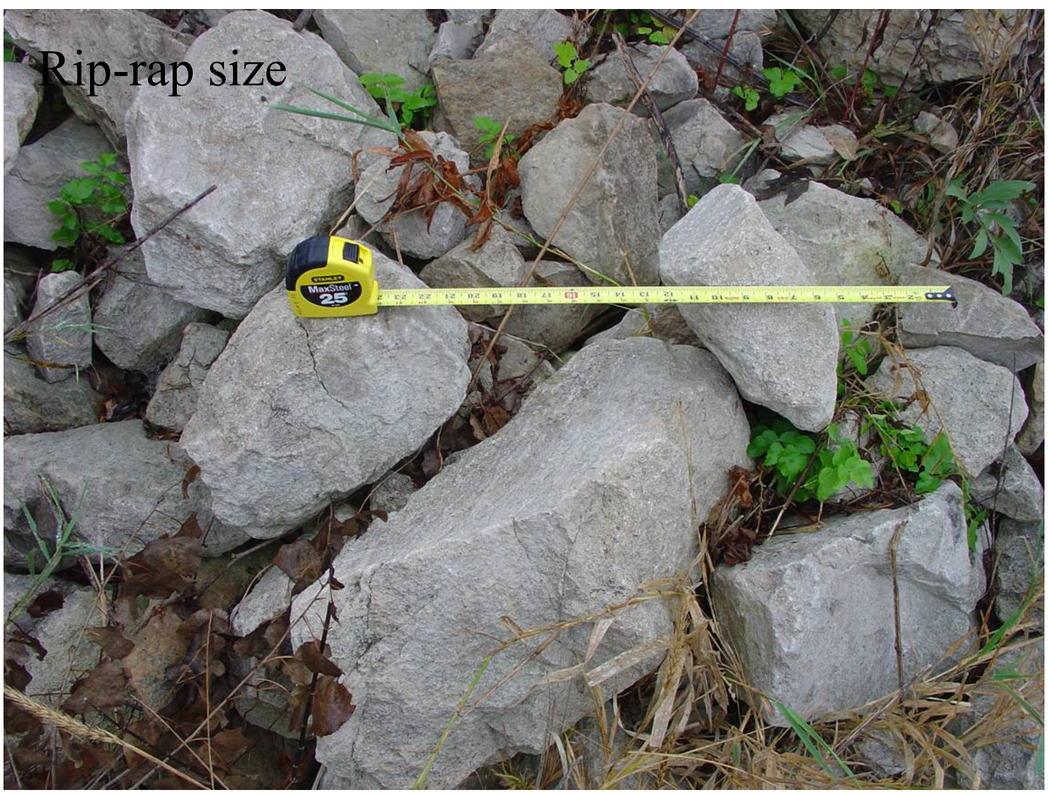


Figure 37i. Riprap size

Figure 37j. General picture


Figure 37k. General picture

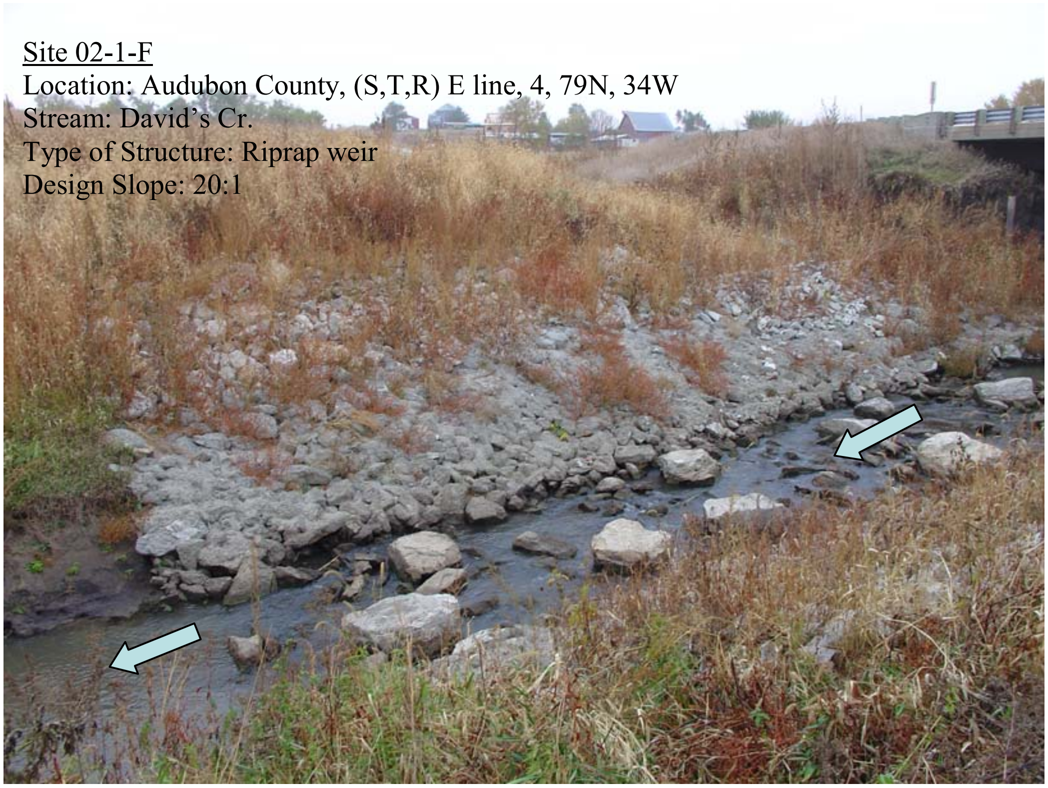


Figure 38a. Description of site 02-1-F

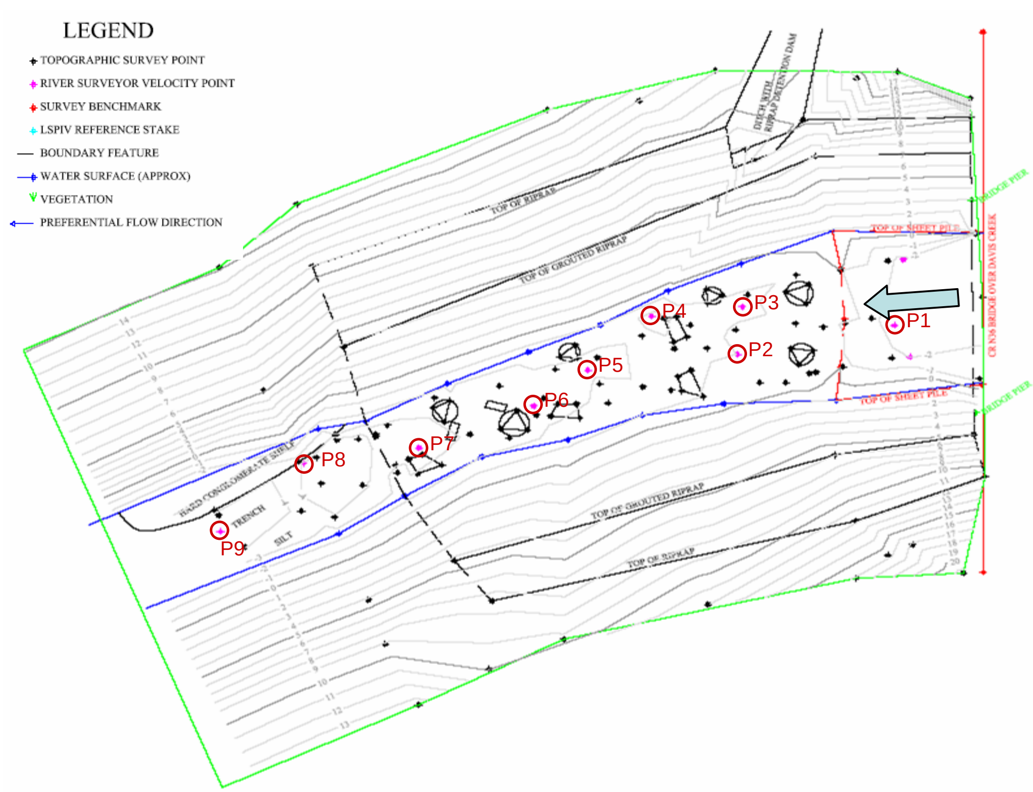


Figure 38b. Topographic plot

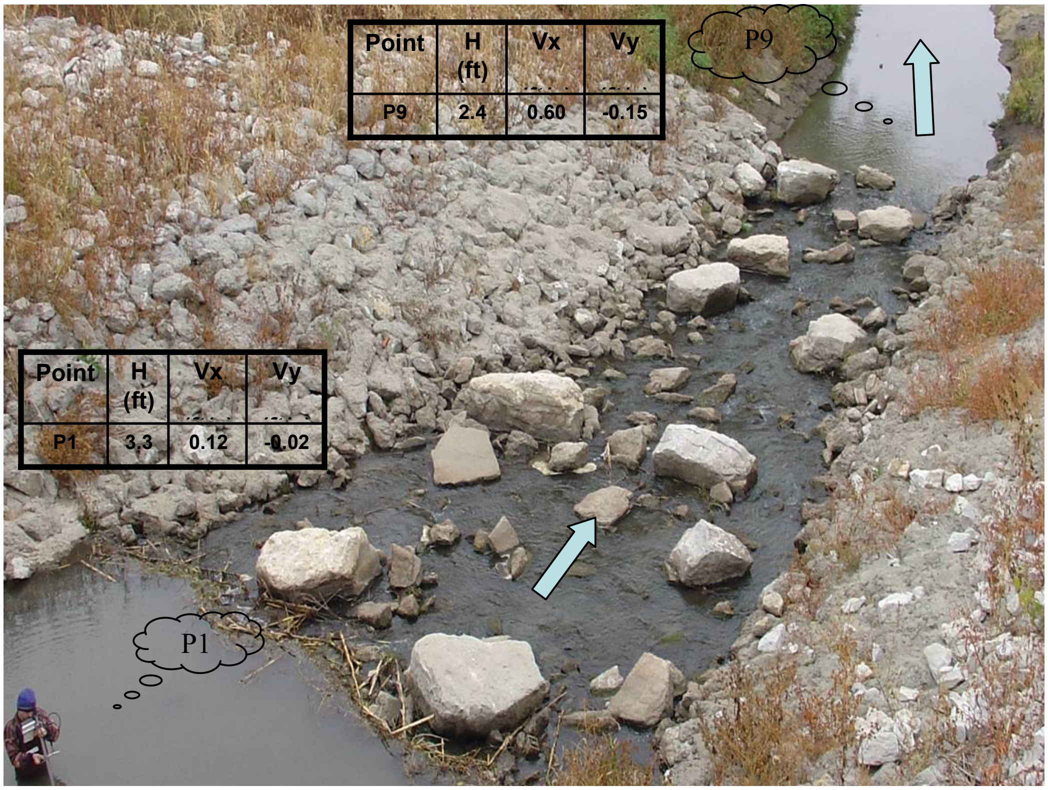


Figure 38c. Flowtracker measurements

Figure 38d. Flowtracker measurements

Figure 38e. Flowtracker measurements

Figure 38f. Flowtracker measurements

Figure 38g. Flowtracker measurements

Figure 38h. Riprap size

Figure 38i. Riprap size

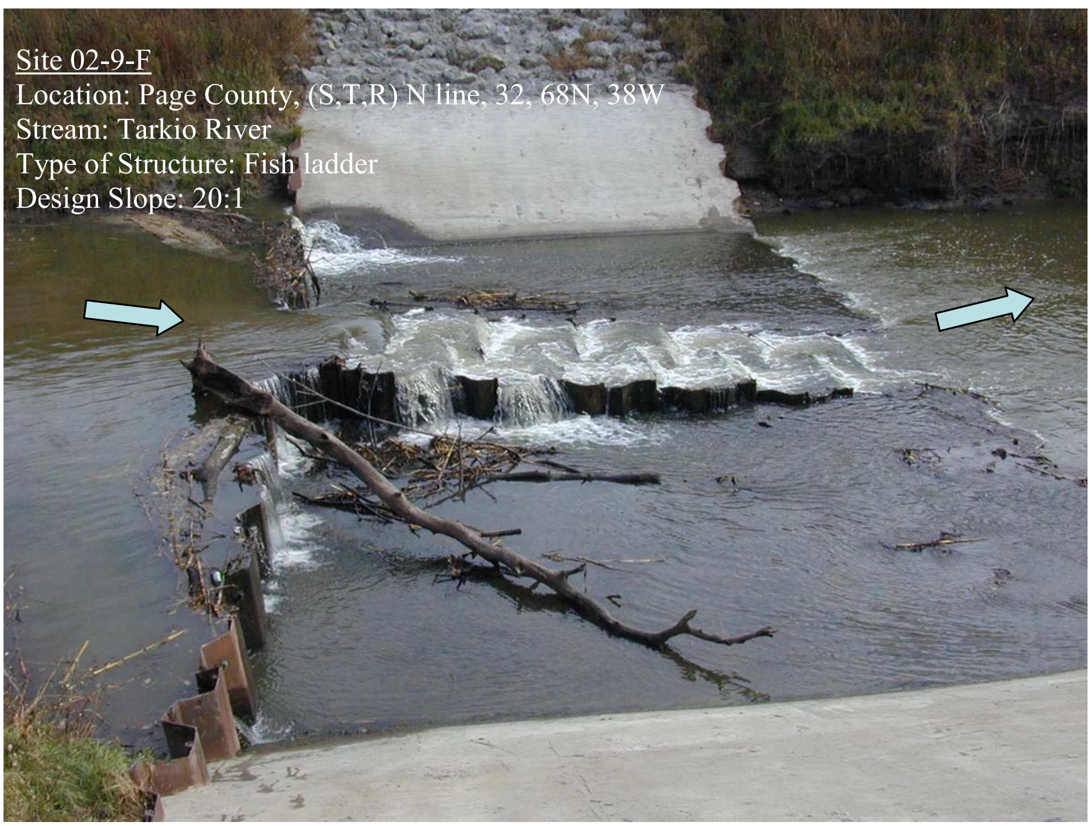


Figure 39a. Description of site 02-9-F

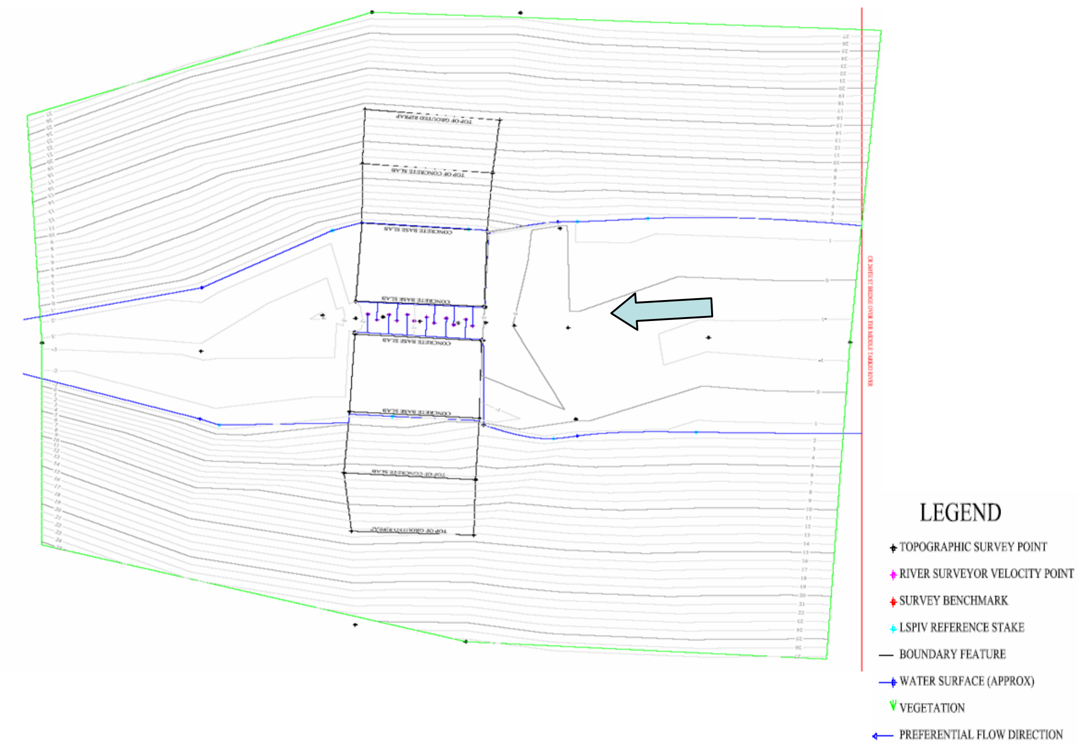


Figure 39b. Topographic plot

Figure 39c. LSPIV image

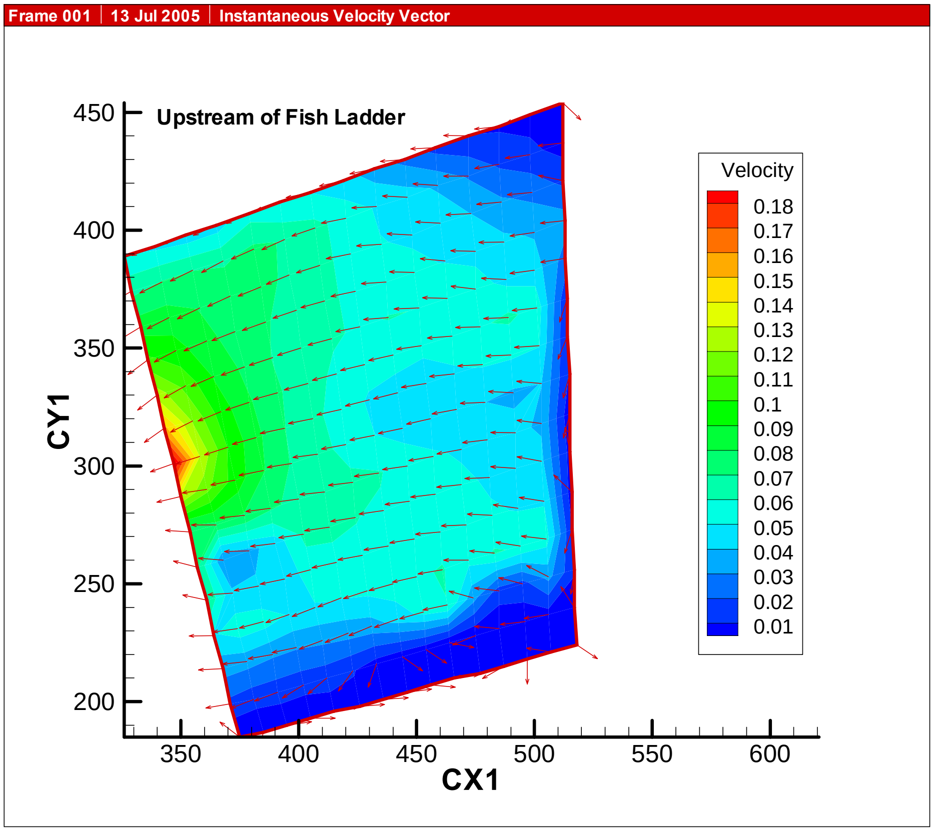


Figure 39d. LSPIV result (upstream)

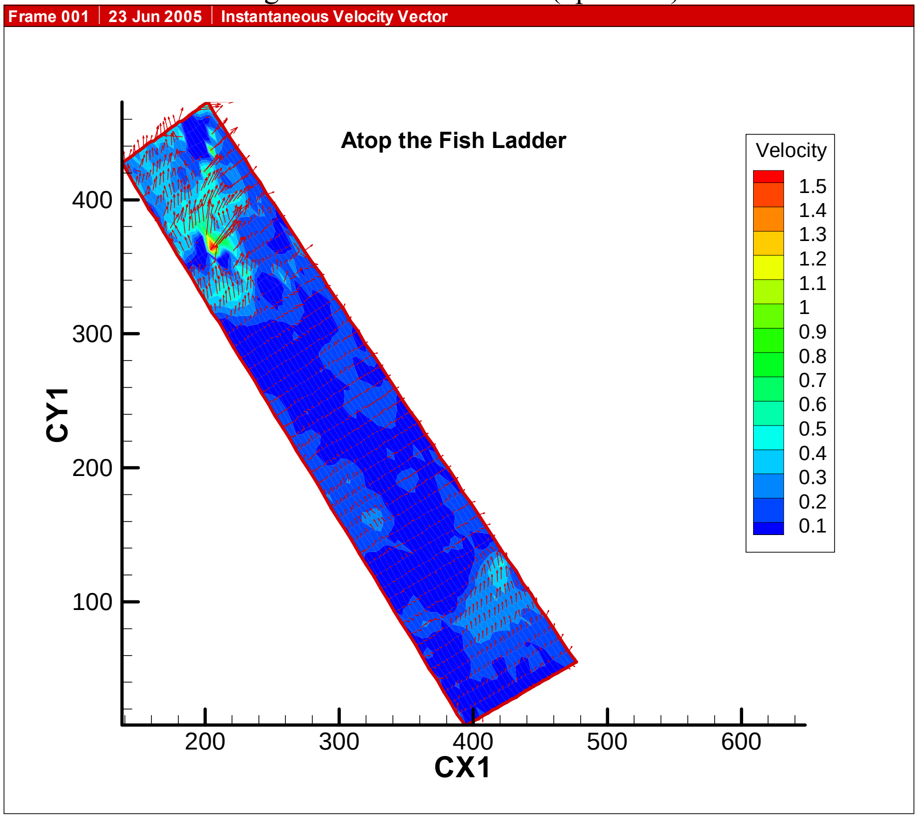


Figure 39e. LSPIV result (atop)

