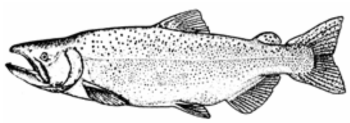
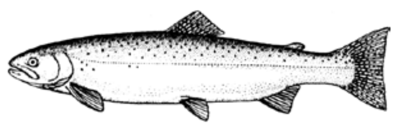
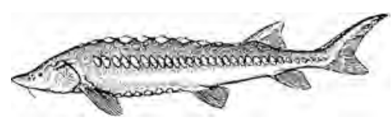
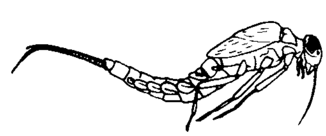
CENTRAL VALLEY PROJECT IMPROVEMENT ACT
FISHERIES INVESTIGATIONS

Annual Progress Report
Fiscal Year 2016

U.S. Fish and Wildlife Service
Lodi Fish and Wildlife Office
850 S. Guild Avenue, Suite 105
Lodi, California 95240

Prepared by staff of
The Anadromous Fish Restoration Program

PREFACE

The following is the Annual Progress Report, Central Valley Project Improvement Act Fisheries Investigations. The purpose of these investigations is to provide scientific information to other CVPIA programs to use in assessing fisheries restoration actions. The purpose of this report is to provide an update on the Anadromous Fish Restoration Program's CVPIA-funded activities and accomplishments during fiscal year 2016 to interested stakeholders.

The field work described herein was conducted by Mark Gard, Rick Williams, John Henderson, Tricia Parker Hamelberg, Tricia Bratcher, Kes Benn, Paul Cadrett, Zack Jackson, Laura Heironimus, Michele Buckhorn, Steve Thomas and April McEwan.

Written comments or questions can be submitted to:

Mark Gard, Senior Biologist
Anadromous Fish Restoration Program
U.S. Fish and Wildlife Service
Lodi Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, California 95825

Mark_Gard@fws.gov

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OVERVIEW

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act provided for enactment of all reasonable efforts to double sustainable natural production of anadromous fish stocks including the four races of Chinook salmon (fall, late-fall, winter, and spring), steelhead trout, white and green sturgeon, American shad and striped bass. In 2016, the following fisheries investigation tasks (Figure 1) were selected for study: 1) Feather River Sunset Pumps pre-restoration assessment; 2) Clover Creek upstream passage study; 3) Bear Creek upstream passage study; 4) Lower Deer Creek Falls fish ladder pre-restoration monitoring; 5) Deer Creek Irrigation District Diversion Dam roughened channel fish passage pre-restoration monitoring; 6) Mill Creek Upper Diversion Dam fish ladder pre-restoration monitoring; 7) Mill Creek Ward Dam fish ladder passage assessment; 8) Antelope Creek Lower Slab passage assessment; 9) Antelope Creek floodplain feasibility study; 10) Sacramento River juvenile green sturgeon habitat data collection; 11) San Joaquin River white sturgeon spawning habitat data collection; 12) Stanislaus River upstream passage assessment; 13) Yuba River Hammon Bar validation velocity data collection; 14) North Fork Cottonwood Creek flows investigation; 15) Feather Water District screen evaluation; and 16) Central Valley Structured Decision Model technical support.

We performed the following fisheries investigations to assess fisheries restoration actions:

1) In FY 2016, we completed a hydraulic model of the Sunset Pumps weir on the Feather River and developed information to use in designing a solution to the fish passage problem at this location.
2) We collected data on critical riffles to assess the relationship between stream flows and upstream passage of anadromous salmonids on Clover Creek.
3) We collected data on critical riffles to assess the relationship between stream flows and upstream passage of anadromous salmonids on Bear Creek.
4) We conducted pre-project monitoring of the Lower Deer Creek Falls fish ladder project.
5) We conducted pre-project monitoring of the Deer Creek Irrigation District Diversion Dam roughened channel fish passage project.
6) We conducted pre-project monitoring of the Mill Creek Upper Diversion Dam fish ladder project.
7) We developed a hydraulic model at the Mill Creek Ward Dam fish ladder project to develop a solution to upstream passage at this location.
8) We modified a hydraulic model at the Antelope Creek Lower Slab to develop a solution to the upstream passage barrier at this location.
9) We conducted a feasibility study of potential floodplain restoration actions on Antelope Creek.
10) We collected topographic and hydraulic data for portions of the Sacramento River where juvenile green sturgeon have been detected.
11) We collected topographic and hydraulic data for portions of the San Joaquin River where white sturgeon spawning has been observed.