Figure 39f. Riprap size

Figure 39g. Riprap size

Figure 39h. General picture


Figure 39i. General picture

Figure 39j. General picture

Figure 39k. General picture

Figure 40a. Description of site 69-6114-1-23

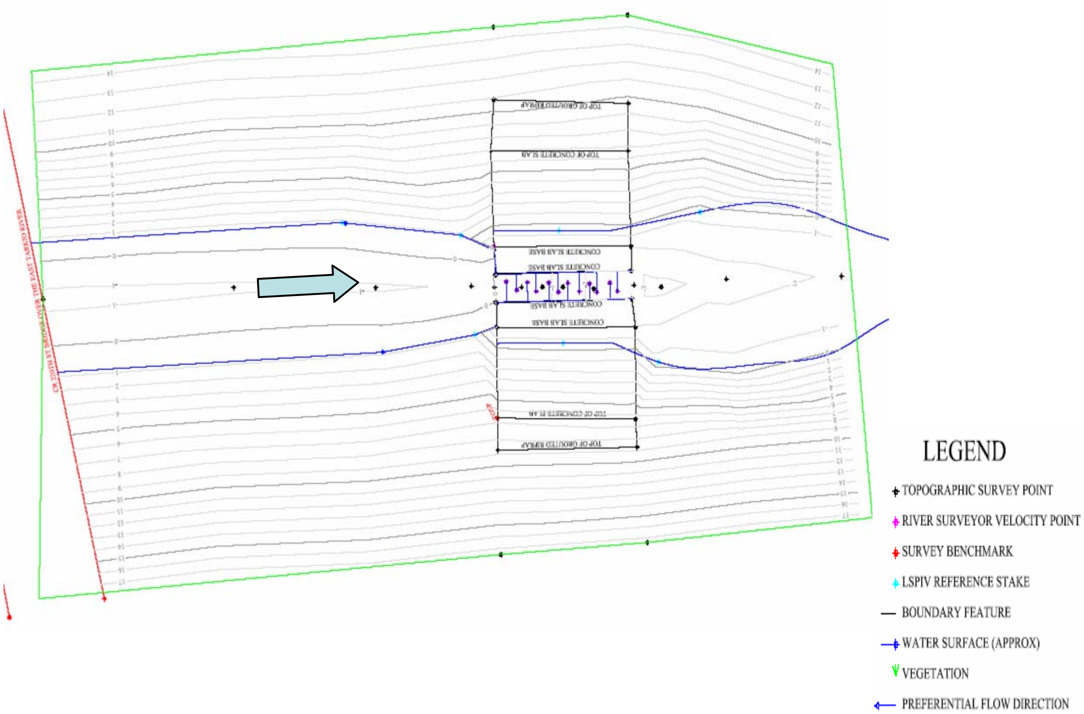


Figure 40b. Topographic plot

Figure 40c. LSPIV image

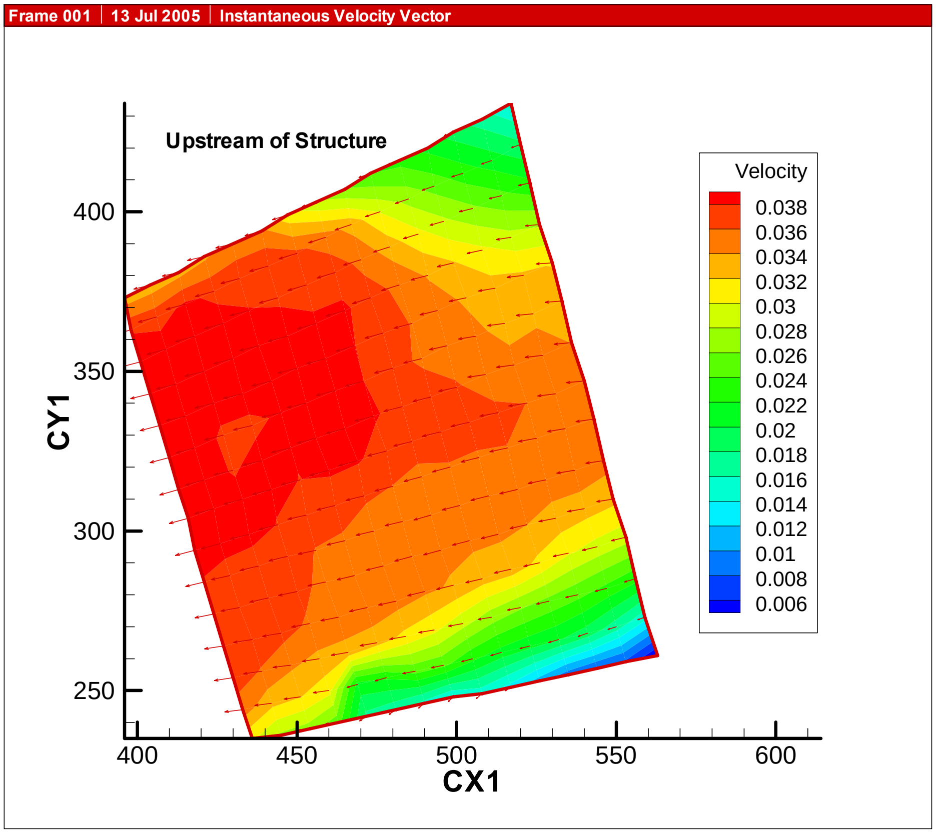


Figure 40d. LSPIV result (upstream)

Figure 40e. Riprap size

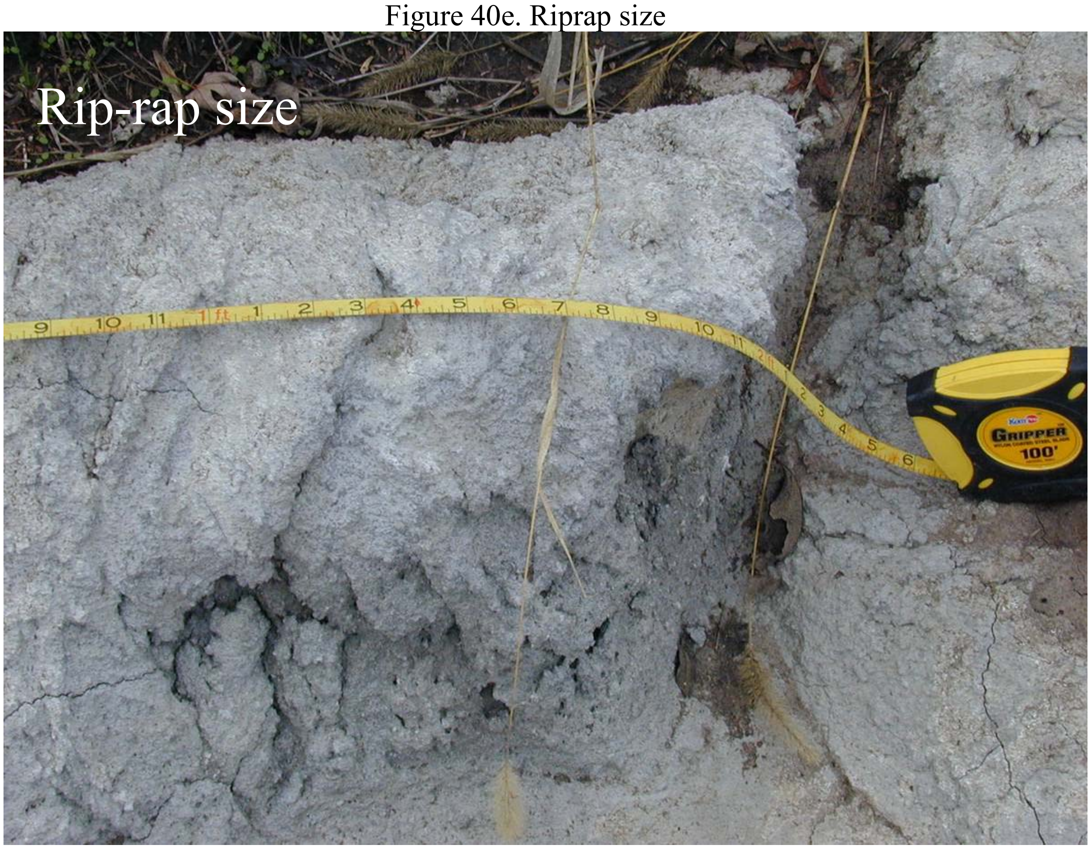


Figure 40f. Riprap size

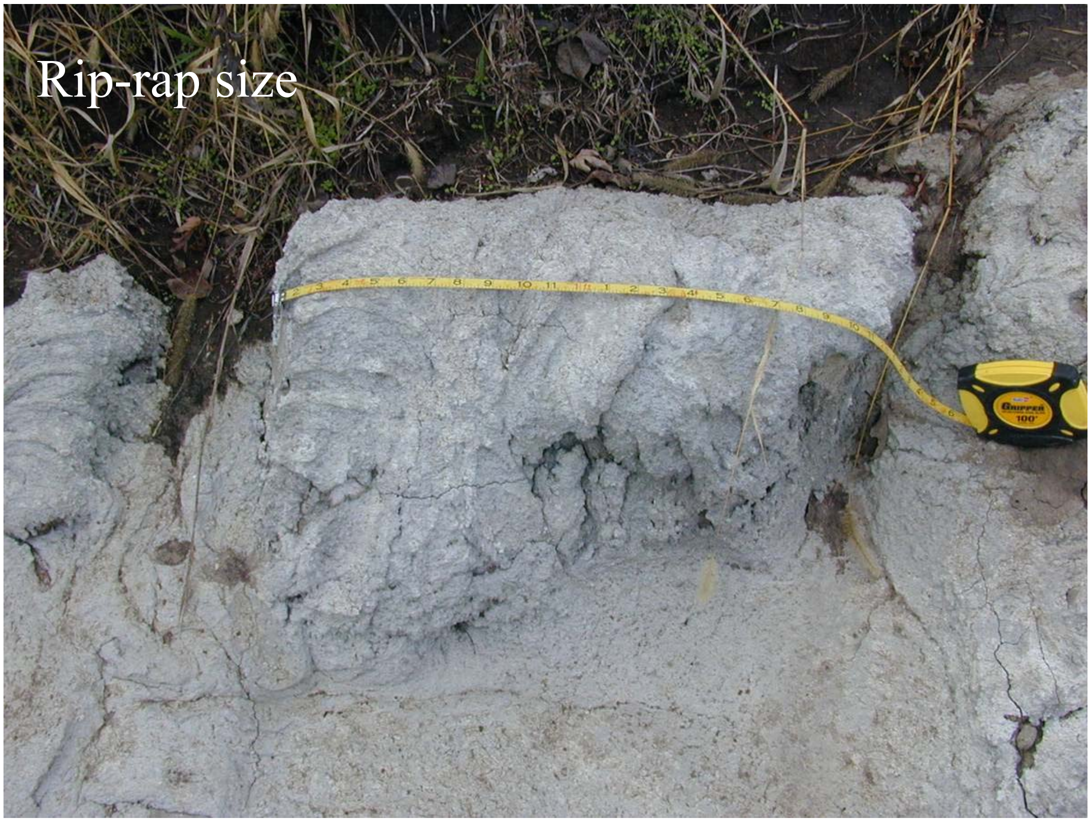


Figure 40g. Riprap size

Figure 40h. General picture

Figure 40i. General picture

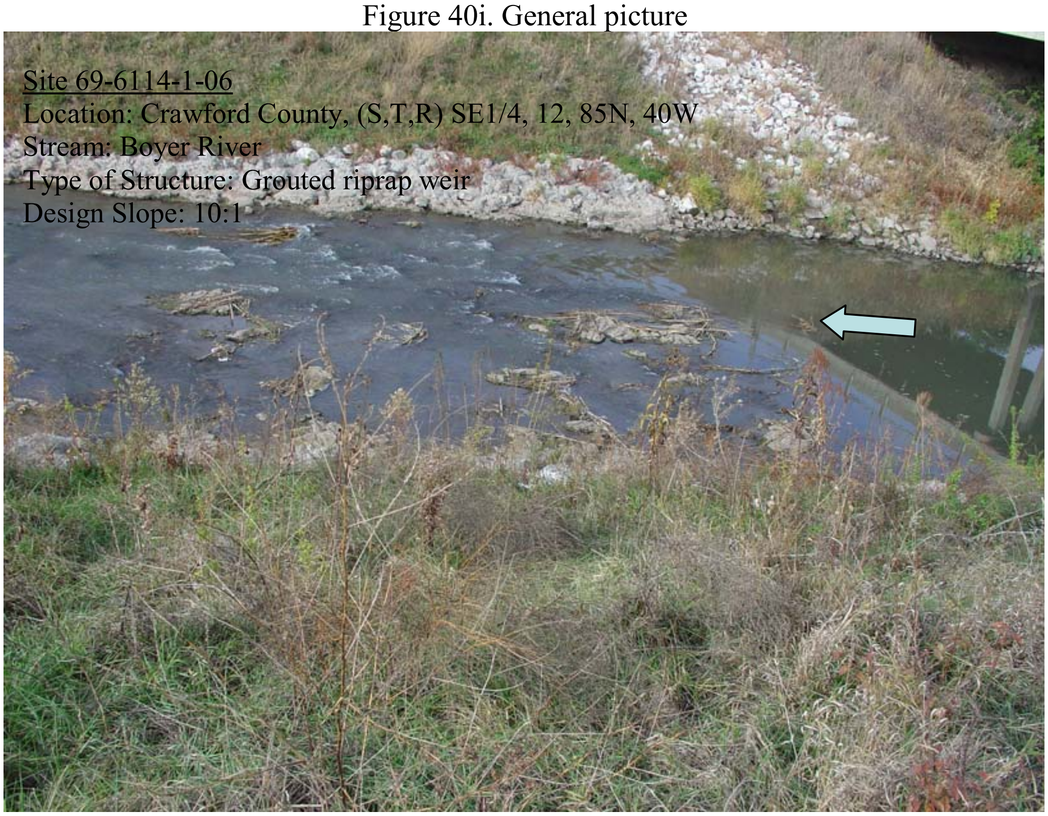


Figure 41a. Description of site 69-6114-1-06

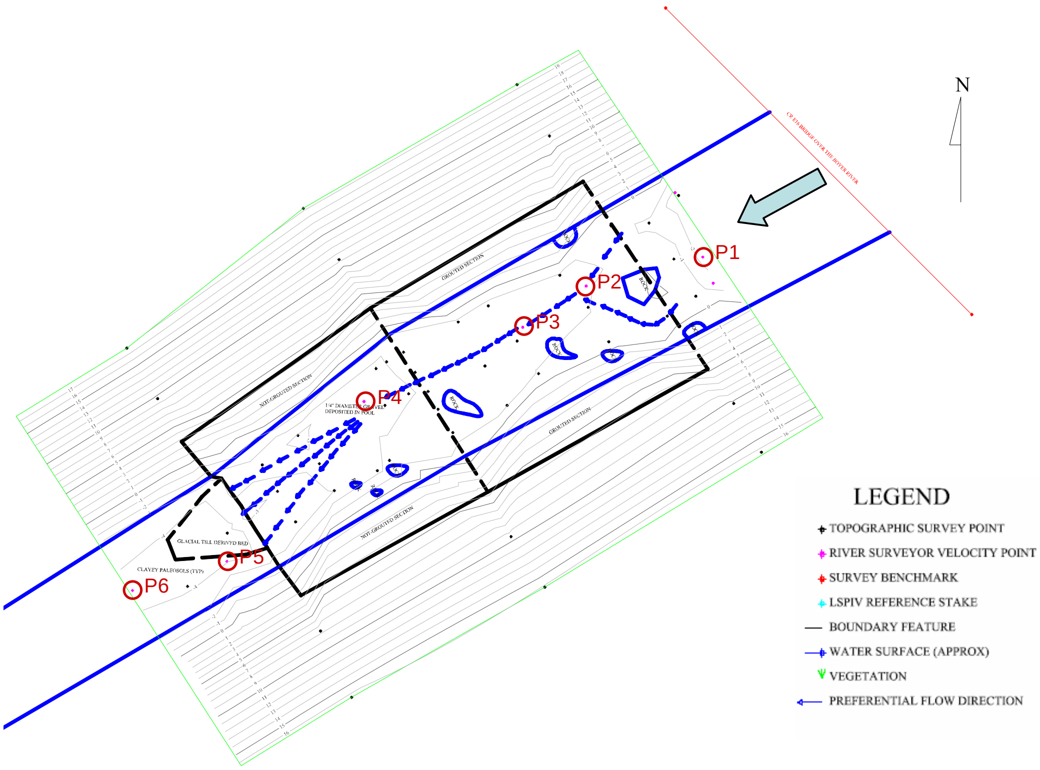
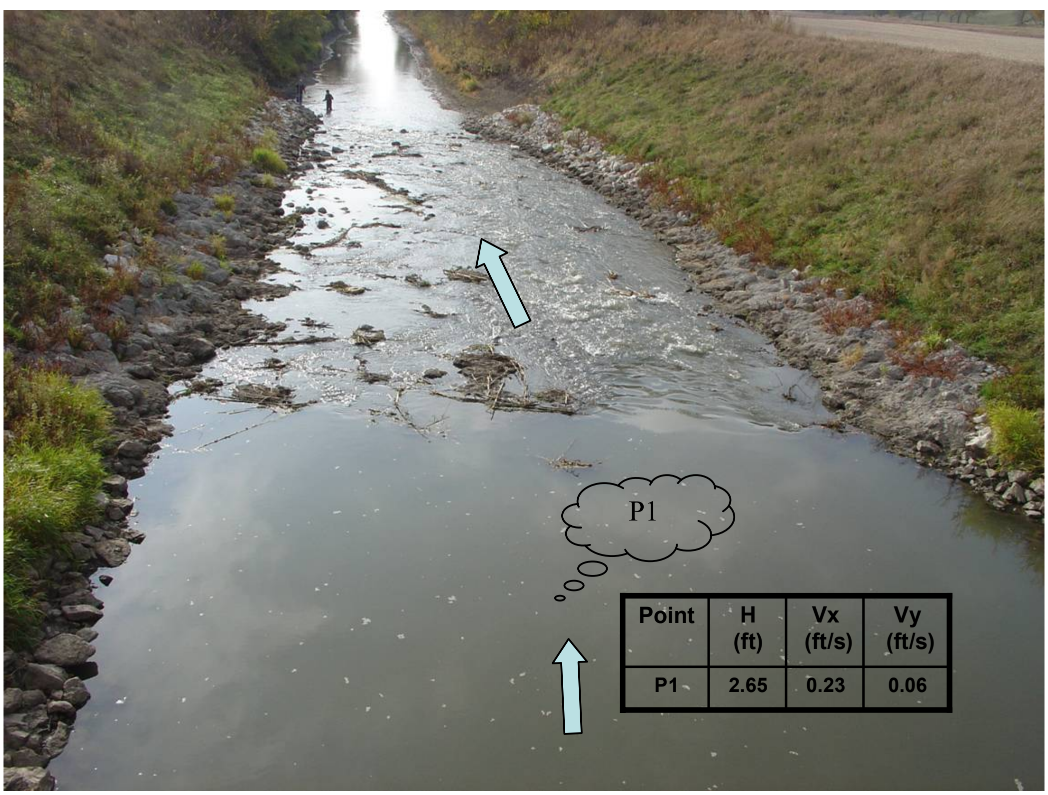


Figure 41b. Topographic plot



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P1	2.65	0.23	0.06

Figure 41c. Flowtracker measurements

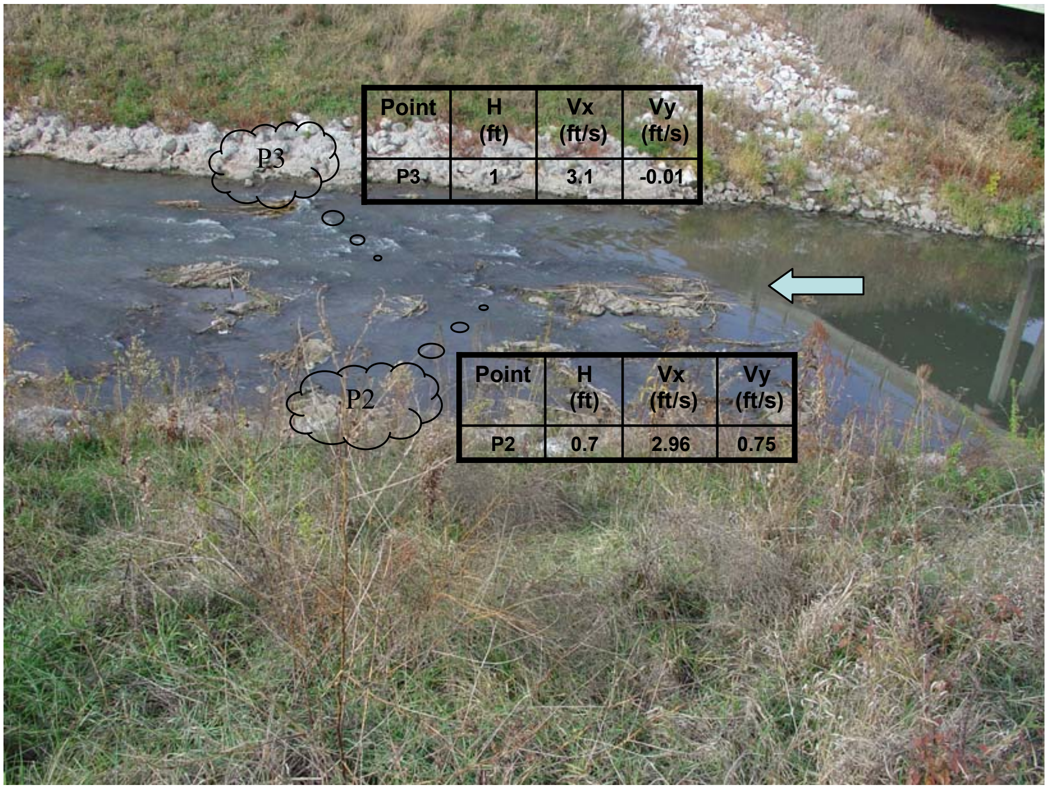


Figure 41d. Flowtracker measurements

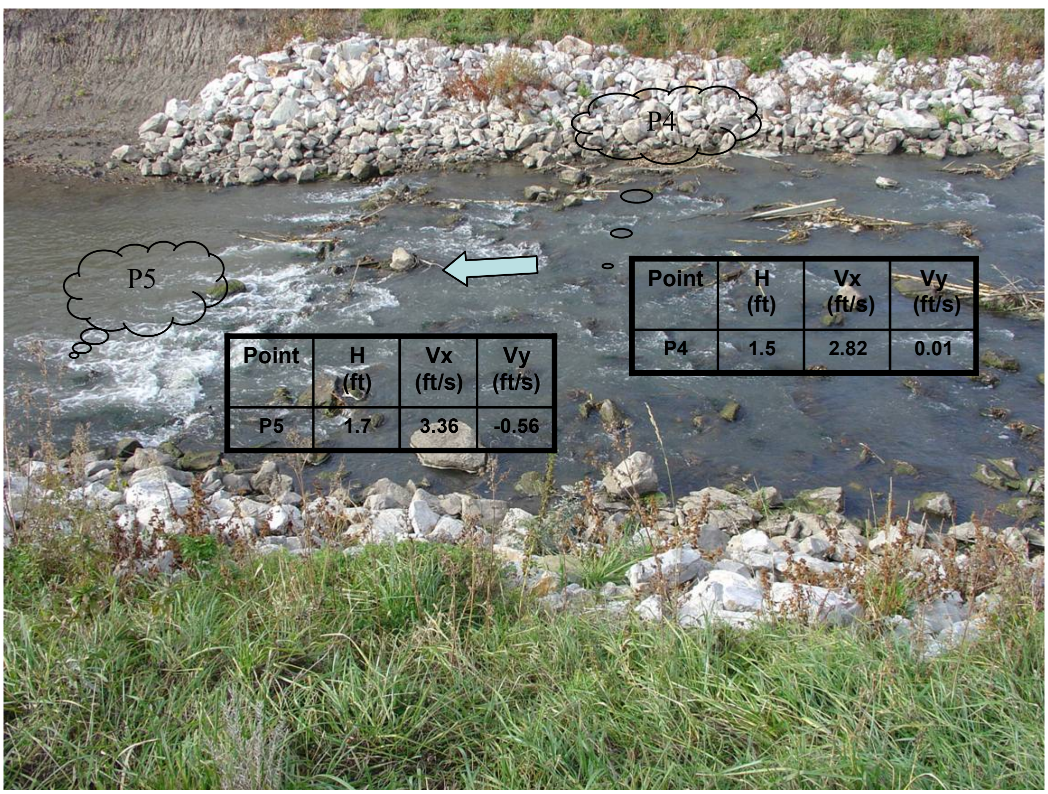
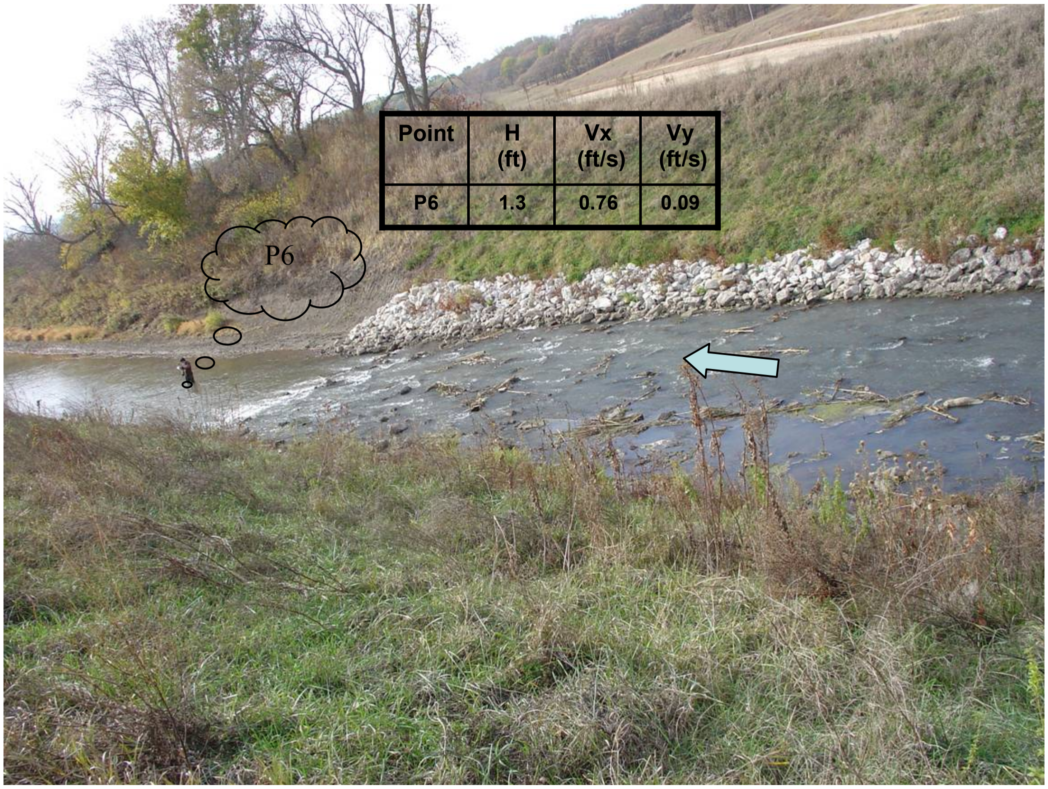


Figure 41e. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P6	1.3	0.76	0.09

Figure 41f. Flowtracker measurements

Figure 41g. General picture

Figure 41h. General picture

Figure 42a. Description of site 02-15-F and 02-16

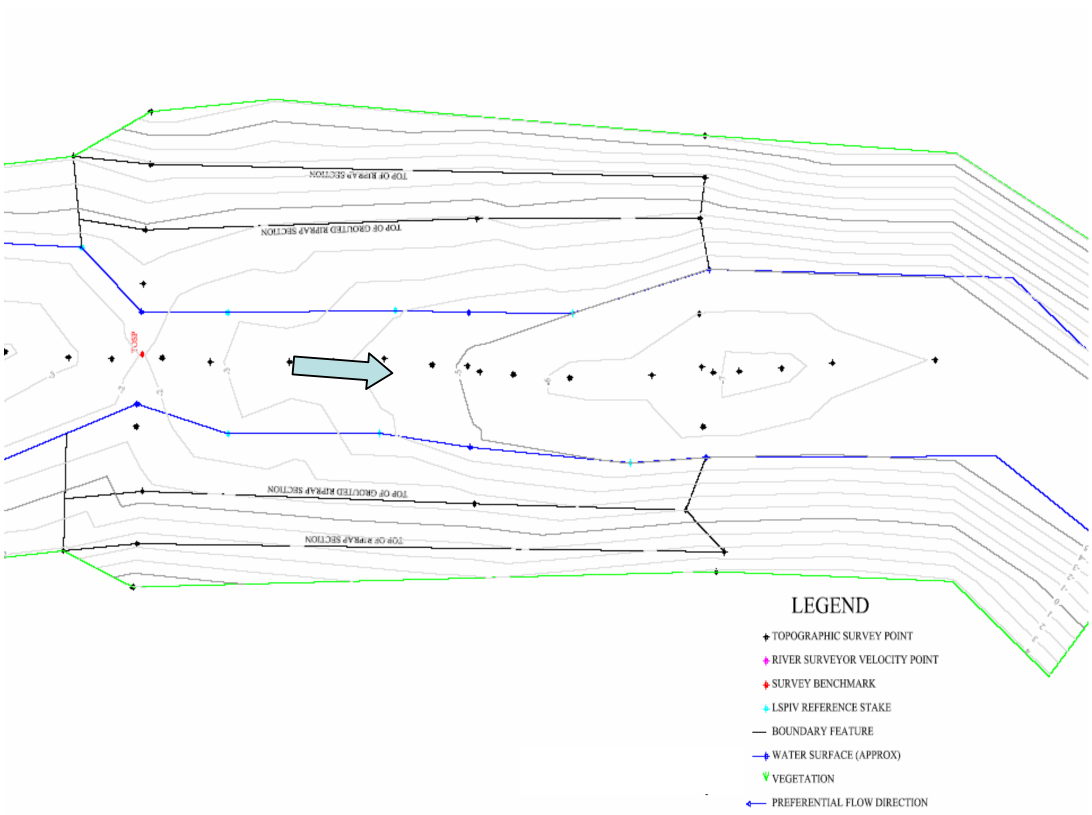


Figure 42b. Topographic plot

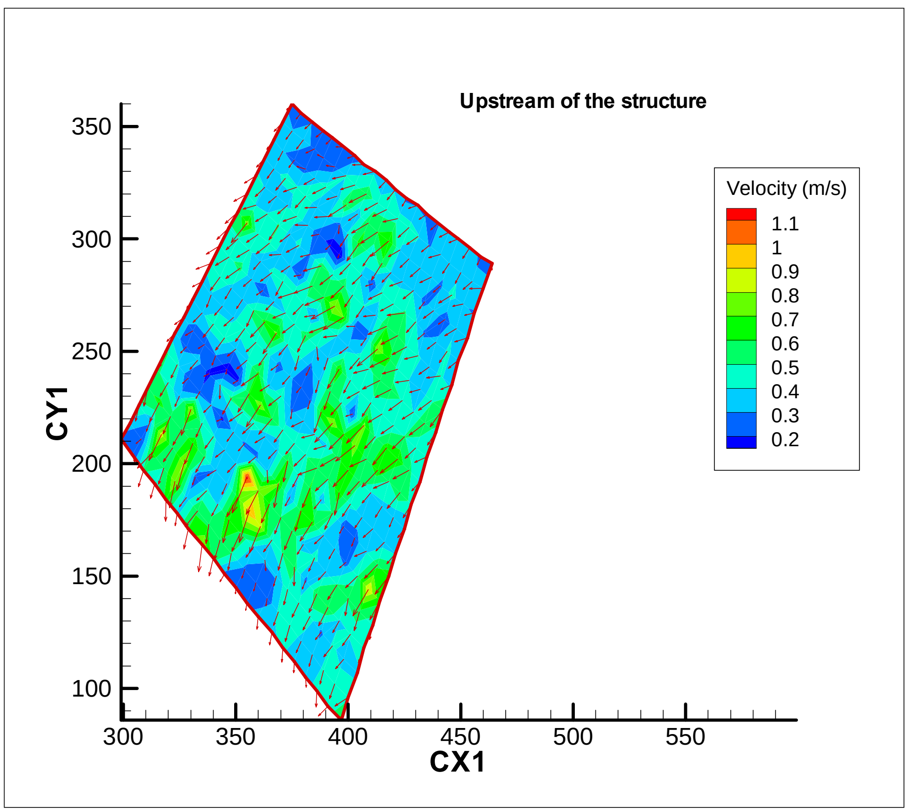


Figure 42c. LSPIV result (upstream)