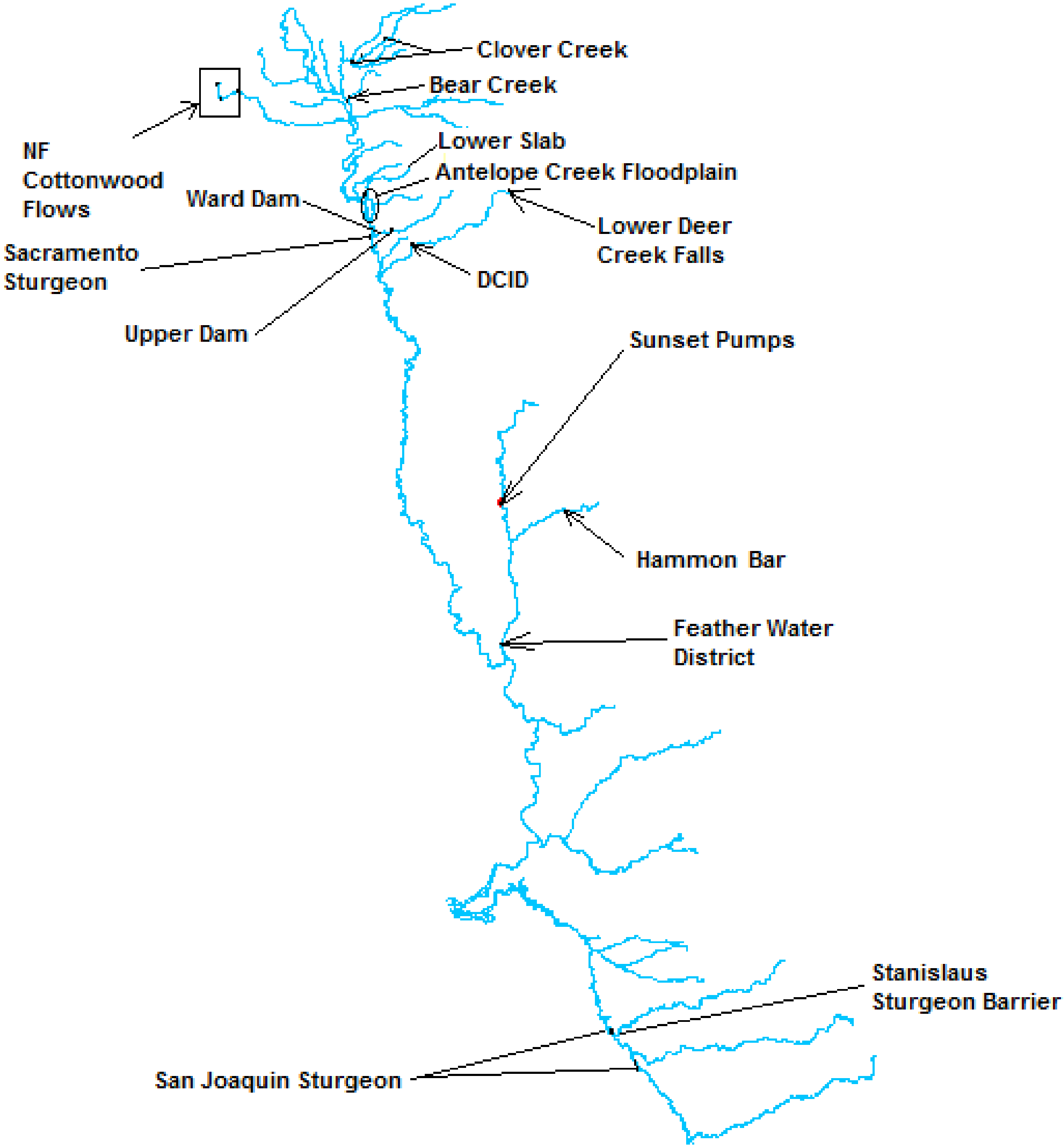

Figure 1
Fiscal Year 2016 Fisheries Investigation Tasks

12) We collected topographic and hydraulic data to assess a potential sturgeon upstream passage barrier on the Stanislaus River.
13) We collected velocity data to validate a habitat model of the Yuba River Hammon Bar restoration project.
14) We conducted a flows investigation on North Fork Cottonwood Creek.
15) We conducted a hydraulic evaluation of the Feather Water District cone screens, with funding from the Anadromous Fish Screen Program.
16) We reviewed the Central Valley Structured Decision Model to identify needed changes to the model and sources of data that could be used to improve the parameterization of the model, with funding from CVPIA Program Administration.

The results of these scientific investigations were provided to other CVPIA programs. The following sections summarize the sixteen project activities that were performed between October 2015 and September 2016.

FISHERIES INVESTIGATIONS

Feather River Sunset Pumps Upstream Passage Assessment

Methods

The purpose of this task was to develop a hydraulic model of the Feather River at the Sunset Pumps weir (at RM 119.4) near Live Oak, California to assess upstream passage of spring-run Chinook salmon and sturgeon over a range of flows. Based on data from the California Department of Water Resources (CDWR), the 10-foot tall Sunset Pumps boulder weir (Figure 2) is a barrier to upstream passage of green sturgeon for Feather River flows less than 6,000 cfs. The topography data collected to develop the hydraulic model will also be useful in designing any potential restoration projects to solve the upstream passage barrier at this location.

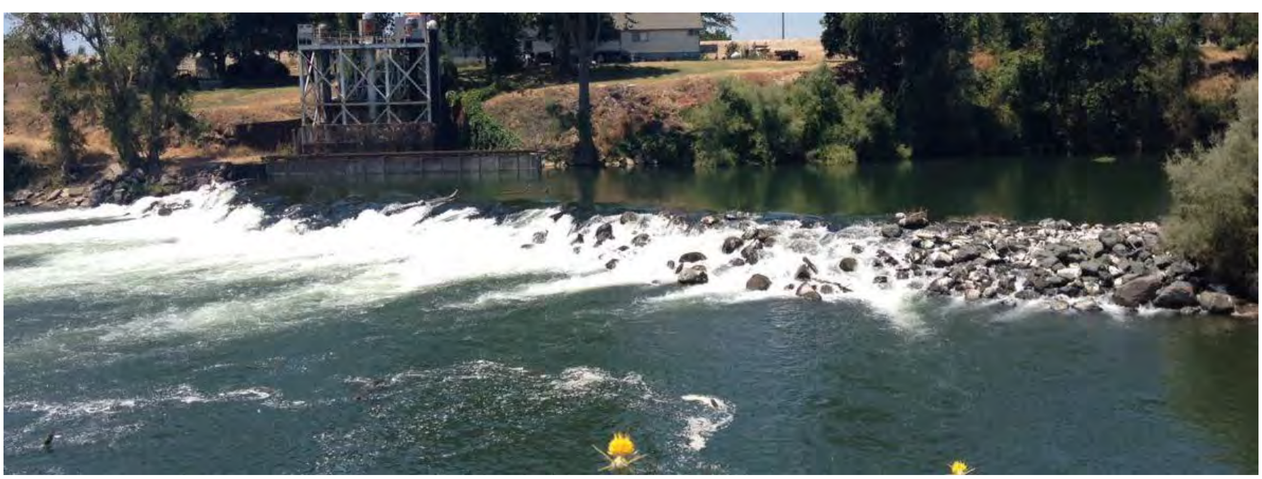

Figure 2
Sunset Pumps weir

The topographic data for the 2-D model (contained in bed files) are first processed using the R2D_Bed software, where breaklines are added to produce a smooth bed topography. The resulting data set is then converted into a computational mesh using the R2D_Mesh software, with mesh elements sized to reduce the error in bed elevations resulting from the mesh-generating process to 0.1 foot where possible, given the computational constraints on the number of nodes. The resulting mesh is used in River2D to simulate depths and velocities at the flows to be simulated. We used data from a pressure transducer that we installed at the downstream end of the 3400-foot-long study site[1] to develop the downstream boundary conditions for the hydraulic model. The initial bed roughnesses used by River2D are based on the observed substrate sizes and cover types, using the conversions in Table 1. A multiplier is applied to the resulting bed roughnesses, with the value of the multiplier adjusted so that the water surface elevation (WSEL) generated by River2D at the inflow end of the site match the WSEL measured at the inflow end of the site[2]. The River2D model is run at the simulation flows to use in assessing upstream passage. Upstream passage of adult green sturgeon was evaluated using the following criteria: 1) depth greater than three feet with a width greater than ten feet; and 2) velocity less than six feet per second[3].

A bed file representing conditions after removal of the weir was generated by deleting the bed topography points for the weir and adding breaklines to connect features above and below the weir. Topography of the site with and without the weir were imported into Civil3D to compute the volume of the weir. The volume of sediment upstream of the weir that would be expected to move downstream following removal of the weir was computed in Civil3D by defining a feature line following the thalweg upstream of the weir, and then sloped grading to daylight near the banks.