Figure 42d. Riprap size

Figure 42e. Riprap size

Figure 42f. General picture

Figure 42g. General picture

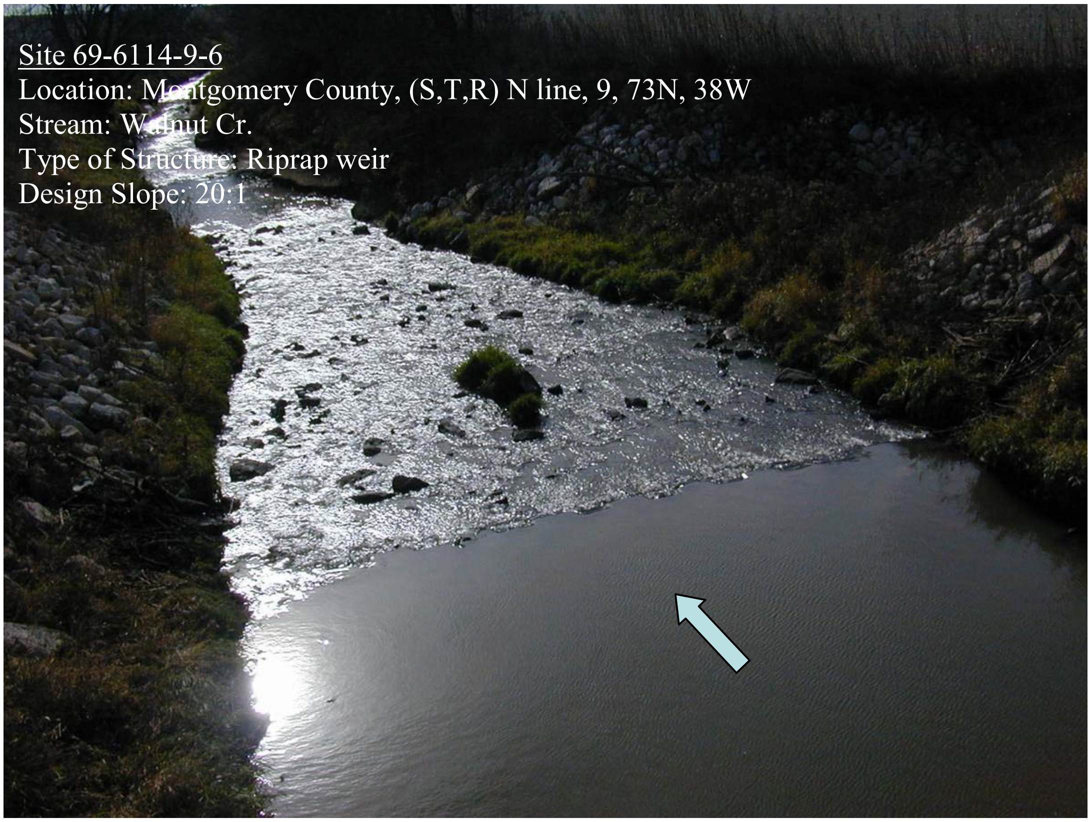


Figure 43a. Description of site 69-6114-9-6

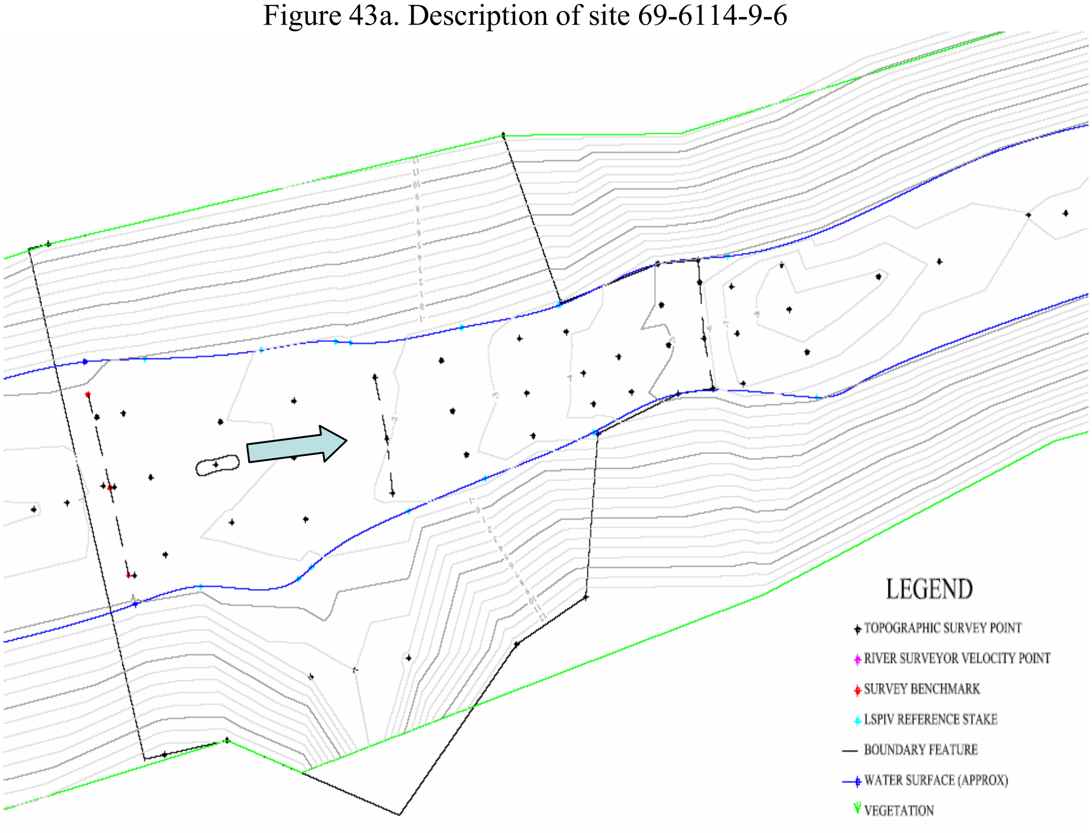


Figure 43b. Topographic plot

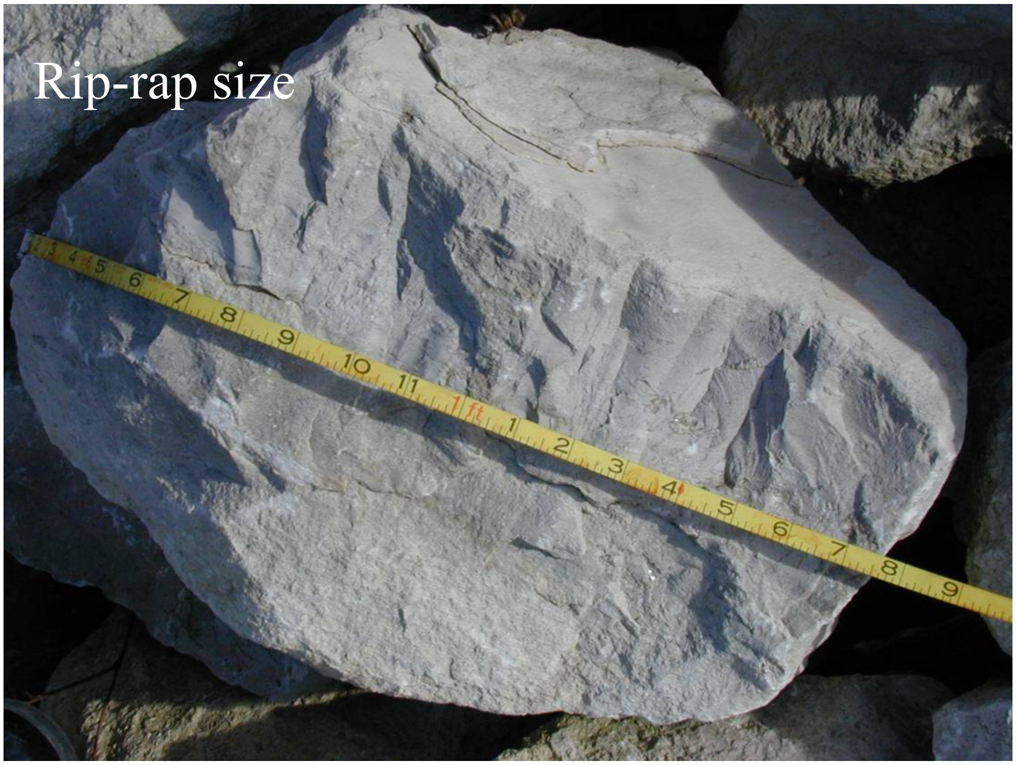


Figure 43c. Riprap size

Figure 43d. Riprap size

Figure 43e. General picture

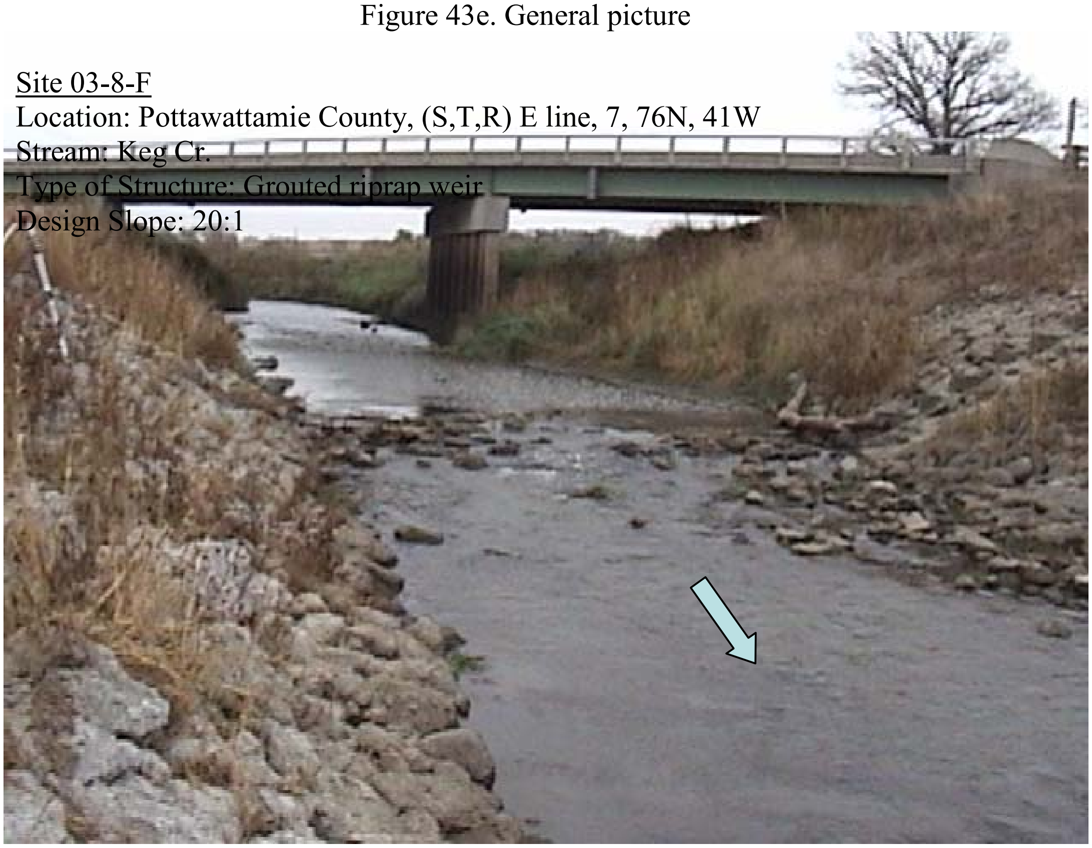


Figure 44a. Description of site 03-8-F

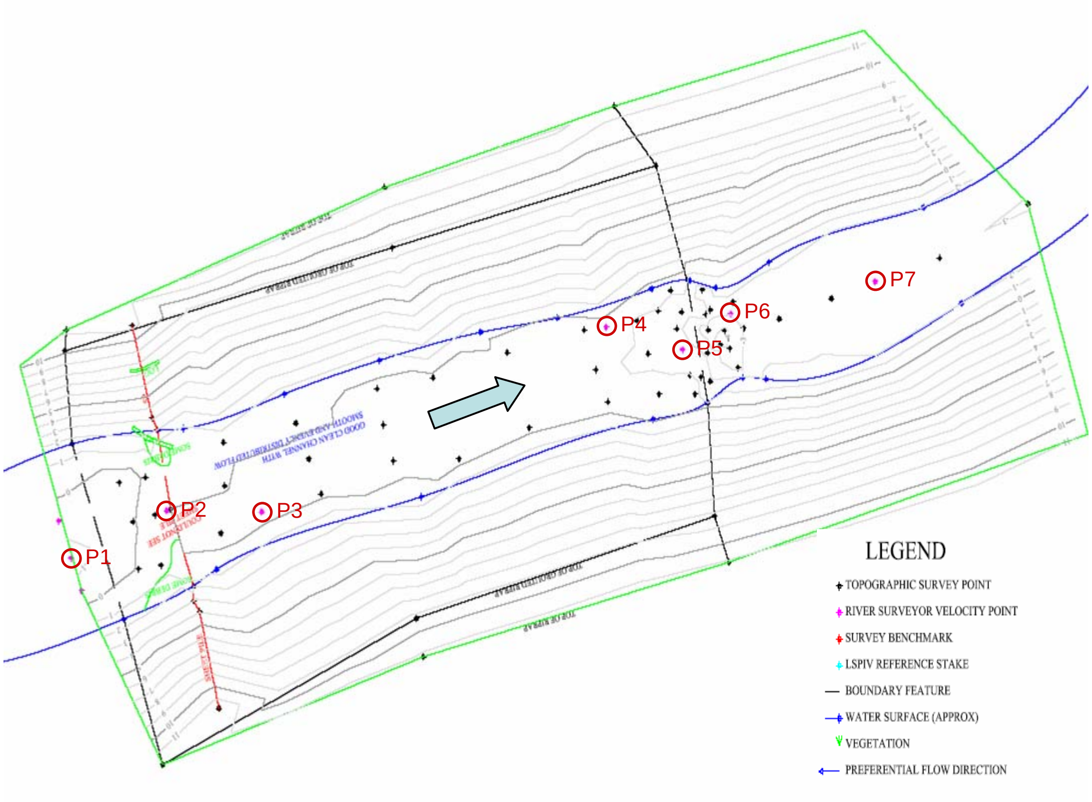


Figure 44b. Topographic plot

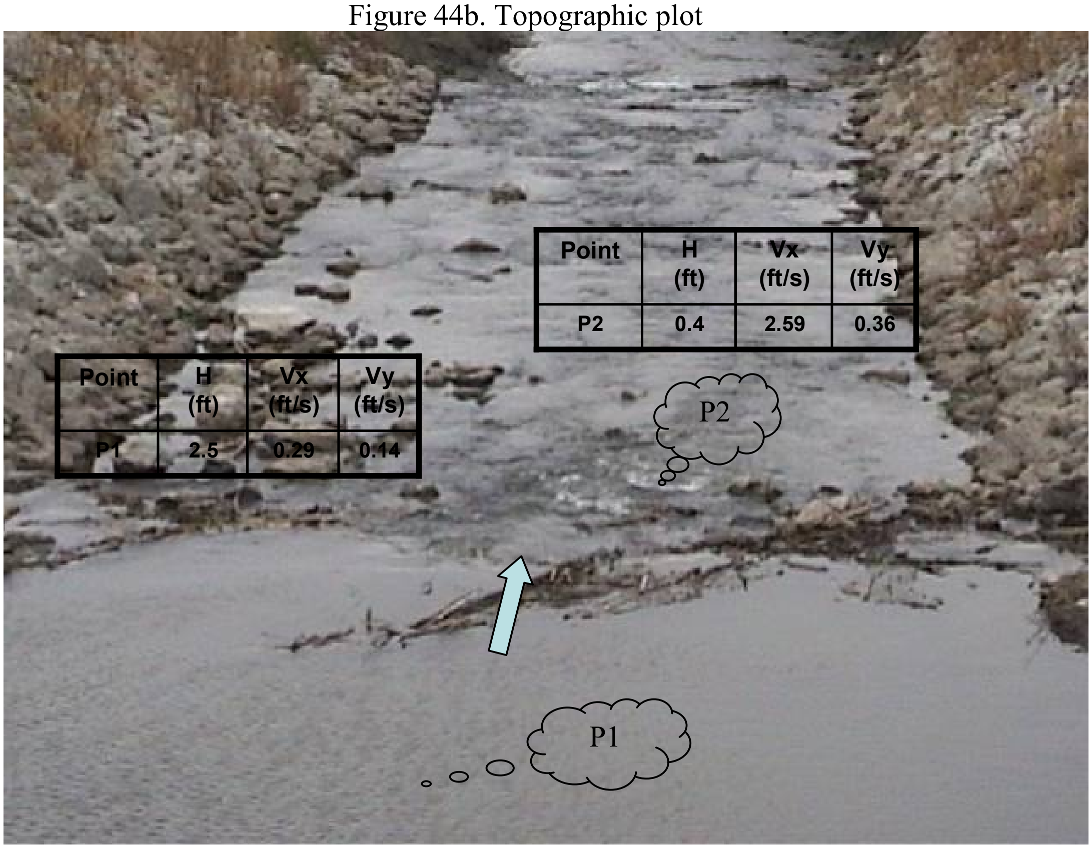
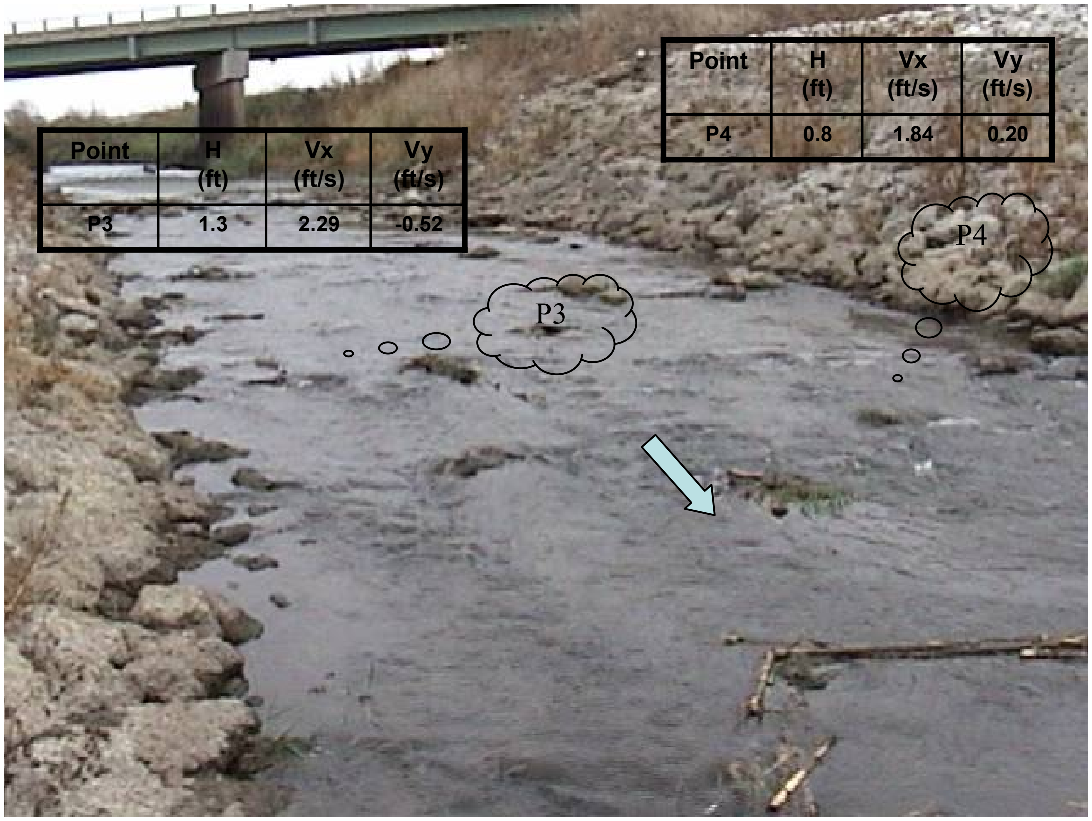


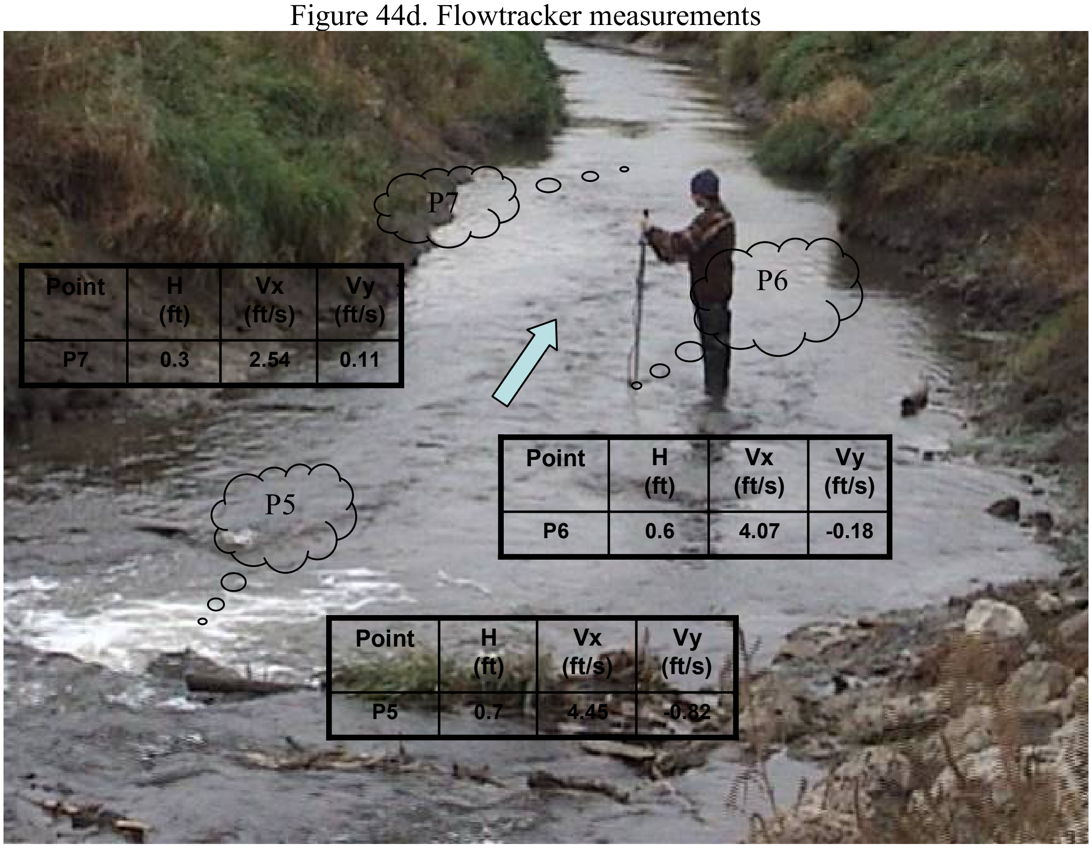
Figure 44c. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P3	1.3	2.29	-0.52

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P4	0.8	1.84	0.20

Figure 44d. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P7	0.3	2.54	0.11

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P6	0.6	4.07	-0.18

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P5	0.7	4.45	-0.82

Figure 44e. Flowtracker measurements

Figure 44f. Riprap size

Figure 44g. General picture

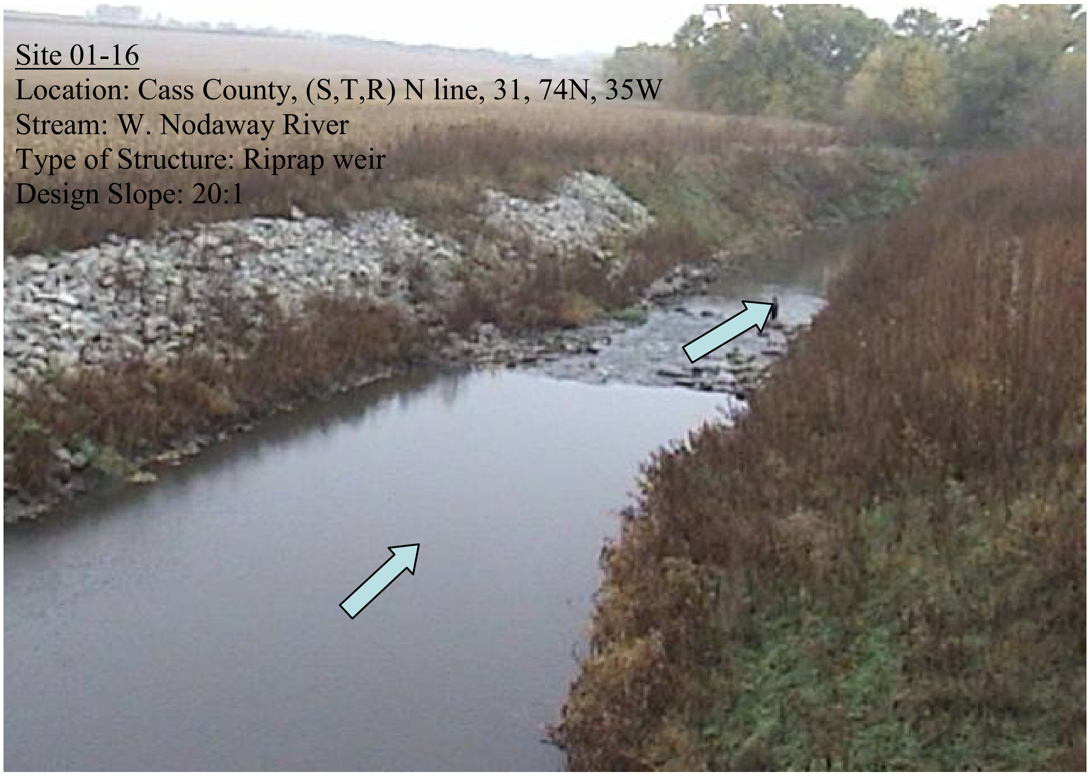


Figure 45a. Description of site 01-16

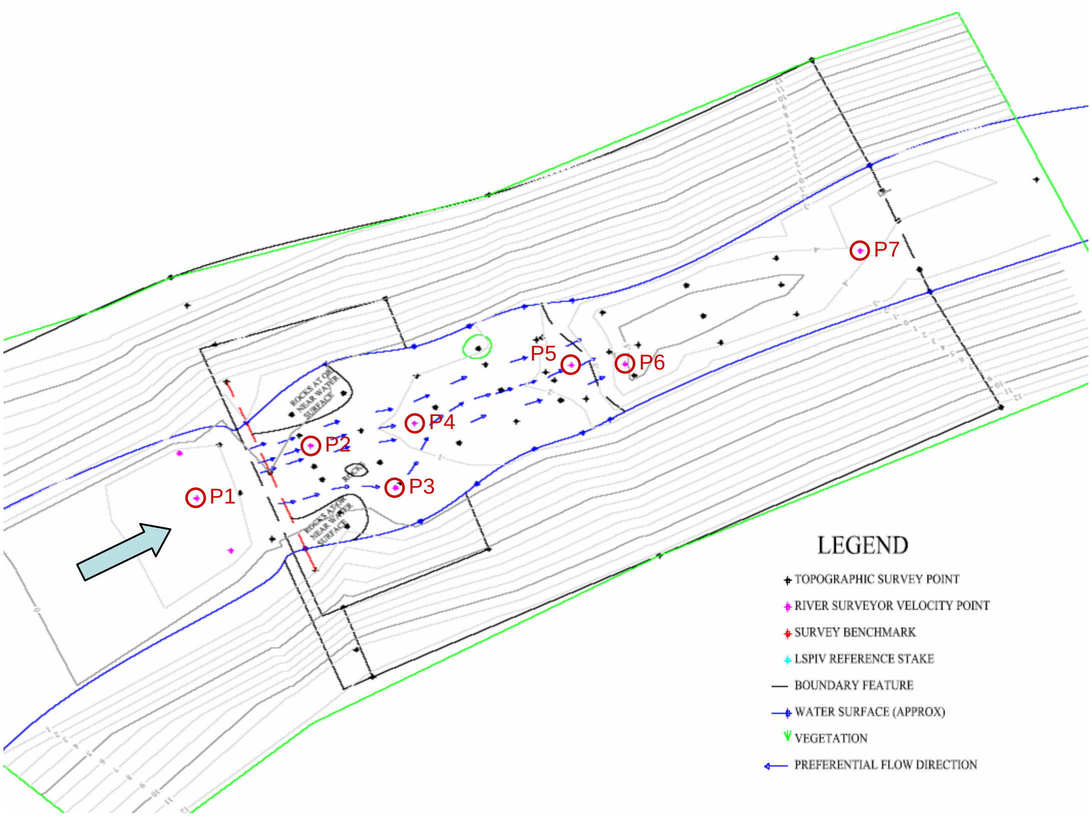


Figure 45b. Topographic plot

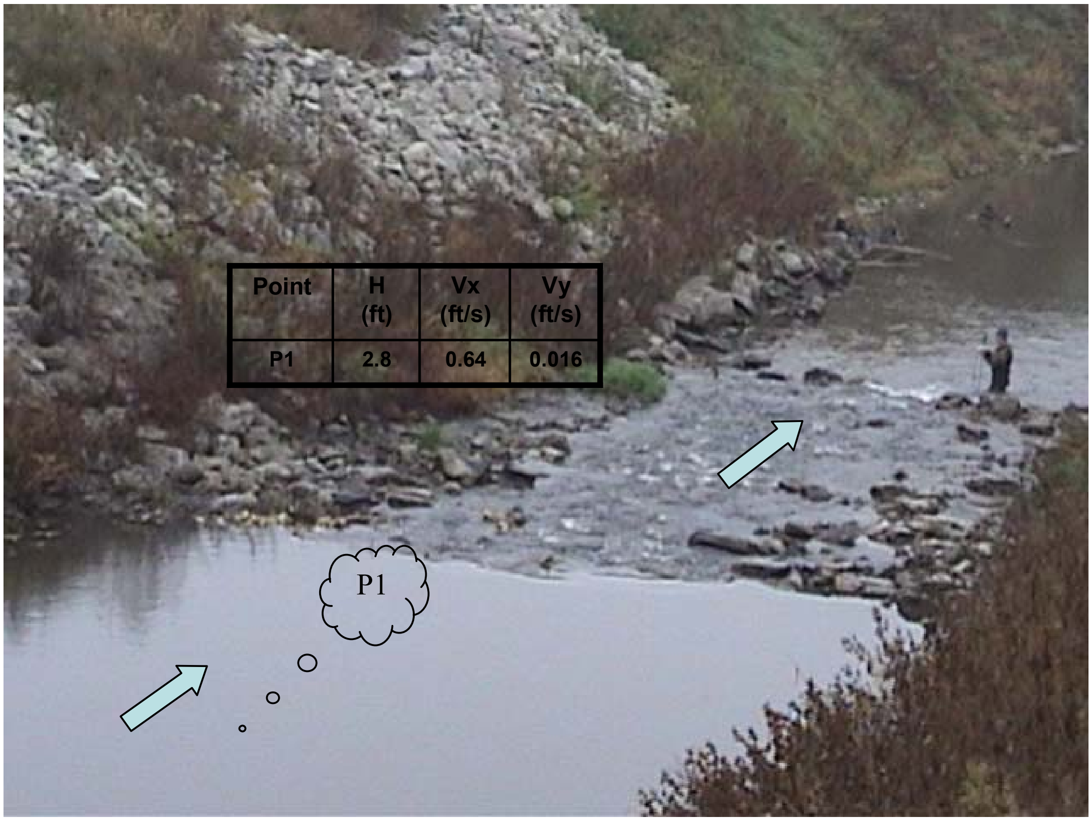


Figure 45c. Flowtracker measurements

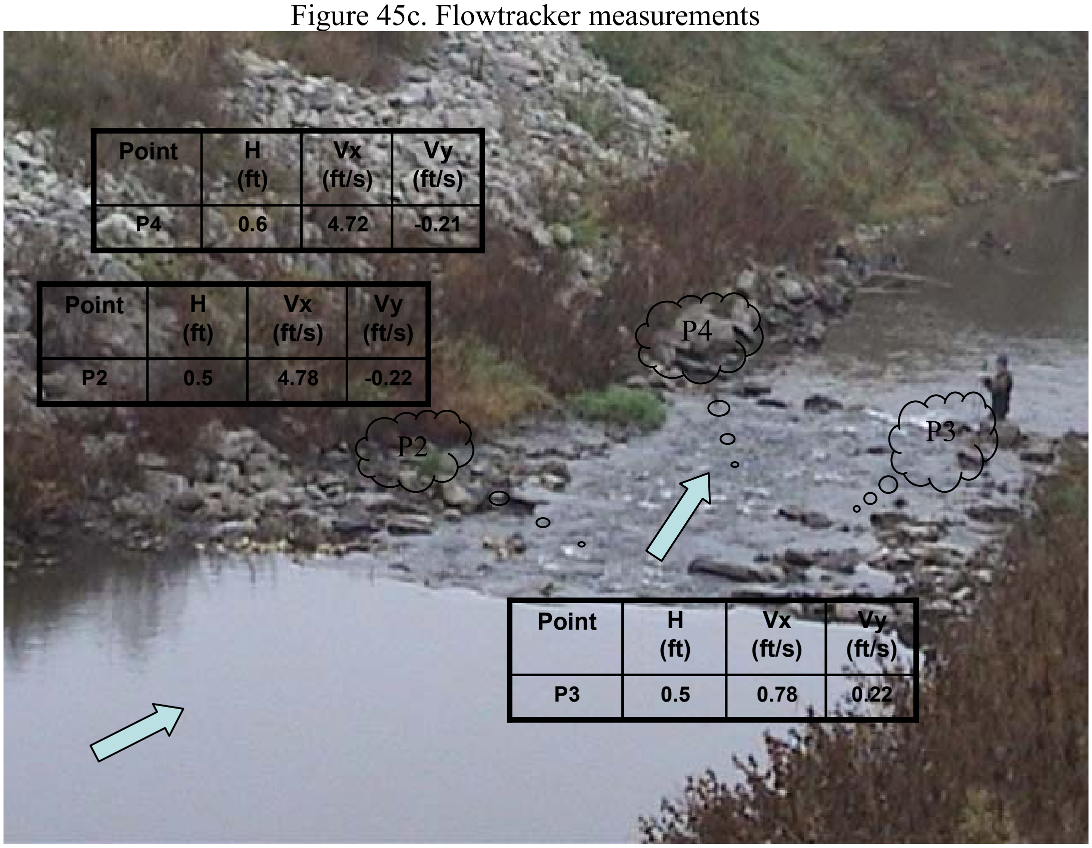
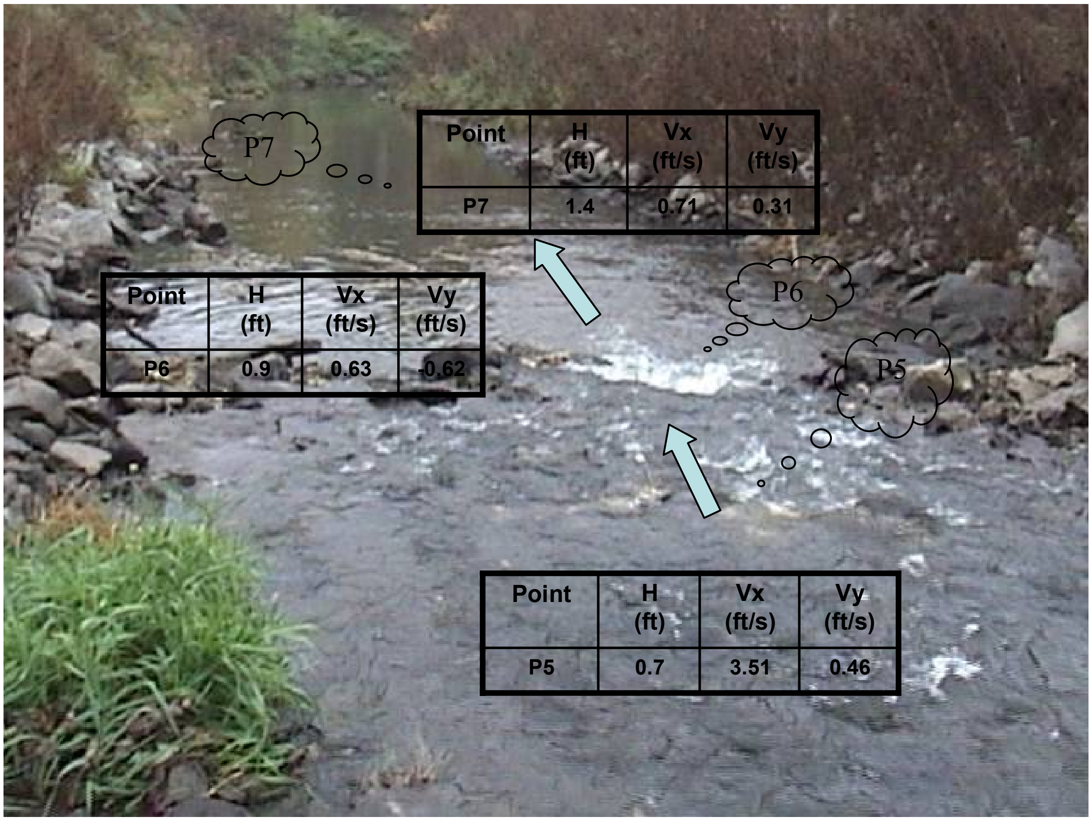


Figure 45d. Flowtracker measurements



Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P7	1.4	0.71	0.31

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P6	0.9	0.63	-0.62

Point	H (ft)	Vx (ft/s)	Vy (ft/s)
P5	0.7	3.51	0.46

Figure 45e. Flowtracker measurements

Spring Period

Figure 46a. Description of site 69-6114-9-4 (Spring)


Figure 46b. General picture

Figure 46c. General picture

Figure 47a. Description of site 00-24 (Spring)


Figure 47b. General picture


Figure 47c. General picture

Figure 48a. Description of site 02-1-F (Spring)


Figure 48b. General picture

Figure 48c. General picture

Figure 49a. Description of site 02-9-F (Spring)


Figure 49b. General picture


Figure 49c. General picture

Figure 50a. Description of site 69-6114-1-23 (Spring)

Figure 50b. General picture

Figure 50c. General picture

Figure 51a. Description of site 69-6114-9-6 (Spring)

Figure 51b. General picture

Figure 51c. General picture

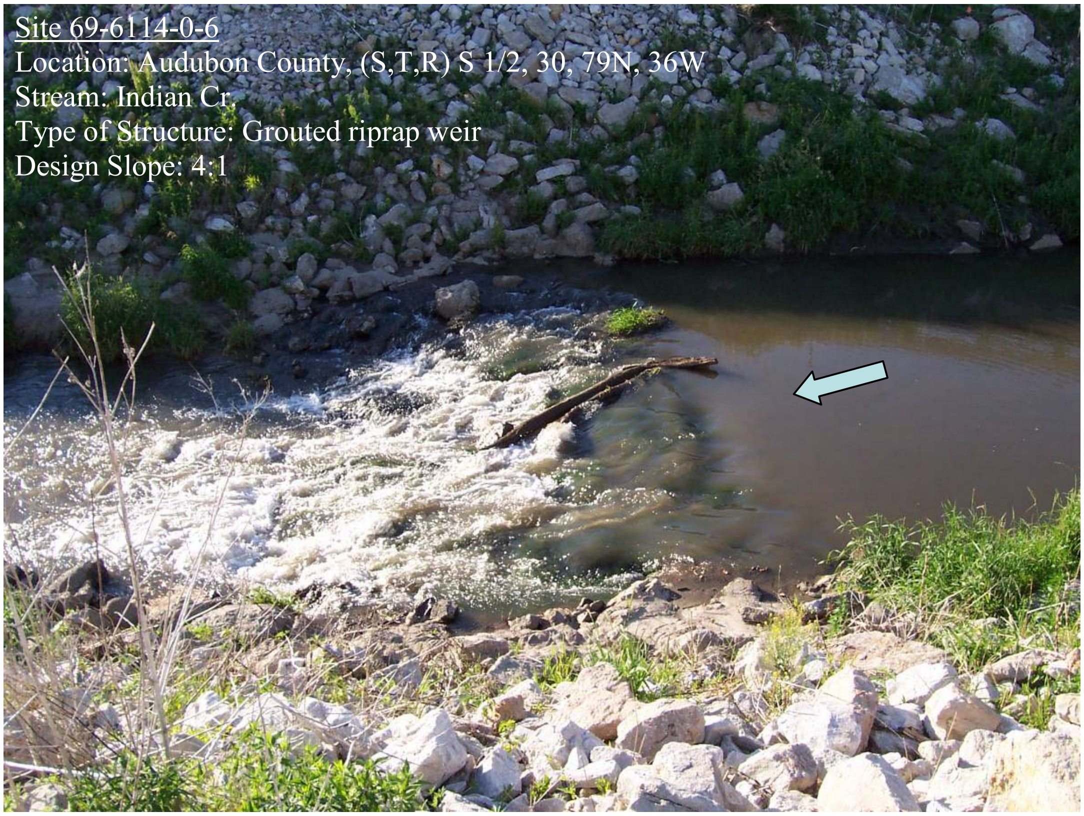


Figure 52a. Description of site 69-6114-0-6 (Spring)