Two HEC-RAS models were extracted from the CDWR Sacramento Valley HEC-RAS model to evaluate larger spatial-scale effects of removing the weir: 1) a simplified model only including the Feather River between Jack Slough and Honcut Creek (RM 109.7 to 127.2); and 2) a complete model including the Feather River from the Yuba River to the Oroville Fish Barrier Dam (RM 107.9 to 147.4) and tributaries. The complete model was run at typical low, medium and high flows (864, 2836 and 6745 cfs at the downstream end of the model) to assess effects on upstream diversions. The simplified model was run at 18 flows (ranging from the 1.01 year flow of 619 cfs to the 1,000 year flow of 422,839 cfs)[4] to assess effects of removing the weir on flood risk. On February 12, 2016, at a flow of 954 cfs, we measured the depths of diversion intakes in the 10 miles upstream of the Sunset Pumps weir to assess what effect removing the weir might have on their operation.

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[1] The weir is located 1800 feet upstream of the downstream end of the site.
[2] This is the primary technique used to calibrate the River2D model.
[3] These criteria were selected because they are being used by CDWR to design modifications of the Fremont Weir for upstream passage of adult green sturgeon (James Newcomb, CDWR, personal communication).
[4] These were the Q_{95} flows computed from the Gridley gage for the period 1969 to 1998.

Table 1
Initial bed roughness values

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05, 0.76, 2[5]	9	0.29
10	1.4	9.7	0.57
		10	3.05

Results

In FY 2016, we completed the bed file, developed the mesh file and completed hydraulic simulations of the site both with and without the weir, for flows of 500 to 6,000 cfs, by 500 cfs increments. To calibrate the hydraulic model with the weir, we needed to increase the groundwater transmissivity to a value of 3 (compared to the default value of 0.1) to capture the effect of water going through the boulder weir. This was necessary due to the extreme porosity

[5] For substrate code 9, we used bed roughnesses of 0.76 and 2, respectively, for cover codes 1 and 2, and a bed roughness of 0.05 for all other cover codes. The bed roughness value for cover code 1 (cobble) was estimated as five times the assumed average size of cobble (6 inches [0.15 m]). The bed roughness values for cover code 2 (boulder) was estimated as five times the assumed median size of boulders (1.3 feet [0.4 m]). Bed roughnesses of zero were used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

of the weir. We used the default value for groundwater transmissivity for the hydraulic simulations without the weir. The hydraulic model predicted that all of the flow at the shallowest part of the weir was subsurface for flows of 500 to 1,500 cfs. The shallowest location on the thalweg over the weir had a depth ranging from 0.4 feet at 2,000 cfs to 2.8 feet at 6,000 cfs. Without the weir, the width across the former weir location with a depth greater than 3 feet was 174.5 feet at 500 cfs. The maximum velocity at the former weir location ranged from 0.81 ft/s at 500 cfs to 4.35 ft/s at 6,000 cfs.

The estimated volume of the weir is 7,325 cubic yards, while the estimated volume of material that would be expected to be scoured upstream of the weir (Figures 3 and 4) is 13,576 cubic yards, based on a thalweg going from 11.6 to 11.8 meters through the scour area. The volume of the weir will be useful in estimating the cost of weir removal, while the volume of material that will be scoured will be useful in evaluating the effects of weir removal.

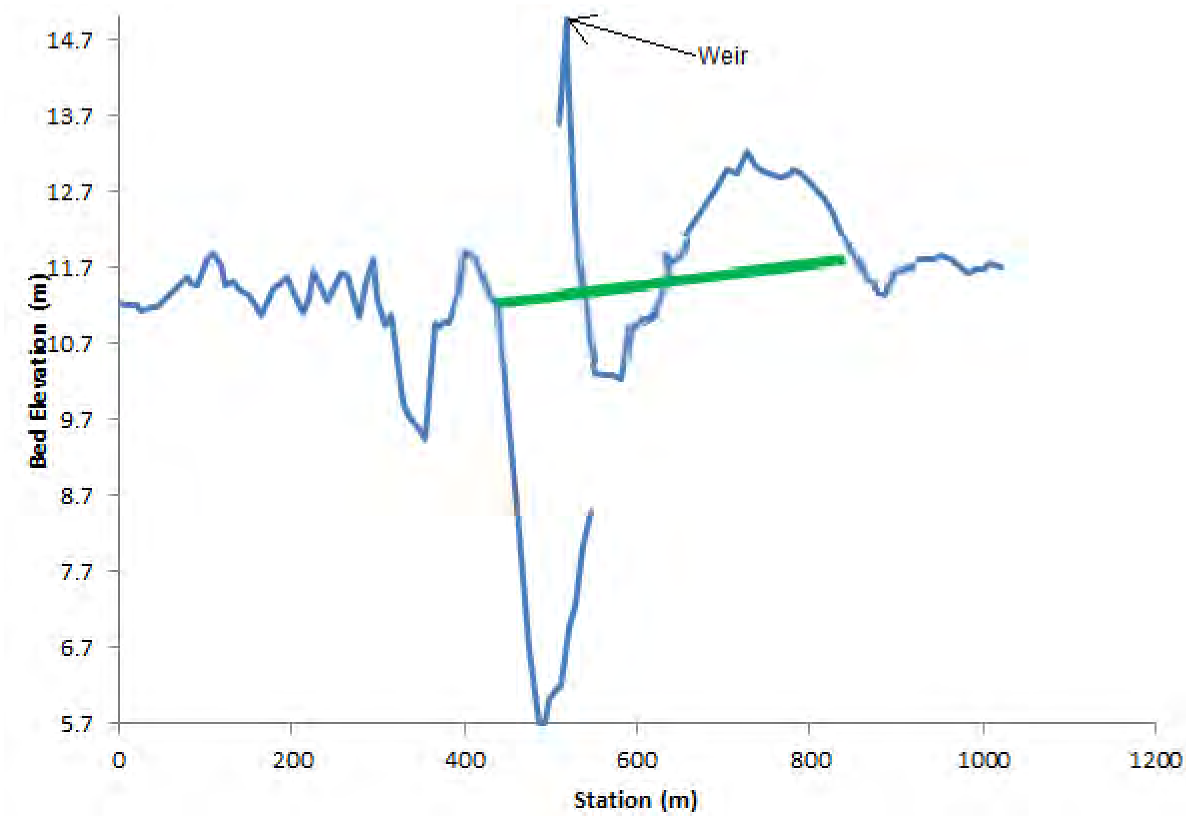

Figure 3
Sunset Pumps Existing Conditions (with weir) Thalweg Profile (blue line). The blue line is broken due to the discontinuity of the thalweg at the weir. Green line is the feature line used to calculate scour volume upstream of the weir.