Figure 52b. General picture

RIPRAP WEIR

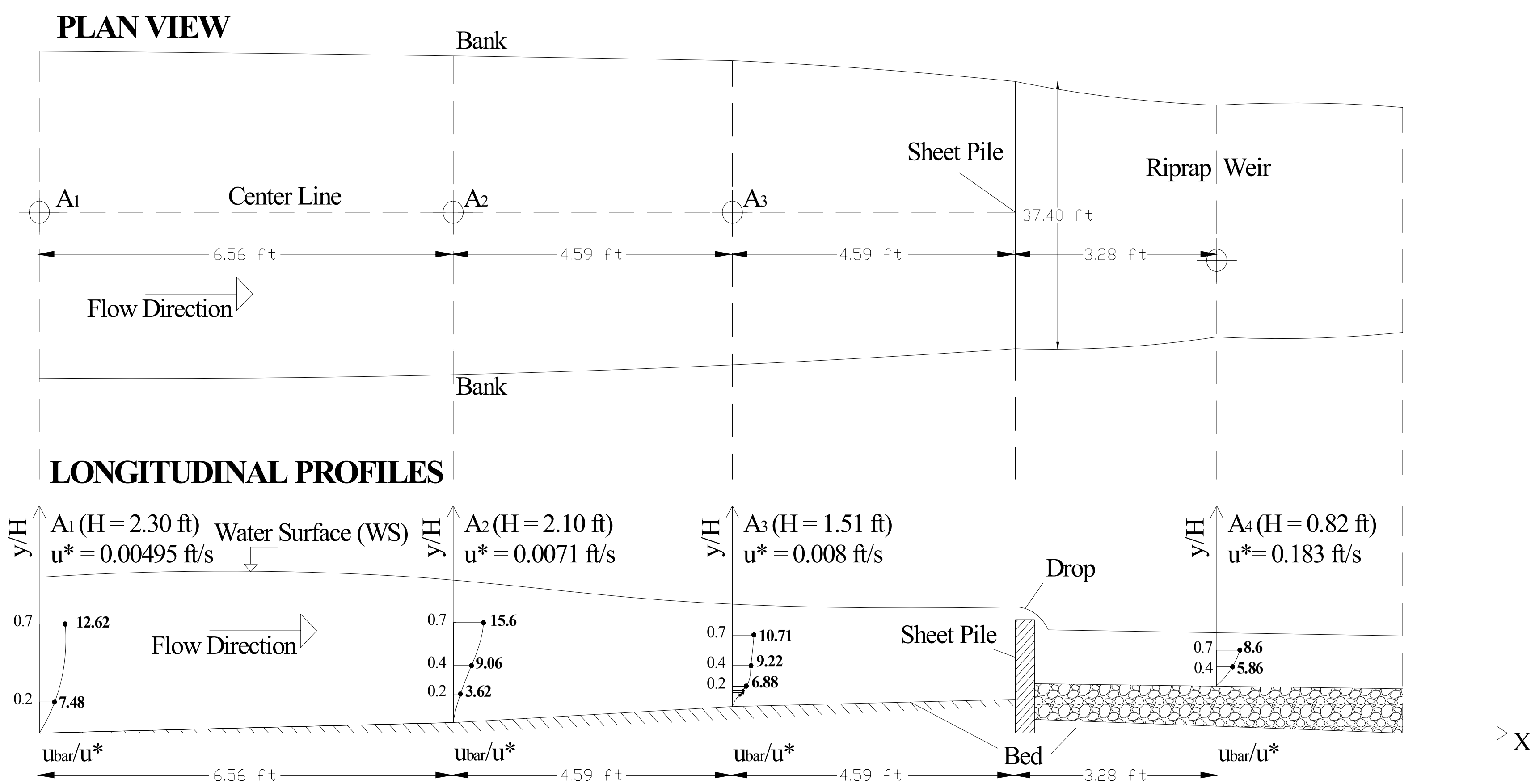


Figure 55a. u_{bar}/u^* diagram for riprap weir

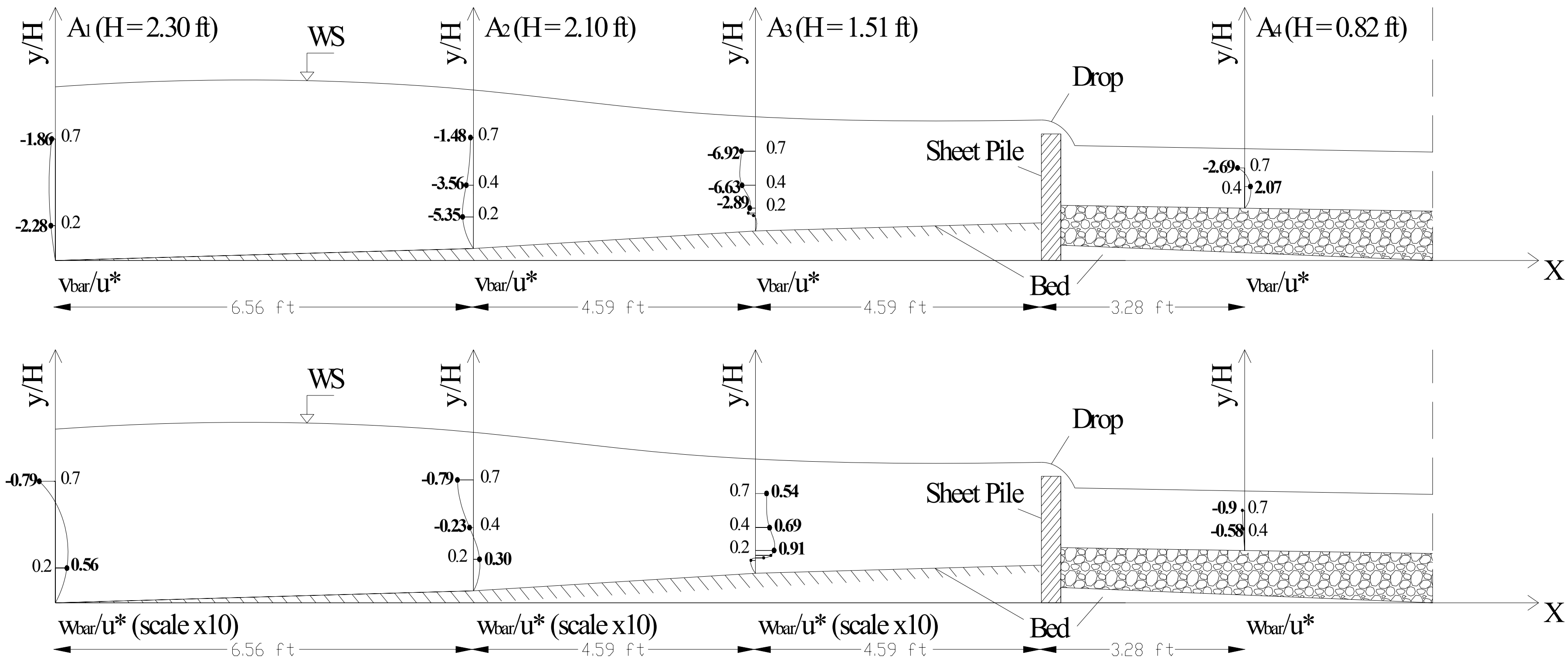


Figure 55b. v_{bar}/u^* and w_{bar}/u^* diagrams for riprap weir

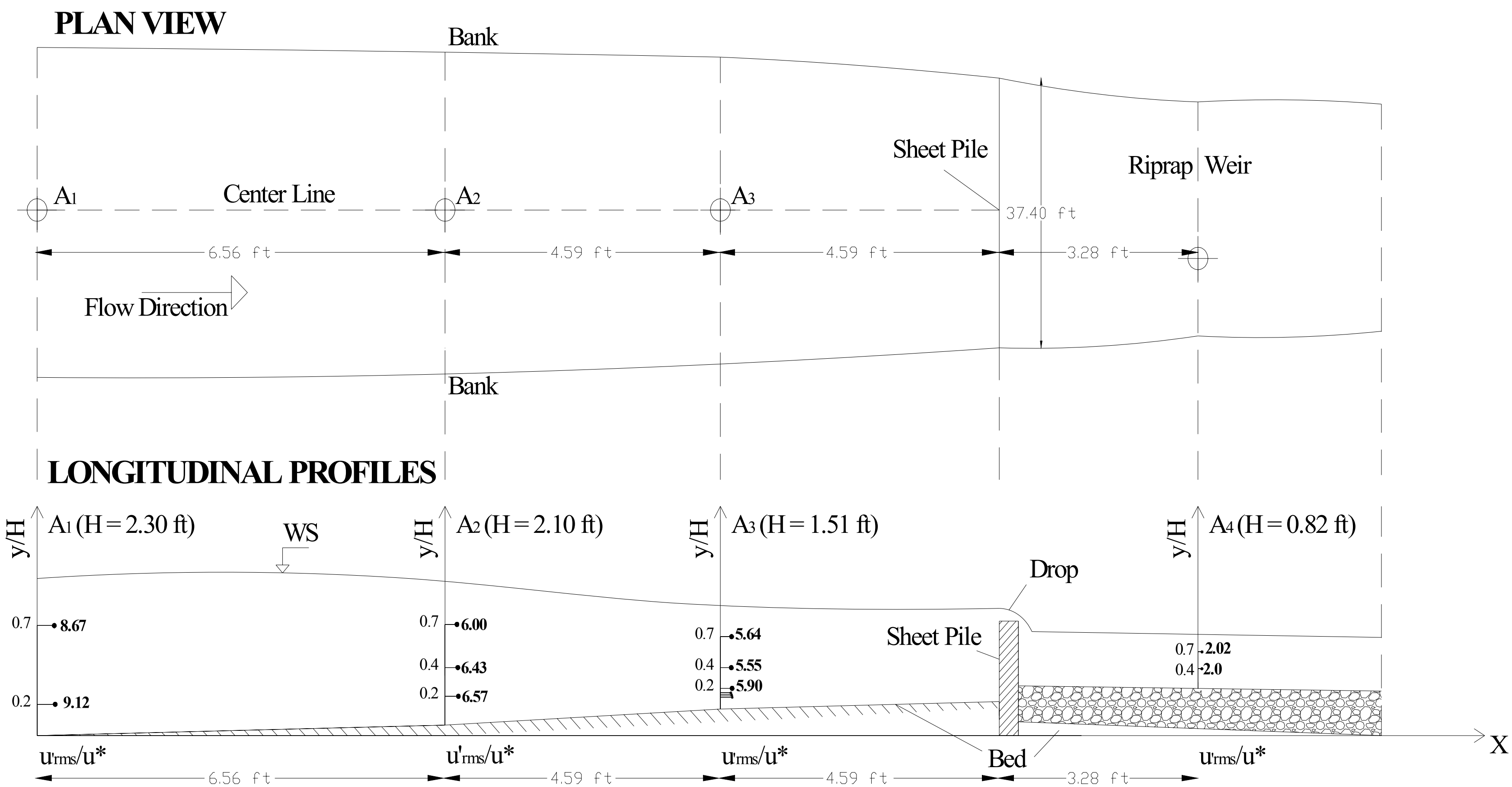


Figure 55c. u'_{rms}/u^* diagram for riprap weir

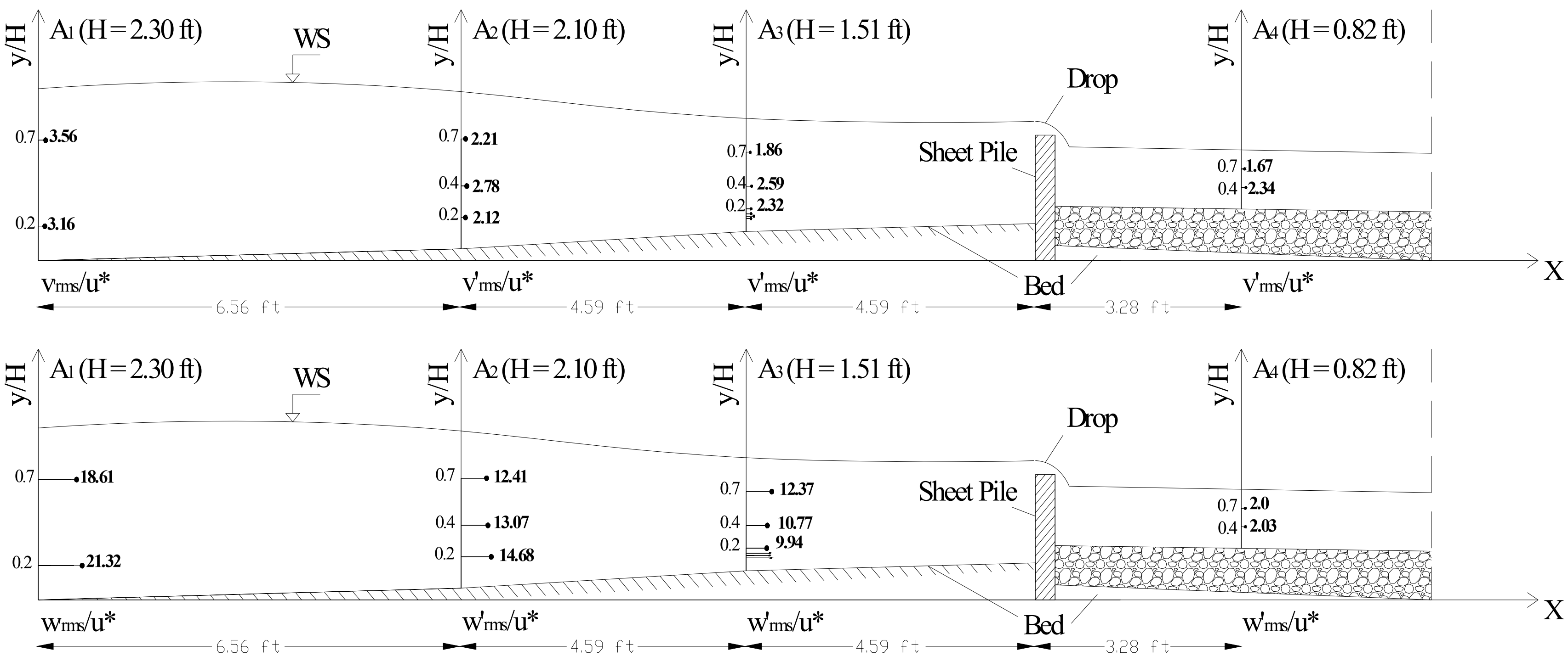


Figure 55d. v'_{rms}/u^* and w'_{rms}/u^* diagrams for riprap weir

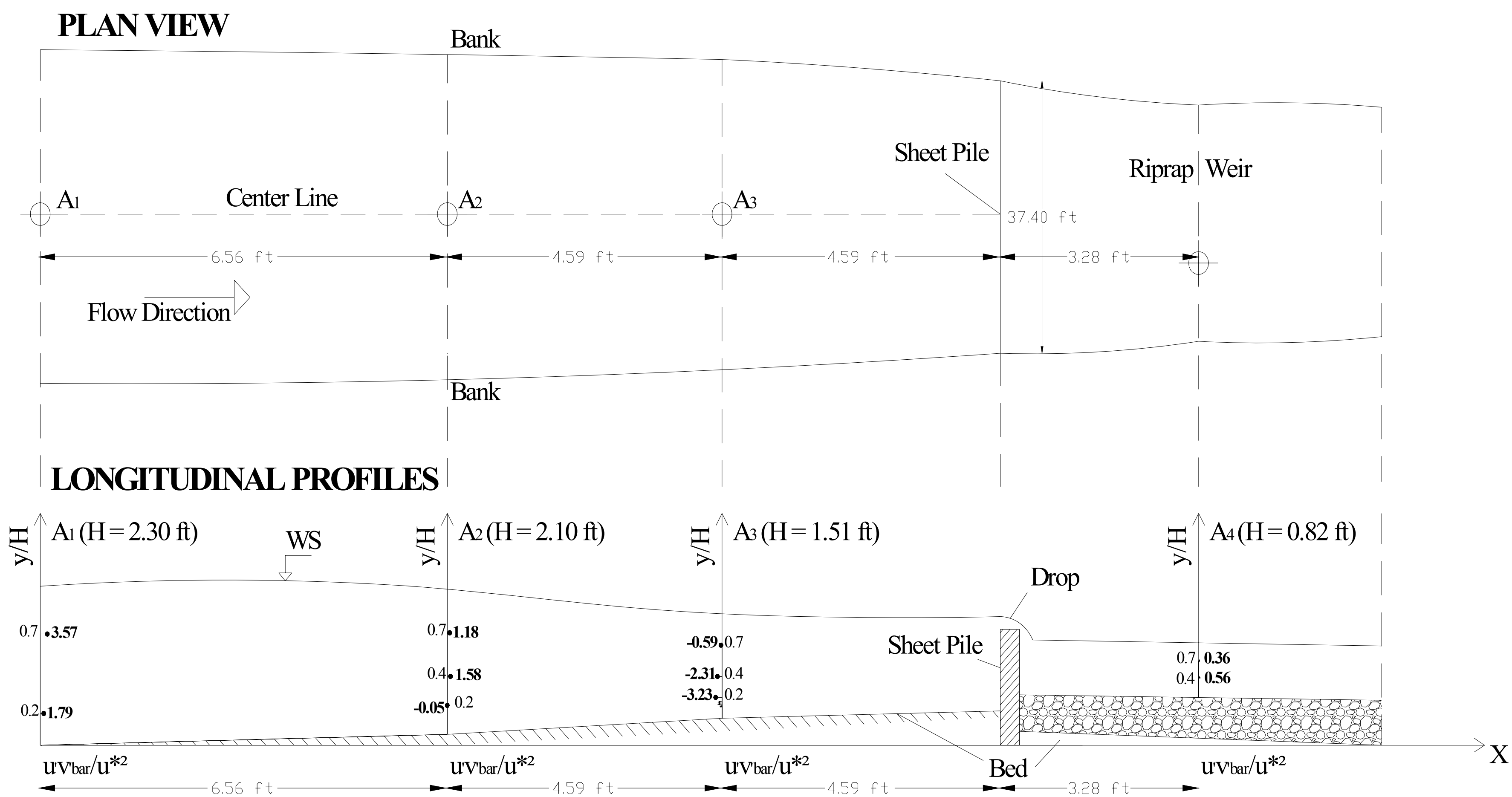


Figure 55e. u'v'$_{bar}$/u*^{2} diagram for riprap weir

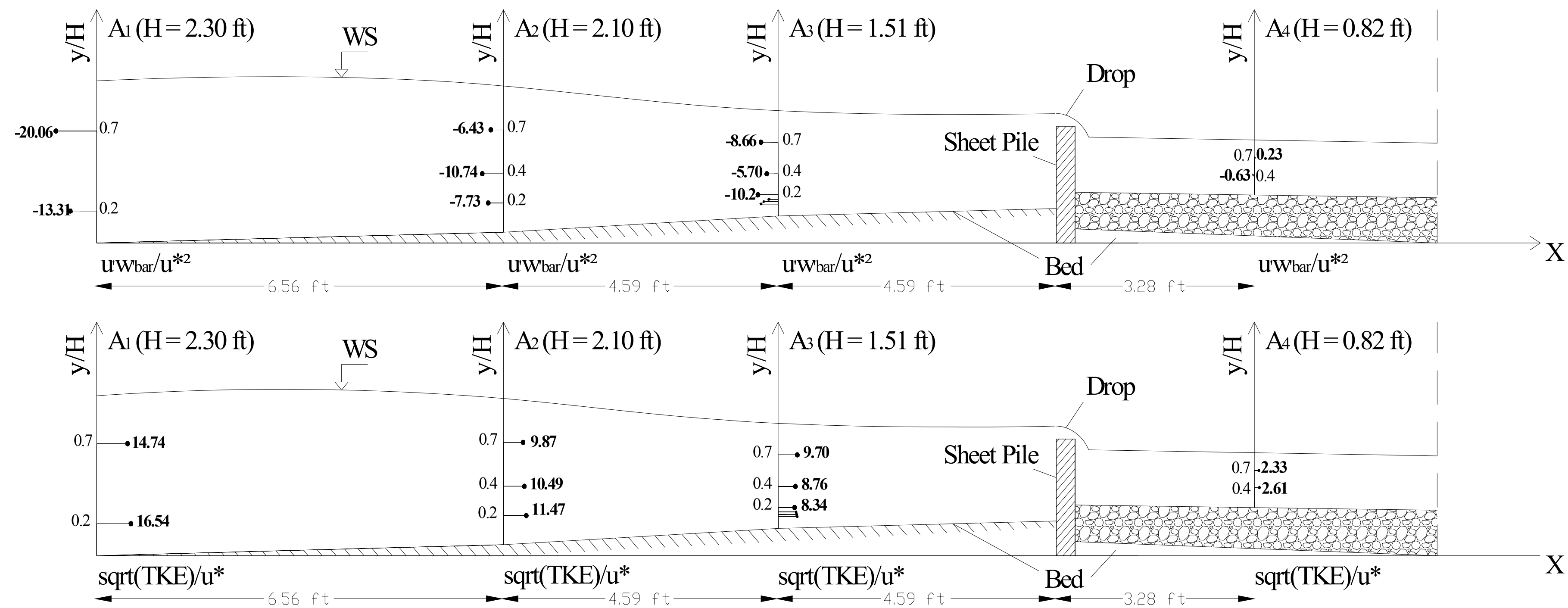


Figure 55f. u’w’$_{bar}$/u*^{2} and sqrt(TKE)/u* diagrams for riprap weir

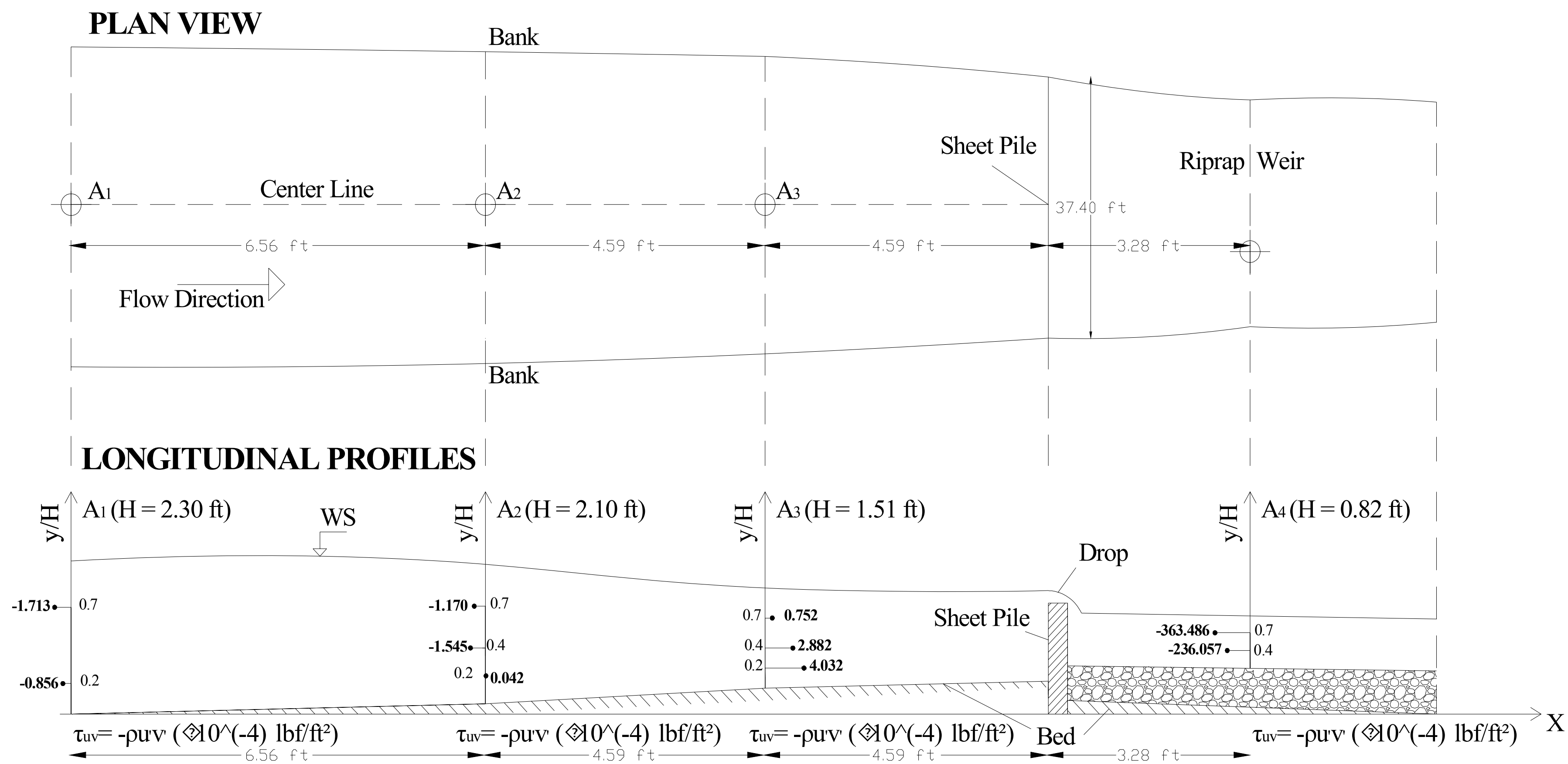


Figure 55g. τ_{uv} diagram for riprap weir

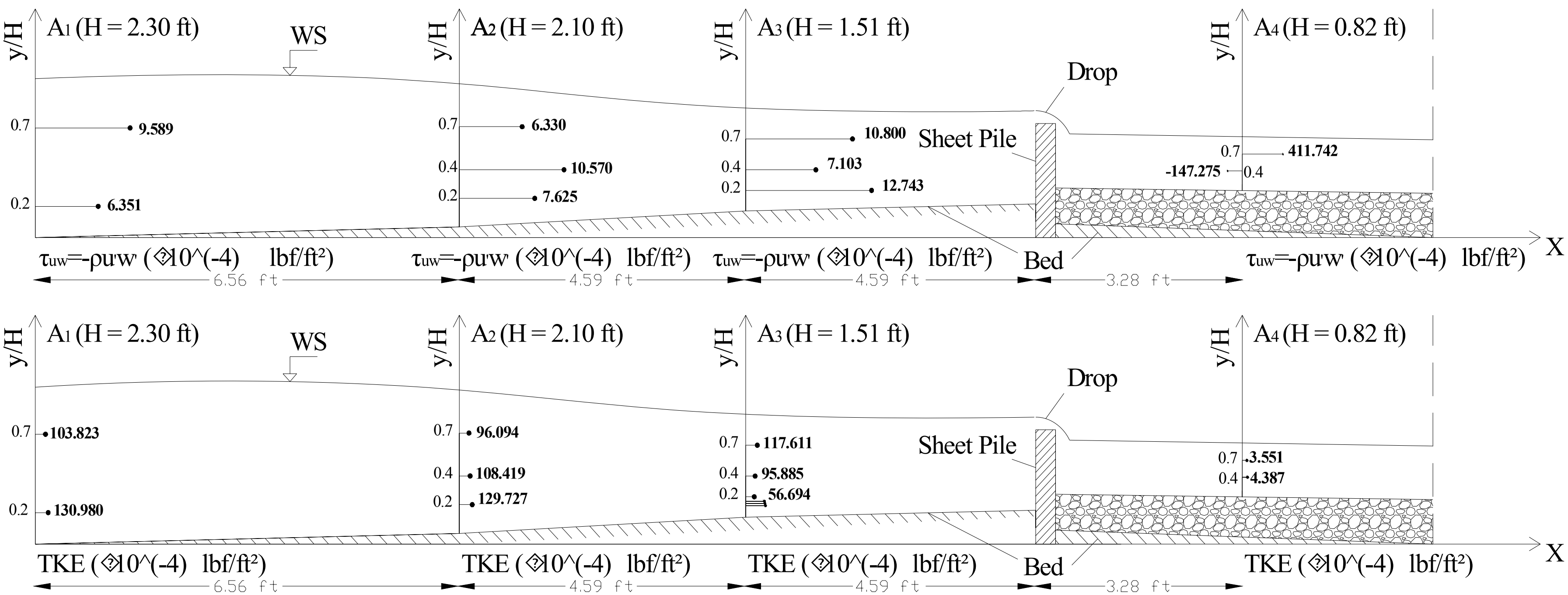


Figure 55h. τ_{uw} and TKE diagrams for riprap weir

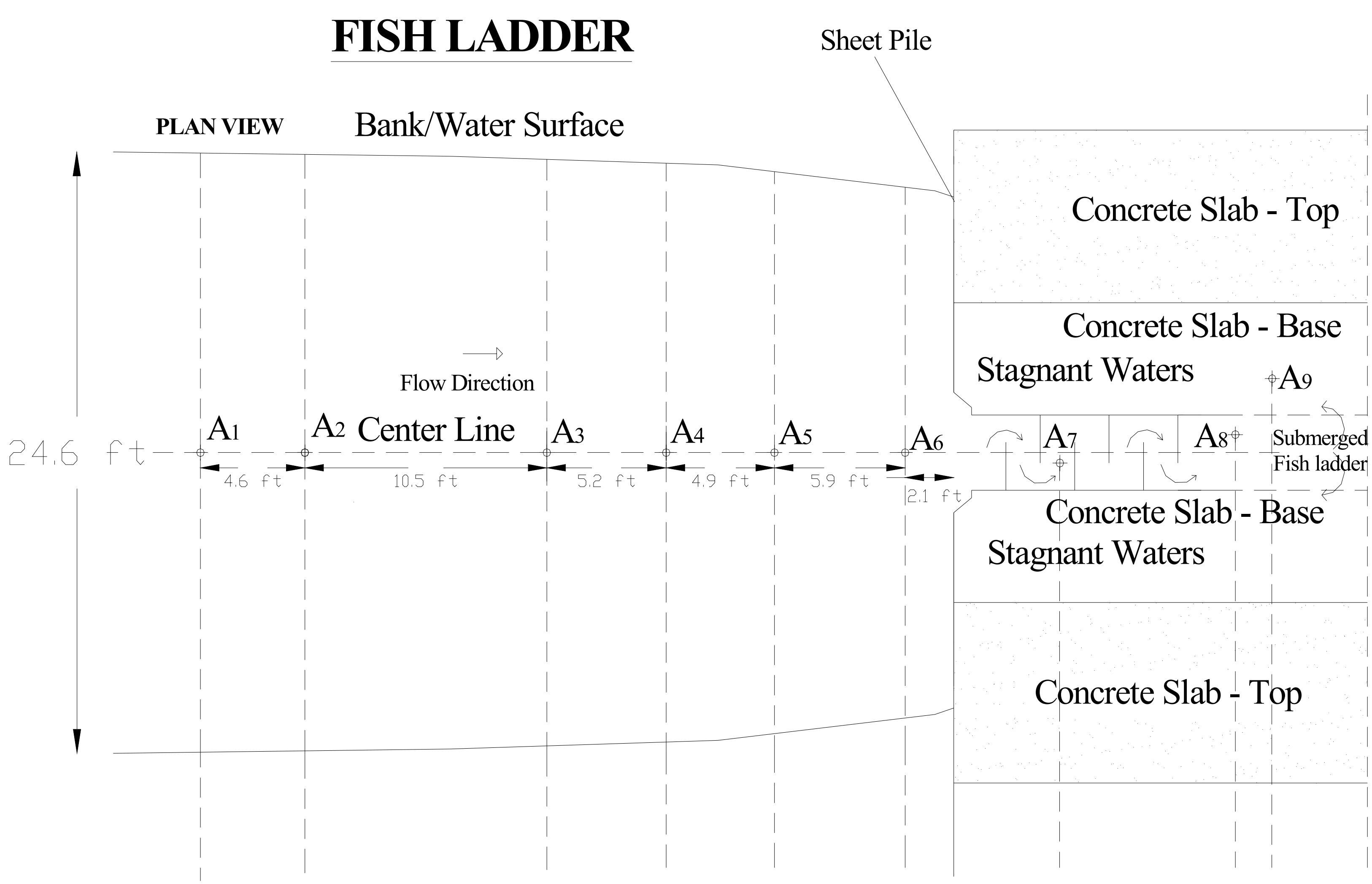


Figure 56a. Plan view of fish ladder

APPENDIX C: TURBULENT MEASUREMENTS

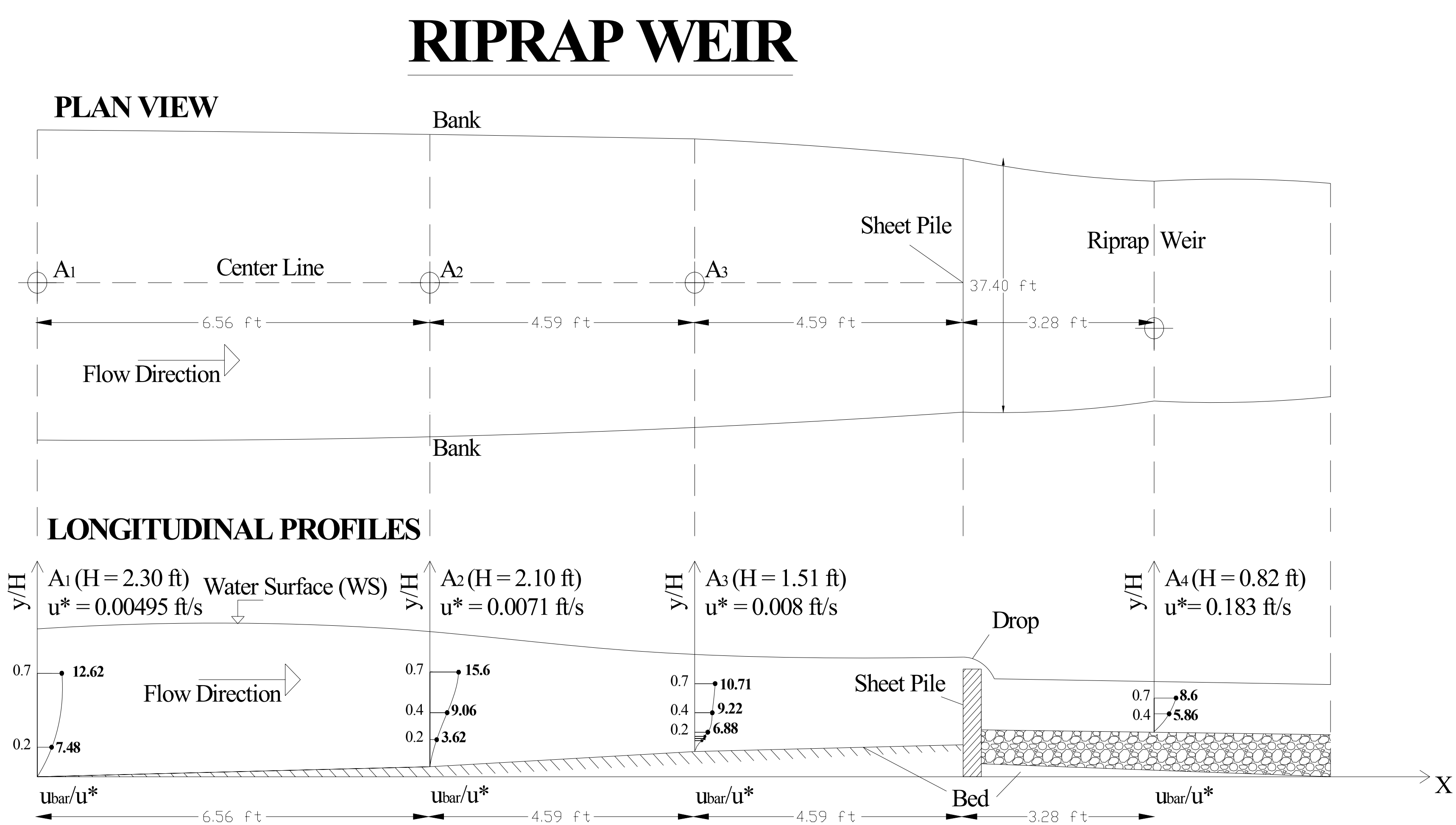


Figure 55a. u_{bar}/u^* diagram for riprap weir

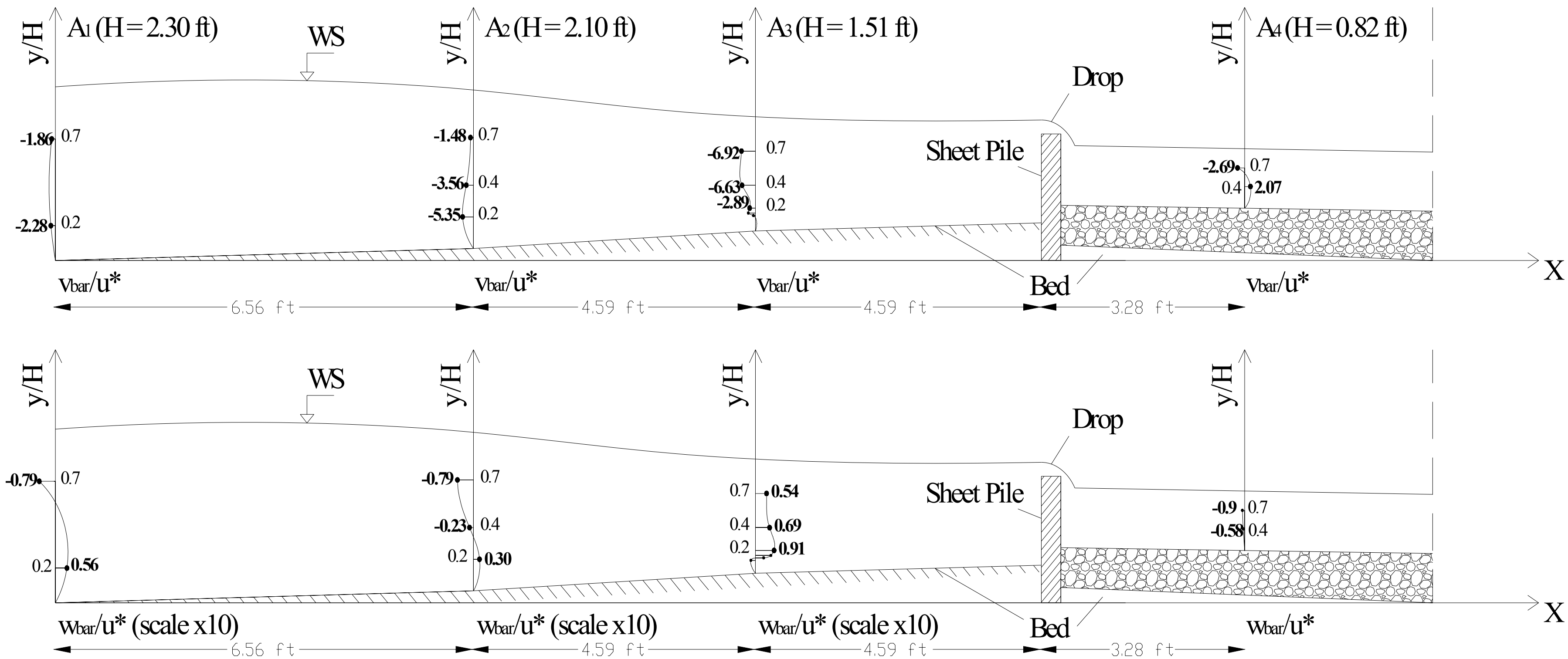


Figure 55b. v_{bar}/u^* and w_{bar}/u^* diagrams for riprap weir

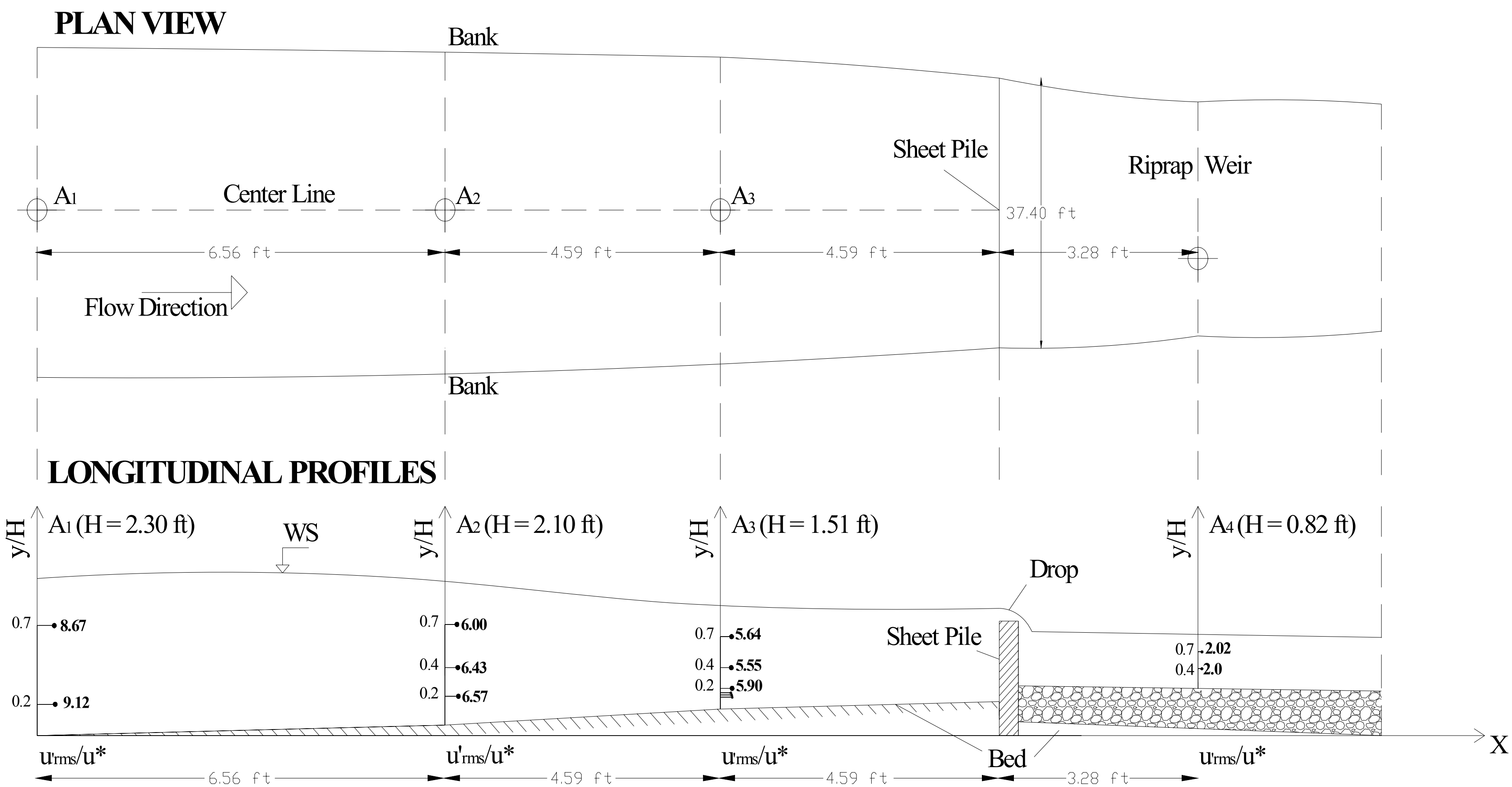


Figure 55c. u'_{rms}/u^* diagram for riprap weir

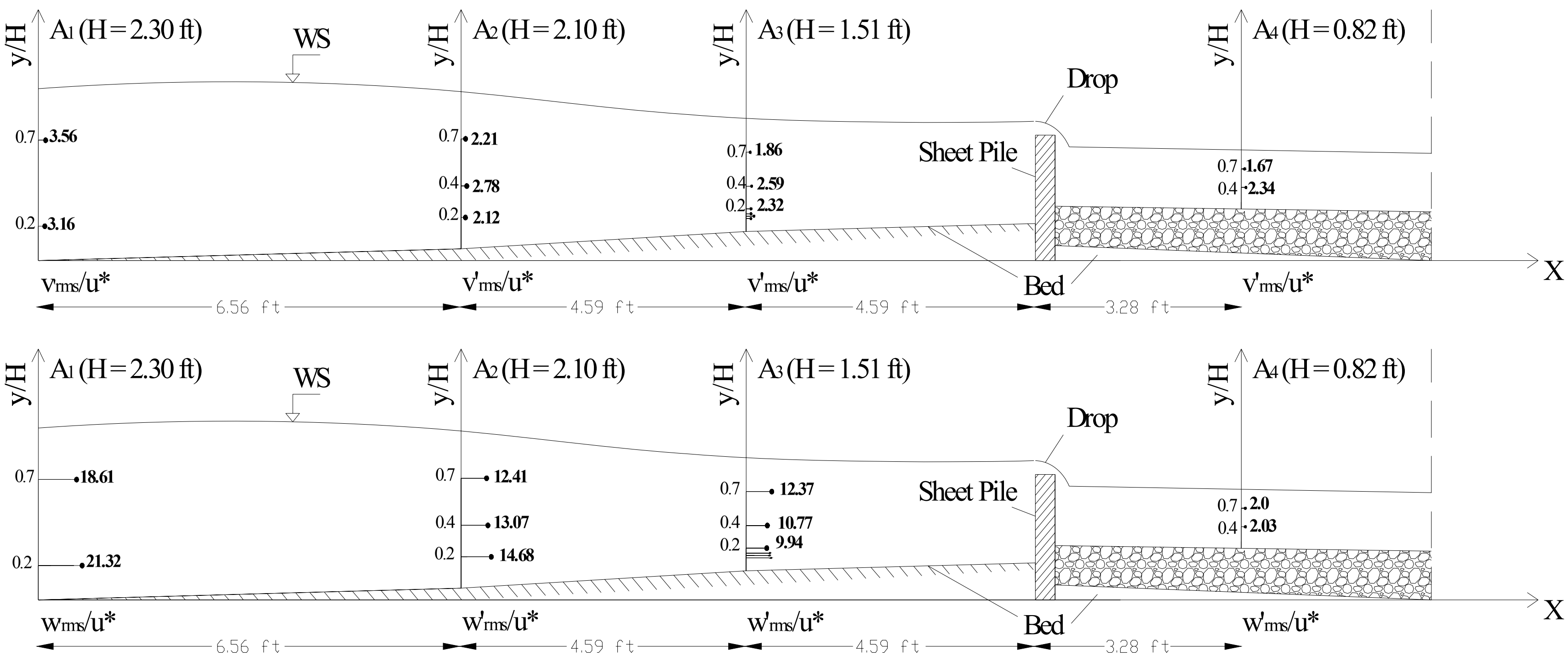


Figure 55d. v'_{rms}/u^* and w'_{rms}/u^* diagrams for riprap weir

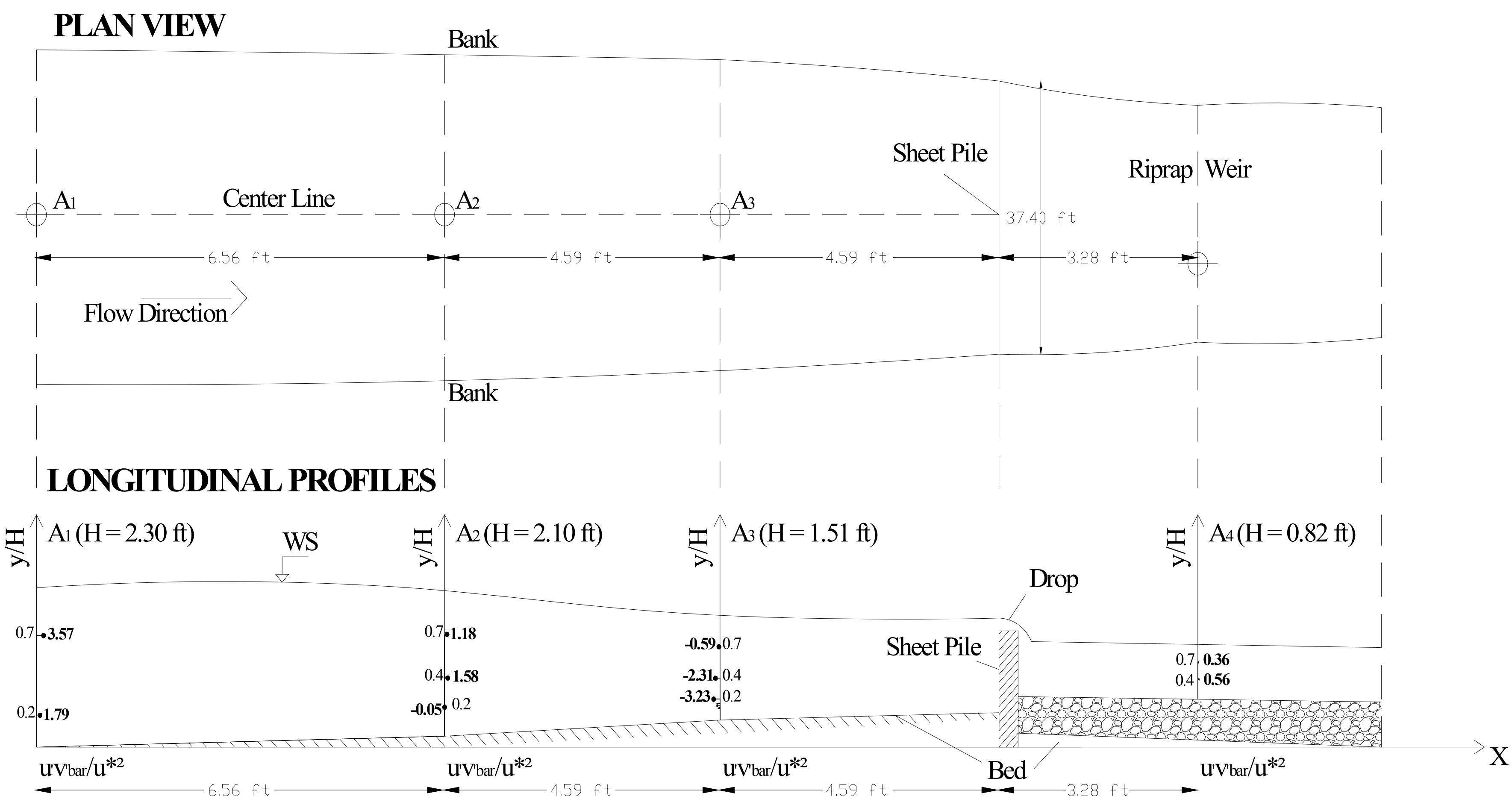


Figure 55e. $u'v'_{bar}/u^{*2}$ diagram for riprap weir

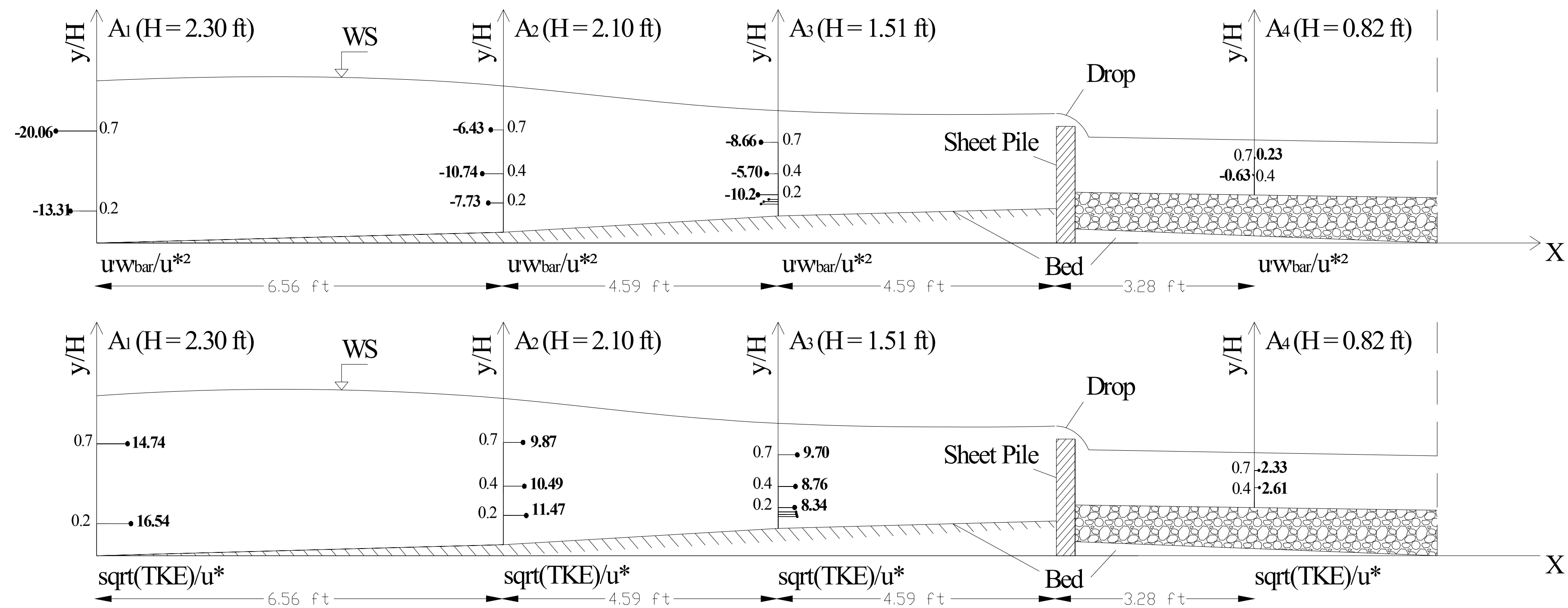