Elevations Table

Minimum Elevation	Maximum Elevation	Color
5.70	11.91	
11.91	12.80	
12.80	14.20	
14.20	15.26	
15.26	16.55	
16.55	18.05	
18.05	19.28	
19.28	20.00	

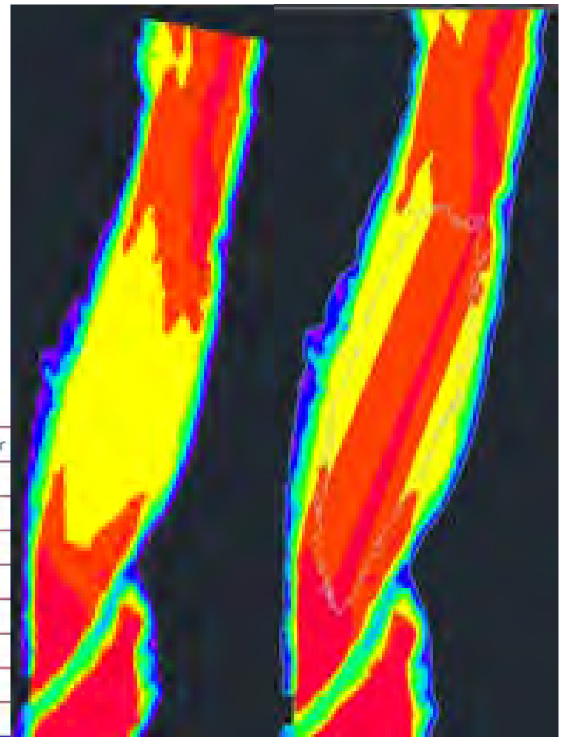

Figure 4
Existing Conditions (with weir, left) and Estimated Post-Scour Conditions (without weir, right) upstream of Sunset Pumps weir. Units of Elevation are meters.

Results of the HEC-RAS models are shown in Figures 5 and 6. Removing the weir reduces water surface elevations, particularly at low flows and near the weir location. Removing the weir reduces flood risk at lower flows and has no effect on flood risk at higher flows. As shown in Table 2, lowered river levels associated with removing the weir should have a minimal effect on upstream diversions, requiring an additional two feet of 6-10 inch flexible pipe at the first two diversions upstream of Sunset Pumps, but may require modification of the Live Oak boat ramp.

Discussion

While the River2D model for existing conditions likely underestimated depths over the weir, the results of the model were consistent with CDWR observations that green sturgeon upstream passage is blocked at flows of less than 6,000 cfs. The performance of River2D for existing conditions likely reflects the limited ability of the model to simulate subsurface flows, as well as the complex flow paths through the boulder weir that were not sufficiently captured in our data collection. In addition, localized velocities of water going over the weir likely have a vertical component exceeding 10%, violating one of the basic assumptions of River2D. As a result, the River2D model likely underestimated depths at the weir. In contrast, the River2D simulations of the conditions without the weir do not have any of the above issues associated with them. The modeling confirms that removal of the weir will remove the upstream barrier for adult green sturgeon, even at very low Feather River flows. The results of this study should be of great use in the permitting, design and implementation of this restoration project.

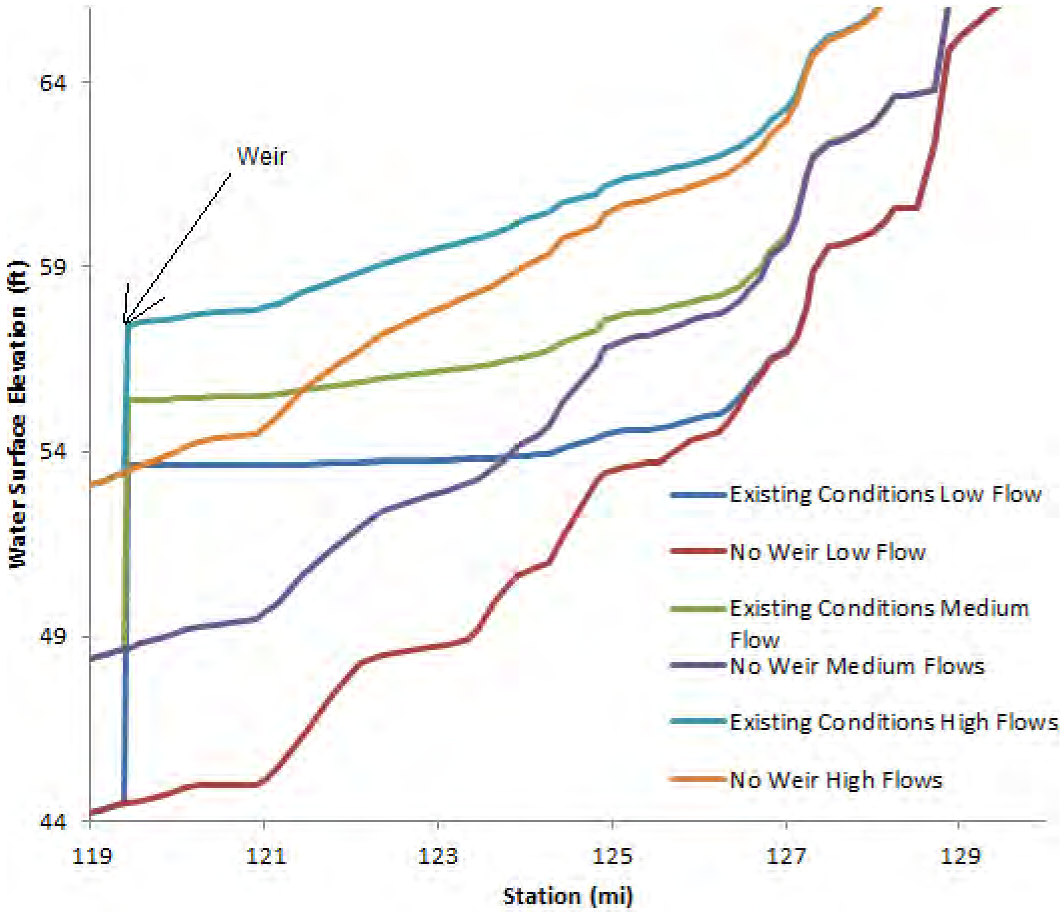

Figure 5
Full HEC-RAS model output showing that the No Weir Low Flow red line option would be a better option than existing conditions

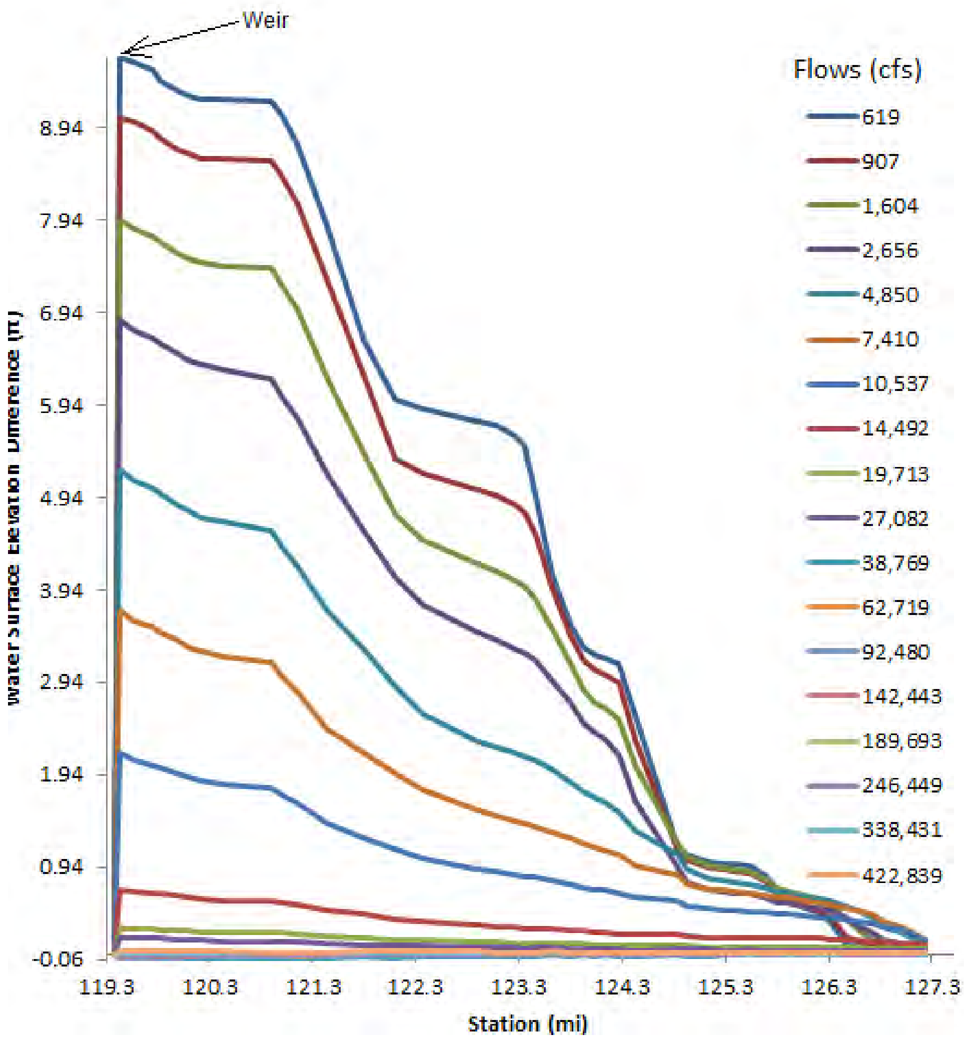

Figure 6
Simplified HEC-RAS model output. Sunset Pumps is at RM 119.4.

Table 2
Depths (ft) at Upstream Diversions and Structures

River Mile	With Weir at 954 cfs	Drop in Stage	Without Weir at 954 cfs
120.1	8.0	8.7	Dry
120.9	7.0	8.7	Dry
121.2	No pipe in water	8.2	Unknown
122.4 (Live Oak Ramp)	4.5	5.2	Dry
123.3	6.0	4.9	1.1
123.8	6.7	3.5	3.3
123.9	6.3	3.2	3.1
124.9	1.8	1.0	0.8

Clover Creek Upstream Passage Assessment

Methods

The purpose of this task was to assess flows needed for upstream passage of anadromous salmonids through critical riffles in Clover Creek, using the methods of CDFW (2015). This methodology was selected because preliminary information indicated that upstream passage is likely the critical life stage for instream flows in Clover Creek. The concern is that some upstream migrating fish may not be able to migrate to suitable spawning habitat if they are blocked by shallow water at a riffle. Information from a riffle survey conducted by CDFW staff on November 10, 2015 was used to identify critical riffles. After obtaining landowner permission, three riffles were selected for study. An additional riffle upstream of the Millville Diversion, identified during CDWR habitat mapping, was added after the first sampling event, to represent conditions upstream of the Millville Diversion. Data for the critical riffle analysis (CRA) were collected as a five to seven-part field sampling series, mostly on the receding limb of the hydrograph as flows declined. The sampling events were timed to capture the full range of discharges necessary to adequately bracket and identify passage flows for fall-run Chinook salmon and steelhead adults and juvenile salmonids on Clover Creek (Table 3).

Table 3
Adult migration and juvenile emigration timing for salmonids in Clover and Bear Creeks. Shading indicates timing span, with darker shading indicating months of peak movement.

Species and Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fall Run Chinook Salmon												
Adult												
Juvenile												
Steelhead												
Adult												
Juvenile												

Source: Matt Johnson, California Department of Fish and Wildlife.

Once a riffle was identified for critical riffle analysis, the transect was established, marked on each bank with flagging and rebar, and photographed. A discharge measurement was taken onsite. Onsite discharge measurements were made following procedures of Rantz (1982). A transect was established at each critical riffle running along the shallowest course of the riffle from bank to bank using a measuring tape. The transects are not linear, but instead follow the contours of the riffle along its shallowest course from bank to bank. The critical riffle transect was established during the first sampling event, and then was used repeatedly for each subsequent sampling event at different flows. Staff waded the riffle and determined the shallowest course from bank to bank. Several 2.5 ft pieces of 0.5 inch diameter rebar were hammered into the riffle contour, and a wind-up, light-weight measuring tape was attached to the rebar. The headpin (rebar) for each critical riffle transect is located on the left bank of the river looking upstream, and the tail pin (rebar) on right bank looking upstream. The headpin serves as the starting point for each critical riffle water depth measurement, starting from zero feet, and the tail pin serves as the end point of the measurements. Once head- and tail pins are in place, a wind-up, light-weight measuring tape is attached to the base of the headpin. The tape is then extended working across the riffle, following the contour of shallowest course until reaching the tail pin, where the tape is then attached to the tail pin. This process is followed for each subsequent sampling event.

The Cow Creek flow gage is downstream but in the same watershed. Clover Creek is one of five tributaries in the Cow Creek watershed near Palo Cedro in Shasta County, California. The Cow Creek flow gage (which has a high correlation with Clover Creek flows) was used to assess whether flow levels changed during the data collection. Specifically, a regression equation of 24 measurements of Clover Creek flows by Tricia Bratcher of the California Department of Fish and Wildlife between May 13, 2008 and June 13, 2011, with flows from the Cow Creek gage had an R^2 value of 0.92. Depths were measured every two feet along the transect. A stadia rod (with scale to 100ths of a foot) was used to measure depth along each transect. After measuring water depths, the data were recorded in a field notebook for each distance across the transect. Careful attention was taken to record water depths at individual locations as the fish would encounter and use them.

In accordance with CDFW (2015), depth and velocity criteria were used to assess critical riffles; criteria are presented below in Table 4. A site is deemed passable when a combination of minimum stream flow depths and wetted widths are greater than conditions specified by two evaluation parameters: the percentage of the total transect width meeting the life stage-specific depth criteria and the contiguous percentage of the transect width meeting the life stage-specific depth criteria (Thompson 1972). The more stringent of the two criteria are used to establish passage flows. Passage velocities have been established based on the perceived swimming abilities of salmon and trout to pass over barriers. A maximum passage velocity of 8.0 feet per second (ft/s) is considered appropriate for adult Chinook salmon and steelhead (Thompson 1972; Table 4). The minimum depth criteria used in CRA is based on the water depth needed for a salmonid to adequately navigate over a critical riffle with sufficient clearance underneath it, so that contact with the streambed and abrasion are minimized (R2 Resource Consultants 2008). The minimum depth passage criteria for adult Chinook salmon, adult Steelhead, and juvenile salmonids are 0.9 ft, 0.7 ft, and 0.3 ft, respectively (CDFW 2015; Table 4). Where migration timing overlaps (see Table 3), the deeper body depth criteria must take precedence to protect all species and life stages present.