Figure 55f. u’w’$_{bar}$/u*^{2} and sqrt(TKE)/u* diagrams for riprap weir

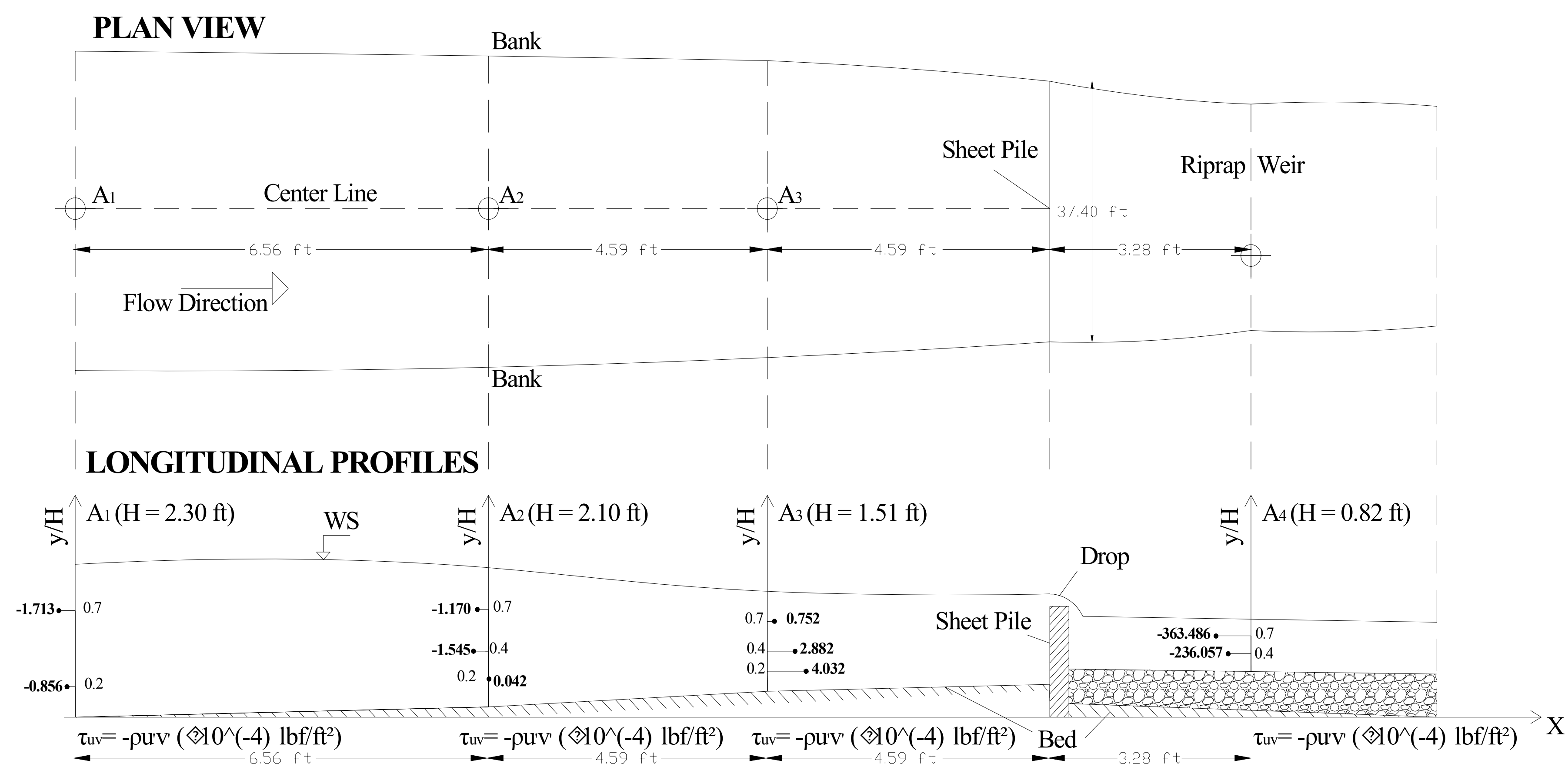


Figure 55g. τ_{uv} diagram for riprap weir

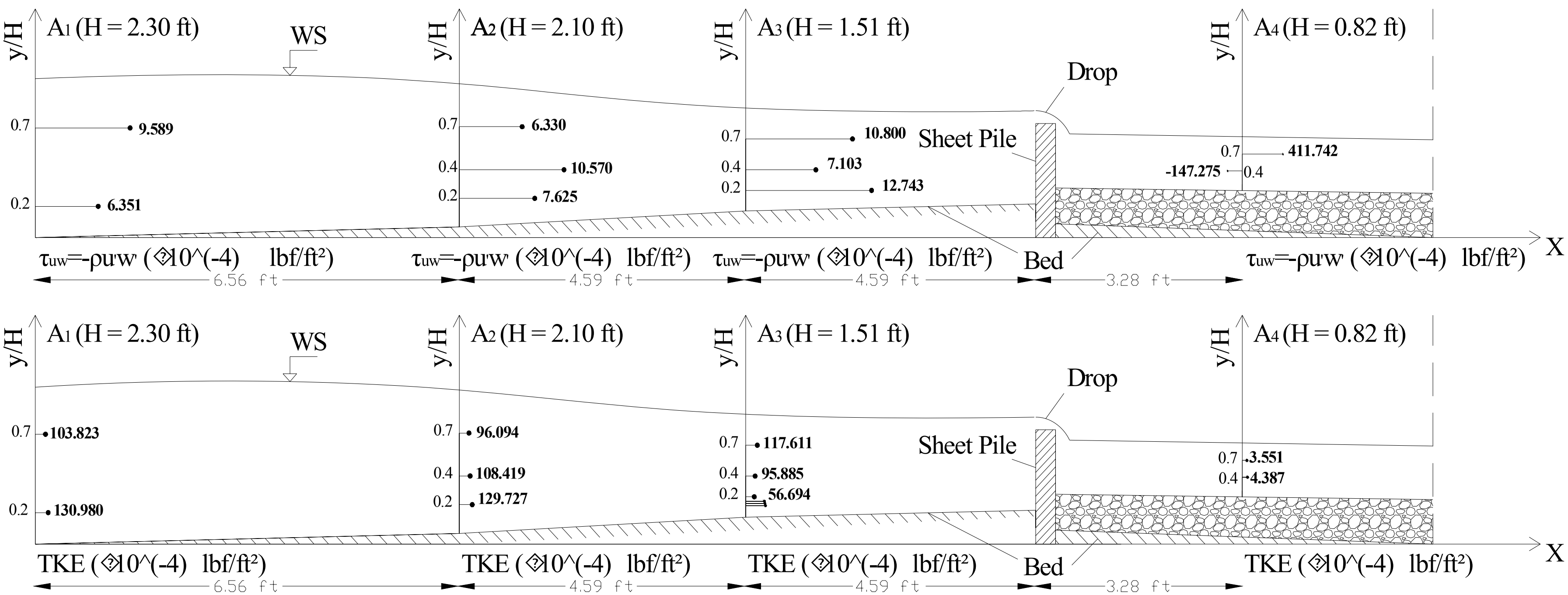


Figure 55h. τ_{uw} and TKE diagrams for riprap weir

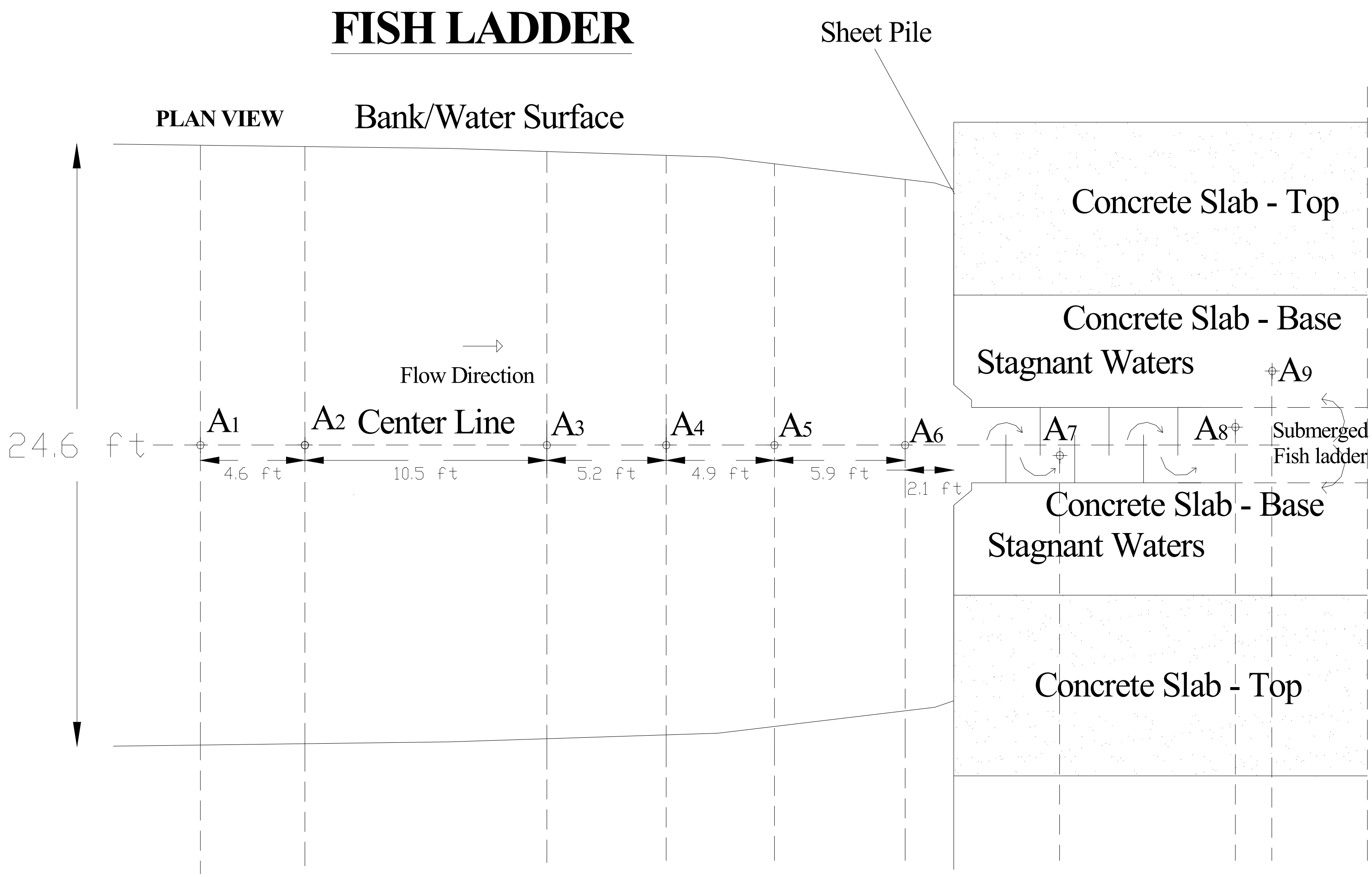


Figure 56a. Plan view of fish ladder

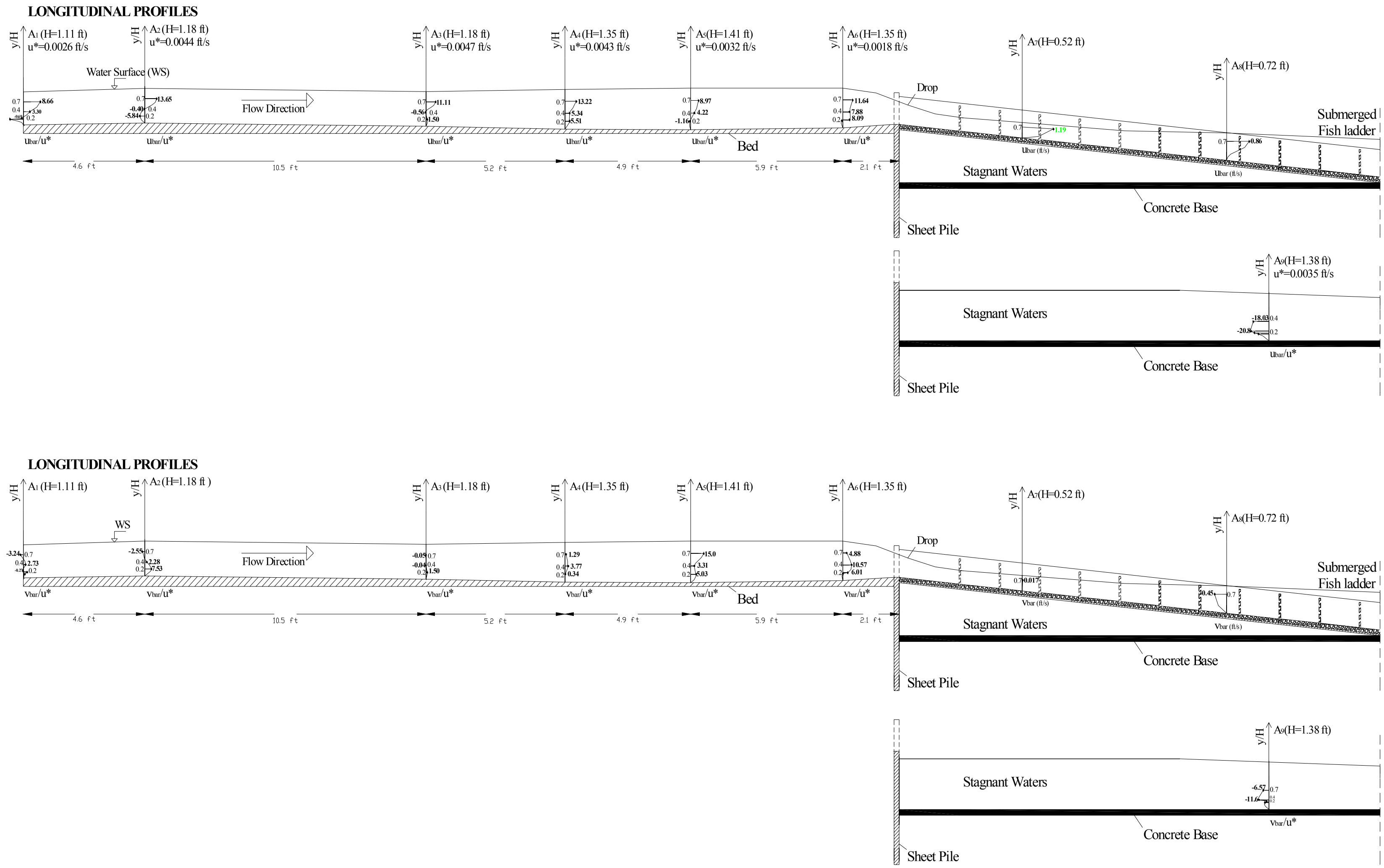


Figure 56b. u_{bar}/u^* and v_{bar}/u^* diagrams for fish ladder

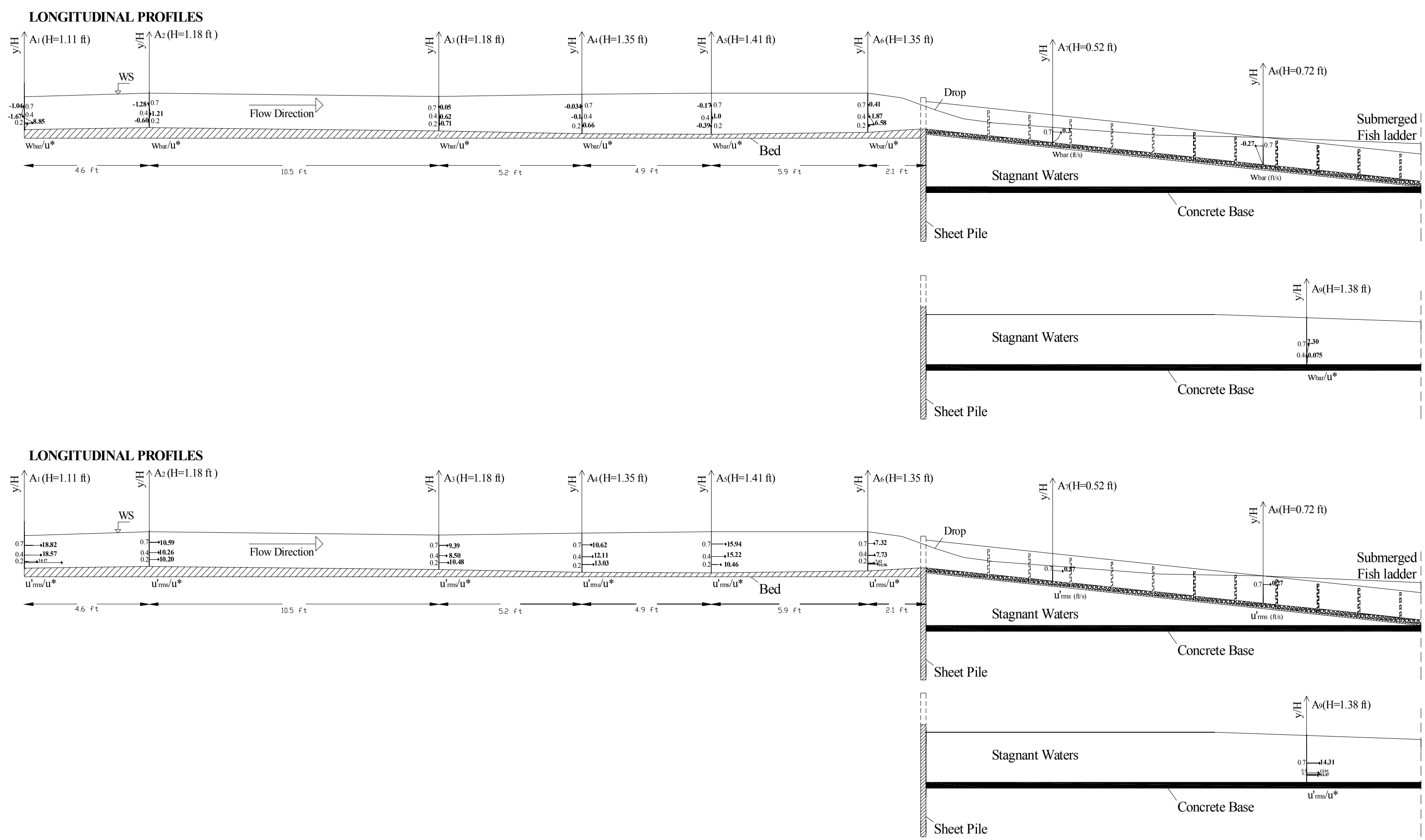


Figure 56c. w_{bar}/u^* and u'_{rms}/u^* diagrams for fish ladder

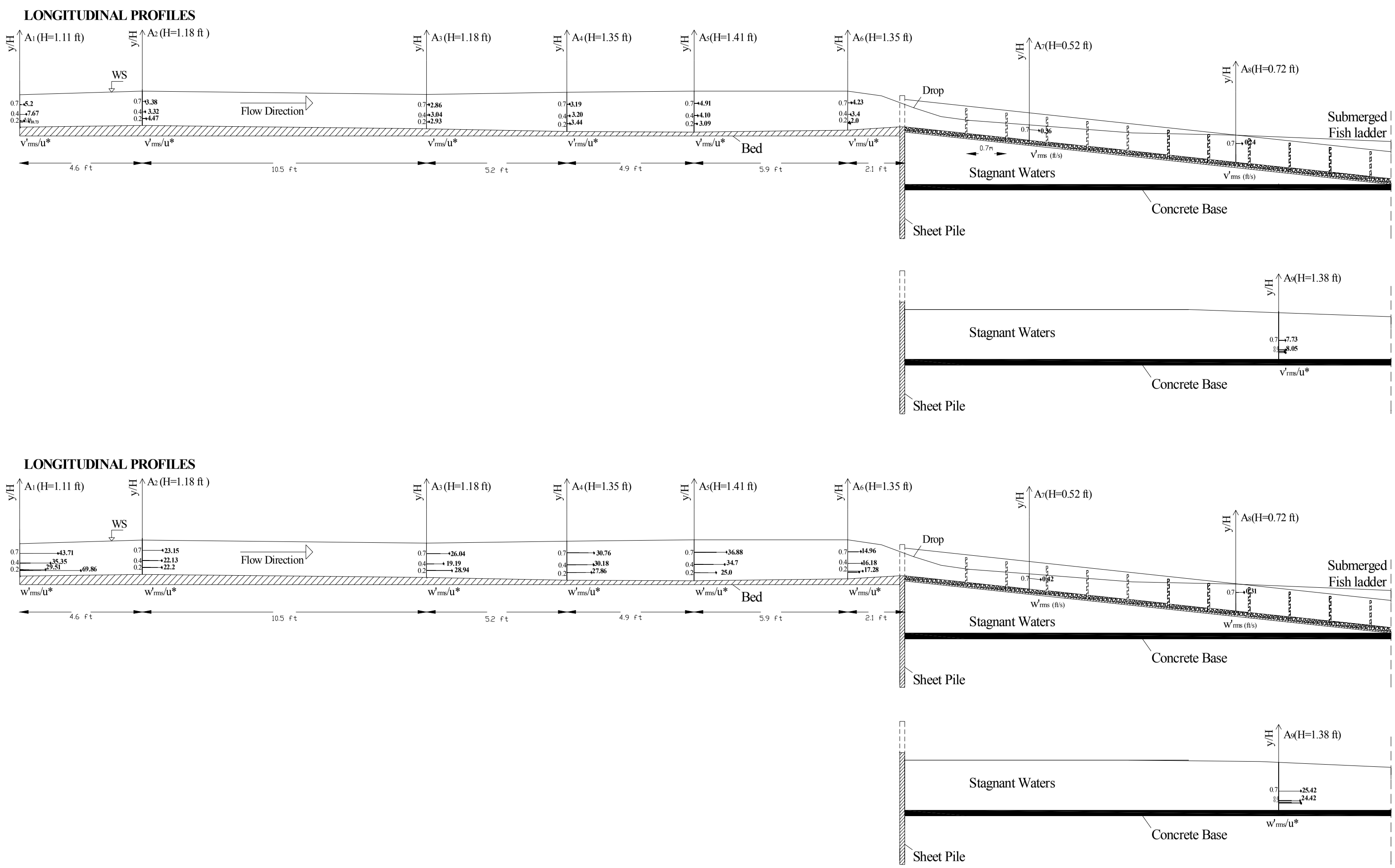


Figure 56d. v'_{rms}/u^* and w'_{rms}/u^* diagrams for fish ladder

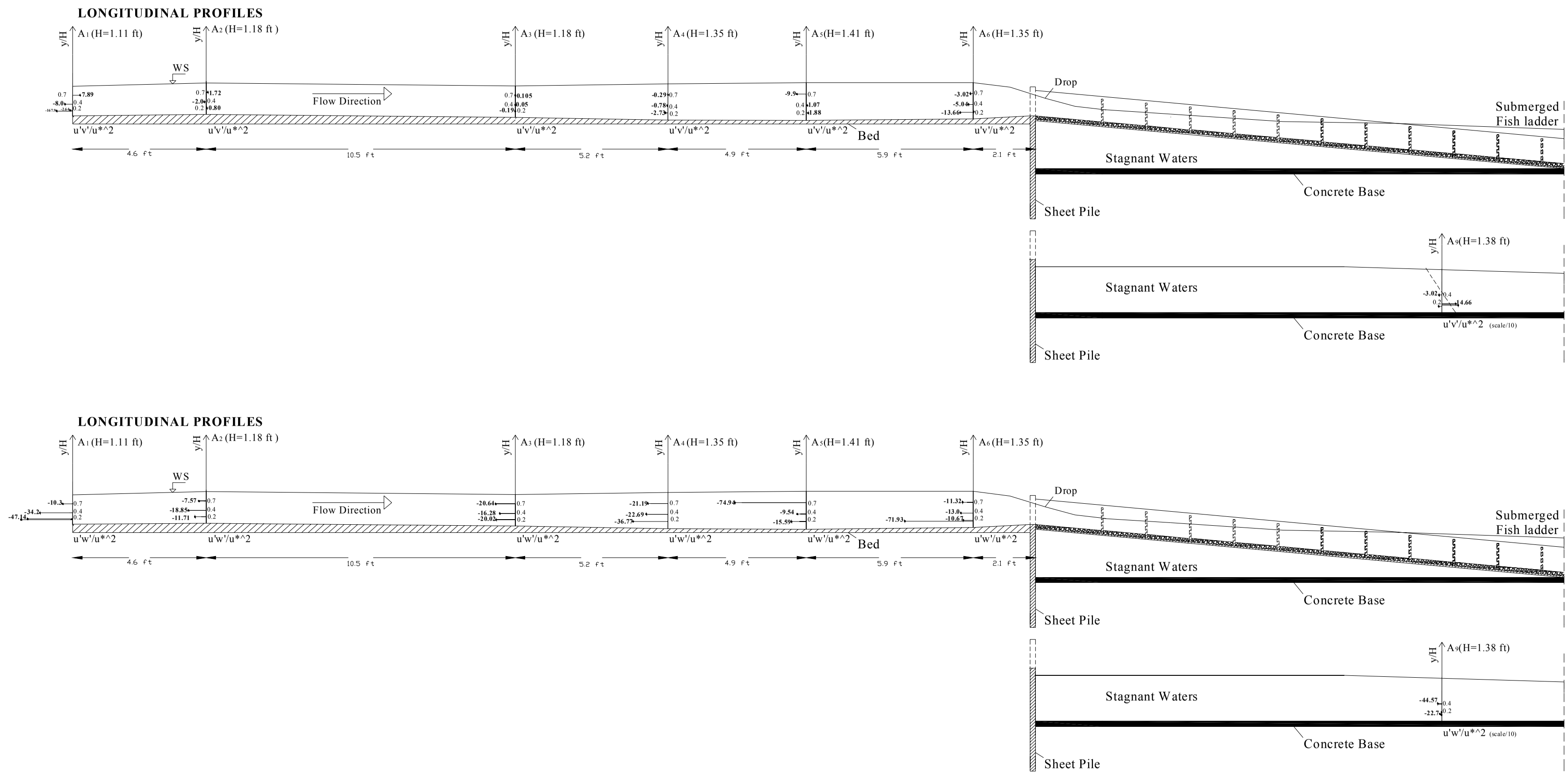


Figure 56e. $u'v'_{bar}/u*^2$ and $u'w'_{bar}/u*^2$ diagrams for fish ladder

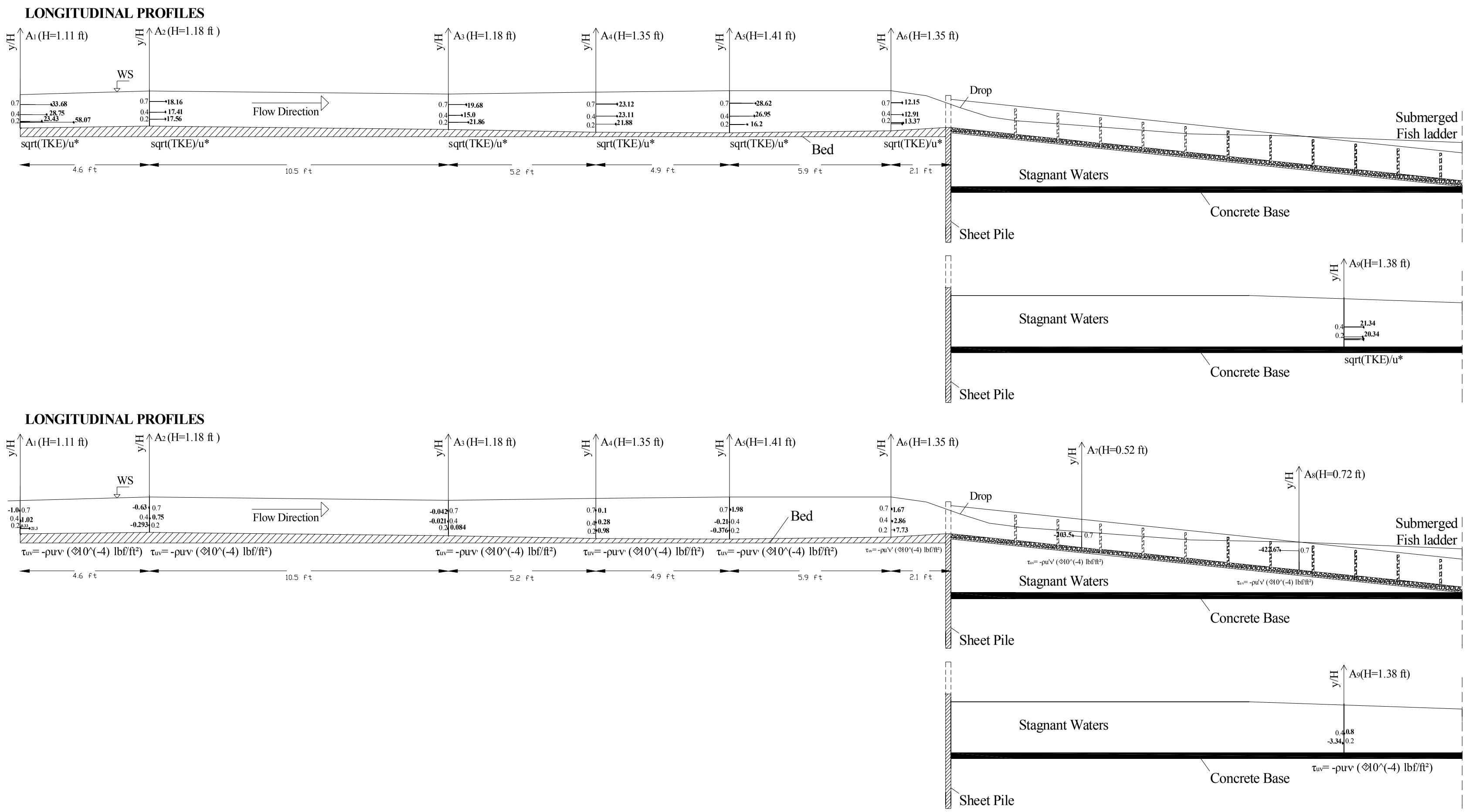
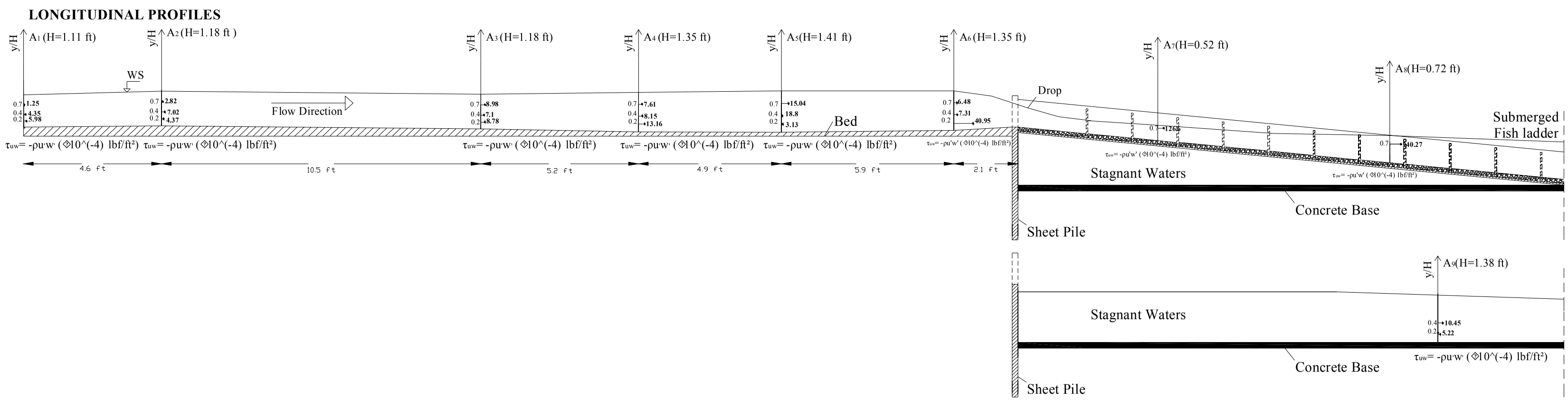


Figure 56f. sqrt(TKE)/u* and τ_{uv} diagrams for fish ladder



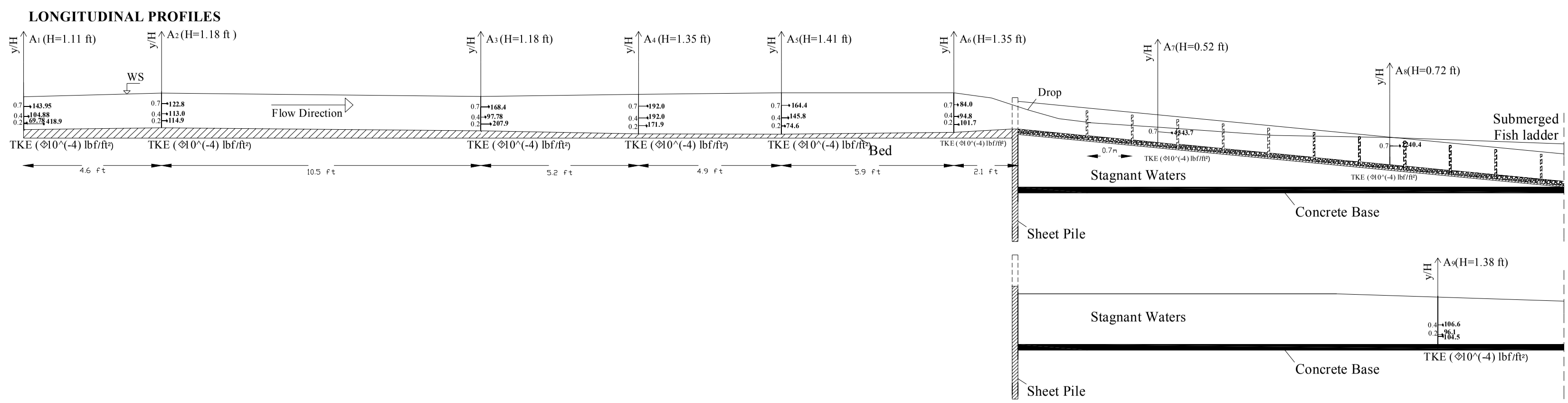


Figure 56g. τ_{uw} and TKE diagrams for fish ladder

APPENDIX D: FISH LADDER DESIGN

Applying the continuity equation upstream of a fish ladder and at the entrance we can get a relation between the appropriate width of the ladder b (ft) and the design discharge Q (ft^3/s) (Figure 57);

$$Q_{upstream} = Q_{entrance} = Q \Rightarrow Q = V_e b h_e \Rightarrow b = \frac{Q}{V_e h_e}$$

where V_e and h_e is the velocity and depth at the entrance of the fish ladder respectively. Because the requirement for fish passage is V_{max}=4ft/s and Y_{min}=1ft (apply here 2ft), the required width of the ladder is;