Table 4
Depth and velocity criteria for adult and juvenile salmonid passage

Species (Life stage)	Minimum depth (ft)	Maximum Velocity (ft/s)
Chinook Salmon (adult)	0.9	8.0
Steelhead (adult)	0.7	8.0
Salmonid (young-of-year/juvenile)	0.3	---

Source: Thompson 1972; R2 Resource Consultants 2008; CDFW 2015.

Results

The thalweg of one of the four riffles was scoured down to bedrock as a result of high flows in mid-March 2016. As a result, this location was no longer a critical riffle, and was dropped from sampling after the third sample was collected. There were also changes in the depths of Riffles 4 and 22 as a result of the high flows in mid-March 2016; as a result, data from the first measurement that were inconsistent with the latter samples (depths ≥ 0.7 feet for both riffles and depths ≥ 0.9 feet for Riffle 22) were not used in the regressions. The three remaining riffles (Figure 7) were sampled five to seven times between March 3 and June 2, 2016 at flows ranging from 12.1 to 87.6 cfs (representing the < 2nd to 82.1st percentile annual flows for Clover Creek). The fastest velocity measured for any of the riffles was 6.05 ft/s. Photos, including latitudes and longitudes of the riffles, and regressions are shown in Appendix A. For Riffle 4, only the highest flow had a non-zero width for depths ≥ 0.9 feet. Similarly, there were multiple flows with zero width for depths ≥ 0.7 feet for Riffle 4 and for depths ≥ 0.9 feet for Riffle 22. Accordingly, we only used the highest flow with a zero width in the regressions for those criteria. The relationships for percent total and contiguous width ≥ 0.3 for Riffle 4 were logarithmic; accordingly, we used a logarithmic regression for those cases. The relationships for percent total and contiguous width ≥ 0.9 for Oilar Riffle were nonlinear; accordingly, we used a second-order polynomial function for the regressions for those cases.

For Riffle 22 and Oilar Riffle for the ≥ 0.3 depth criteria, we were unable to use the regression equations to predict the flow meeting the criteria because the regression equations predicted percentages greater than 25% at a flow of zero. For those cases, we used an alternative but equally valid method by developing a stage-discharge relationship (rating curve) using the flows from the field data points collected and the depth profile measured at the highest flow level sampled. The rating curve was then used to calculate WSELs at each flow of interest for each critical riffle transect, as it is analogous to an empirical version of two-dimensional hydraulic habitat modeling, and similar to the methodology employed in Physical Habitat Simulation (PHABSIM) systems (Waddle 2012). The benefit of using a method that is similar to PHABSIM is the defensibility of the method, due to the widespread use of PHABSIM in instream flow studies. Depths measured for each critical riffle transect, along with the associated WSEL, are

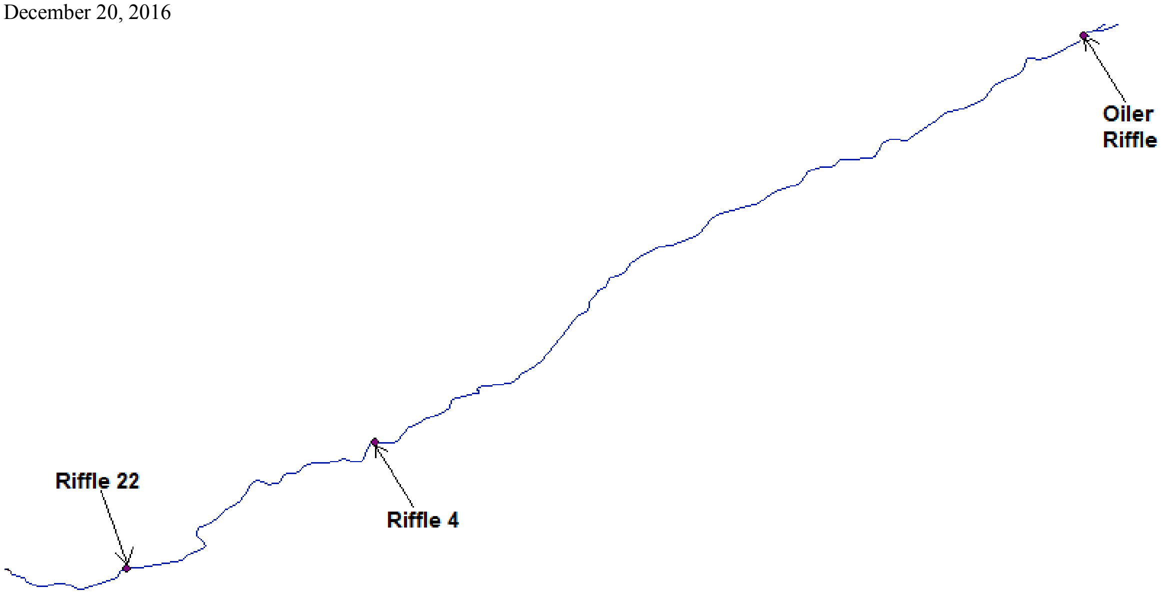

Figure 7
Clover Creek Critical Riffles

used to calculate the bed elevations across the transect. The depths at flows below those measured at the critical riffles are then calculated by subtracting the bed elevations from the WSELs derived from the rating curve. The resulting depths can then be used to determine the total and contiguous widths meeting the depth criteria at each flow of interest.

As shown in Table 5, Riffle 22 was the most critical riffle for upstream passage for adult Chinook (requiring a flow of 125 cfs), Oilar Riffle was the most critical riffle for upstream passage for adult steelhead (requiring a flow of 53.5 cfs), while Riffle 4 (a bedrock shelf) was the most critical riffle for upstream passage for juvenile salmonids (requiring a flow of 12.3 cfs). Riffle 22 is the lowermost riffle that is constraining entry of fish to get higher up in Clover Creek. Mean monthly flows (based on a flow-flow regression with Cow Creek flows) and known diversions and diversion rates for Clover Creek, as per SWRCB (2015), are shown in Table 6. The above results can be used to establish flows for upstream passage in Clover Creek.