$$b = \frac{Q}{V_e h_e} \Rightarrow b = \frac{Q}{4 \times 2} \Rightarrow b = \frac{Q}{8}(ft)$$

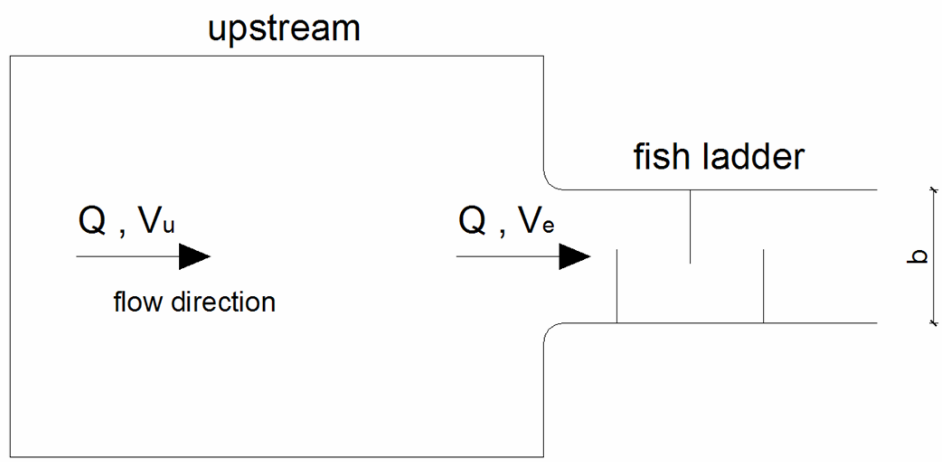


Figure 57. Design of the fish ladder

APPENDIX E: SAMPLE SPREADSHEET FOR FIELD WORK

<table>
<tr><td>Structure description</td><td colspan="6"></td></tr>
<tr><td>Date of Evaluation</td><td colspan="6"></td></tr>
<tr><td>Stream</td><td colspan="3"></td><td colspan="2">County</td><td></td></tr>
<tr><td>Location</td><td colspan="6"></td></tr>
<tr><td>Weather Conditions</td><td colspan="6"></td></tr>
<tr><td>Weir slope</td><td colspan="6"></td></tr>
<tr><td>Weir width</td><td colspan="6"></td></tr>
<tr><td>Estimated Discharge (LSPIV)</td><td colspan="2"></td><td colspan="3">Date of Estimation</td><td></td></tr>
<tr><td>Depth upstream</td><td colspan="6"></td></tr>
<tr><td>Velocity upstream (FLOWTRACKER)</td><td colspan="6"></td></tr>
<tr><td>Depth atop</td><td colspan="6"></td></tr>
<tr><td>Velocity atop (FLOWTRACKER)</td><td colspan="6"></td></tr>
<tr><td>Shear stress and level of turbulence (Field ADV)</td><td colspan="6"></td></tr>
<tr><td colspan="2">Vertical distance upstream-downstream of weir</td><td colspan="5"></td></tr>
<tr><td colspan="2">Distance of GCS from bridge</td><td colspan="5"></td></tr>
<tr><td colspan="2">Average diameter of riprap material</td><td colspan="5"></td></tr>
<tr><td colspan="2">Streambed material</td><td>Clay</td><td>Silt</td><td>Sand</td><td>Gravels</td><td></td></tr>
</table>