Table 5
Results (cfs/flow needed at these sites to ensure upstream/downstream passage of salmonids) of Clover Creek Critical Riffle Study

Criterion	Riffle 4	Riffle 22	Oiler Riffle
Adult Chinook Total Width	86.1	125	86.5
Adult Chinook Contiguous Width	77.1	106	72.5
Adult Steelhead Total Width	50.6	48.5	53.5
Adult Steelhead Contiguous Width	37.5	30.2	38
Juvenile Salmonid Total Width	12.3	1.8	21
Juvenile Salmonid Contiguous Width	10.4	1.5	13

Table 6
Clover Creek Mean Monthly Flows and Diversions

Month	Mean Monthly Flows (cfs)	Mean Monthly Diversions (cfs)
January	149	1.5
February	145	1.5
March	127	1.5
April	84	3.2
May	59	4.1
June	32	4.3
July	19	5.2
August	17	5.2
September	18	5.0
October	24	4.7
November	49	2.3
December	113	1.8

Discussion

The mean monthly flows in Table 6 likely represent impaired flows, since they were derived from a regression equation where the Clover Creek flows used to develop the regression equation were measured downstream of most diversions. The mean monthly diversions in Table 6 are likely underestimates, since the difference between flows measured above and below the major Clover Creek diversion on June 2, 2016 was 8.6 cfs. The implication of this is that effects of diversion on Clover Creek flows are likely larger than would be anticipated based on data from SWRCB (2015). Installation of stream gages upstream of all diversions and near the mouth of Clover Creek would be required to correct this. The next step in developing instream flow requirements for Clover Creek is to address instream water temperature data, since the availability of suitable water temperatures is a consideration in developing instream flow requirements. Both total width, representing all of the passage opportunities through a critical riffle, and continguous width, representing a single path through the riffle that is passable, are considered in evaluating upstream passage.

Bear Creek Upstream Passage Assessment

Methods

The purpose of this task was to assess flows needed for upstream passage of anadromous salmonids through critical riffles in Bear Creek, using the methods of CDFW (2015). This methodology was selected because preliminary information indicated that upstream passage is likely the critical life stage for instream flows in Bear Creek. The concern is that some upstream migrating fish may not be able to migrate to suitable spawning habitat if they are blocked by shallow water at a riffle. Information from CDWR (2012) was used to identify critical riffles.

After obtaining landowner permission, three riffles (Figure 8) were selected for study. One of these riffles was the lowermost riffle in Bear Creek. Data for the critical riffle analysis (CRA) were collected as a six-part field sampling series, mostly on the receding limb of the hydrograph as flows declined. The sampling events were timed to capture the full range of discharges necessary to adequately bracket and identify passage flows for fall-run Chinook salmon and steelhead adults and juvenile salmonids on Bear Creek.

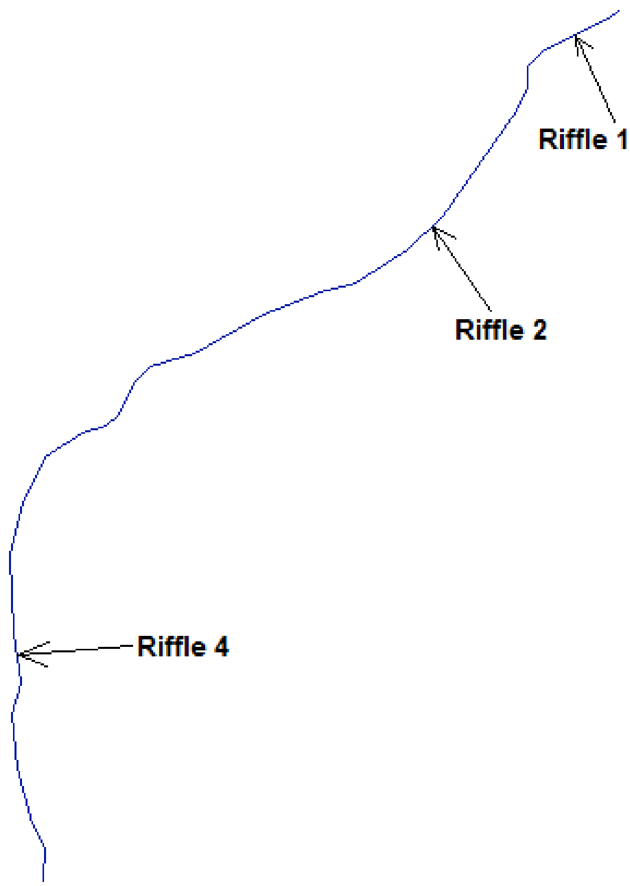

Figure 8
Bear Creek Critical Riffles

Once a riffle was identified for critical riffle analysis, the transect was established, marked on each bank with flagging and rebar, and photographed. A discharge measurement was taken onsite. Onsite discharge measurements were made following procedures of Rantz (1982). A transect was established at each critical riffle running along the shallowest course of the riffle from bank to bank using a measuring tape. The transects are not linear, but instead follow the contours of the riffle along its shallowest course from bank to bank. The critical riffle transect was established during the first sampling event, and then was used repeatedly for each subsequent sampling event at different flows. Staff waded the riffle and determined the shallowest course from bank to bank. Several 2.5 ft pieces of 0.5 inch diameter rebar were hammered into the riffle contour, and a wind-up, light-weight measuring tape was attached to the rebar.

The headpin (rebar) for each critical riffle transect is located on the left bank of the river looking upstream, and the tail pin (rebar) on right bank looking upstream. The headpin serves as the starting point for each critical riffle water depth measurement, starting from zero feet, and the tail pin serves as the end point of the measurements. Once head- and tail pins are in place, a wind-up, light-weight measuring tape is attached to the base of the headpin. The tape is then extended working across the riffle, following the contour of shallowest course until reaching the tail pin, where the tape is then attached to the tail pin. This process is followed for each subsequent sampling event.

The Cow Creek flow gage (which has a high correlation with Bear Creek flows) was used to assess whether flow levels changed during the data collection. Depth were measured every two feet along the transect. A stadia rod (with scale to 100ths of a foot) was used to measure depth along each transect. After measuring water depths, the data were recorded in a field notebook for each distance across the transect. Careful attention was taken to record water depths at individual locations as the fish would encounter and use them.

In accordance with CDFW (2015), depth and velocity criteria were used to assess critical riffles; criteria are presented above in Table 4. A site is deemed passable when a combination of minimum stream flow depths and wetted widths are greater than conditions specified by two evaluation parameters: the percentage of the total transect width meeting the life stage-specific depth criteria and the contiguous percentage of the transect width meeting the life stage-specific depth criteria (Thompson 1972).

Passage velocities have been established based on the perceived swimming abilities of salmon and trout to pass over barriers. A maximum passage velocity of 8.0 feet per second (ft/s) is considered appropriate for adult Chinook salmon and steelhead (Thompson 1972; Table 4). The minimum depth criteria used in CRA is based on the water depth needed for a salmonid to adequately navigate over a critical riffle with sufficient clearance underneath it, so that contact with the streambed and abrasion are minimized (R2 Resource Consultants 2008). The minimum depth passage criteria for adult Chinook salmon, adult Steelhead, and juvenile salmonids are 0.9 ft, 0.7 ft, and 0.3 ft, respectively (CDFW 2015; Table 4). Where migration timing overlaps (see Table 3), the deeper body depth criteria must take precedence to protect all species and life stages present.

Results

The three riffles were sampled six times between March 2 and May 23, 2016 at flows ranging from 38.3 to 124.8 cfs (representing the 56th to 82.5th percentile annual flows for Bear Creek). The fastest velocity measured for any of the riffles was 4.21 ft/s. As a result of high flows in mid-March 2016, the cross-sectional profile of Riffle 2 changed, and as a result, we were unable to use the first measurement for that riffle. Photos, including latitudes and longitudes of the riffles, and regressions are shown in Appendix B. For Riffle 2, only the highest flow had a non-zero width for depths ≥ 0.9 feet; accordingly, we only used the highest flow with a zero width for depths ≥ 0.9 feet in the regressions for those criteria. For Riffle 2, there was a shift in the slope of the relationships for the 0.7 feet depth criteria; accordingly, we excluded the highest flow from the regression equation for those criteria. The relationships for percent total width ≥ 0.3 for Riffle 2 and percent total width ≥ 0.7 for Riffle 4 were nonlinear; accordingly, we used a second-order polynomial function for the regressions for those cases.

For Riffle 4 for the ≥ 0.3 depth criteria, we were unable to use the regression equation to predict the flow meeting the criteria because the regression equation predicted percentages greater than 25% at a flow of zero. For those cases, we used an alternative but equally valid method by developing a stage-discharge relationship (rating curve) using the flows from the field data points collected and the depth profile measured at the highest flow level sampled. The rating curve was then used to calculate WSELs at each flow of interest for each critical riffle transect, as it is analogous to an empirical version of two-dimensional hydraulic habitat modeling, and similar to the methodology employed in PHABSIM systems (Waddle 2012). The benefit of using a method that is similar to PHABSIM is the defensibility of the method, due to the widespread use of PHABSIM in instream flow studies. Depths measured for each critical riffle transect, along with the associated WSEL, are used to calculate the bed elevations across the transect. The depths at flows below those measured at the critical riffles are then calculated by subtracting the bed elevations from the WSELs derived from the rating curve. The resulting depths can then be used to determine the total and contiguous widths meeting the depth criteria at each flow of interest.

As shown in Table 7, Riffle 1 (with a length of 213.5 feet) was the most critical riffle for upstream passage, while Riffle 4 was the least critical riffle for upstream passage. Mean monthly flows (based on the 8 year period of record of daily average flows for USGS Gage 11374100[6]) and known diversions and diversion rates for Bear Creek, as per SWRCB (2015), are shown in Table 8. The above results can be used to establish flows for upstream passage in Bear Creek.

Discussion

The very high flows for adult Chinook upstream passage for Riffle 1, corresponding to a 98.7th exceedance flow, reflects the extended length of this riffle, and that most of the flow was in a 30-foot main channel portion of this riffle. At the adult Chinook upstream passage flow for Riffle 2, Riffle 1 had eight feet of the channel with a depth ≥ 0.9 feet. The conditions at Riffle 4 likely changed dramatically since it was first identified by CDWR in 2008. At the time of our data collection, Riffle 4 was likely no longer a critical riffle, and was more of a glide. Similarly, a fourth critical riffle identified by CDWR (Riffle 3) was blown out by high flows between 2008 and 2016, and was no longer a critical riffle when we were setting up our sites. Flows for USGS Gage 11374100 are intermediate between impaired and unimpaired flows, due to its intermediate

[6] https://waterdata.usgs.gov/ca/nwis/dv?cb_00060=on&format=gif_default&site_no=11374100&referred_module=sw&period=&begin_date=1959-10-01+&end_date=1967-09-30

Table 7
Results (cfs) of Bear Creek Critical Riffle Study

Criterion	Riffle 1	Riffle 2	Riffle 4
Adult Chinook Total Width	650	107.6	55.1
Adult Chinook Contiguous Width	265	106	48.9
Adult Steelhead Total Width	187.5	84	35.25
Adult Steelhead Contiguous Width	147	84	25.8
Juvenile Salmonid Total Width	31	8.8	15.5
Juvenile Salmonid Contiguous Width	34.5	28.3	8

Table 8
Bear Creek Mean Monthly Flows and Diversions

Month	Mean Monthly Flows (cfs)	Mean Monthly Diversions (cfs)
January	163	5.9
February	191	6.0
March	148	6.4
April	163	9.4
May	65	13.8
June	24	12.4
July	9.4	12.1
August	7.3	11.6
September	7.7	11.2
October	21	9.6
November	59	6.5
December	128	16.6

location in the watershed, downstream of some diversions but upstream of other diversions. The implications for using USGS Gage 11374100 are that it underestimates unimpaired flows. The next step in developing instream flow requirements for Bear Creek is to address instream water temperature data, since the availability of suitable water temperatures is a consideration in developing instream flow requirements. Both total width, representing all of the passage opportunities through a critical riffle, and continguous width, representing a single path through the riffle that is passable, are considered in evaluating upstream passage.

Lower Deer Creek Falls Fish Ladder Pre-restoration Monitoring

Methods

The goal of this task was to collect baseline information to assess geomorphic changes to Deer Creek resulting from the installation of a new fish ladder at Lower Deer Creek Falls. In the fall of 2015, we surveyed a total of 6 transects (two upstream of Lower Deer Creek Falls and four downstream of Lower Deer Creek Falls, Figure 9). Bed elevation profiles were measured for each transect using standard surveying techniques (differential leveling), and a wind-up, light-weight measuring tape to record stations. We also conducted a pebble count at each of the 6 transects to provide baseline conditions to estimate how the grain size distribution on the creek bed near the monitoring sections will change as a result of the installation of a new fish ladder at Lower Deer Creek Falls, and took 4 pre-restoration photographs (looking from left bank to right bank, looking from right bank to left bank, looking upstream, and looking downstream) of each of the 6 transects. A minimum of 75 pebbles[7] were counted per cross-section. We used survey-grade Real Time Kinematic Global Positioning System (RTK GPS) equipment to survey a longitudinal profile of the study area. The transect data were entered into an Excel spreadsheet to generate bed elevation profiles.

Results

The longitudinal profile is shown in Figure 10, while the pebble count data are given in Table 9. Cross-section profiles and photographs are shown in Appendix C.

Discussion

The data that we collected will serve as a good baseline to assess the effects of the new fish ladder at Lower Deer Creek Falls. Construction began in July 2016 and is still underway as of December 2016. The plan is to re-measure the transects and conduct new pebble counts and longitudinal surveys after the first, second and third high flows.

[7] While this is less than the standard of 100 pebbles given in Harrelson et al. (1994), it was judged to be sufficient to evaluate the effects of a new fish ladder at Lower Deer Creek Falls because of the generally large size of the substrate.

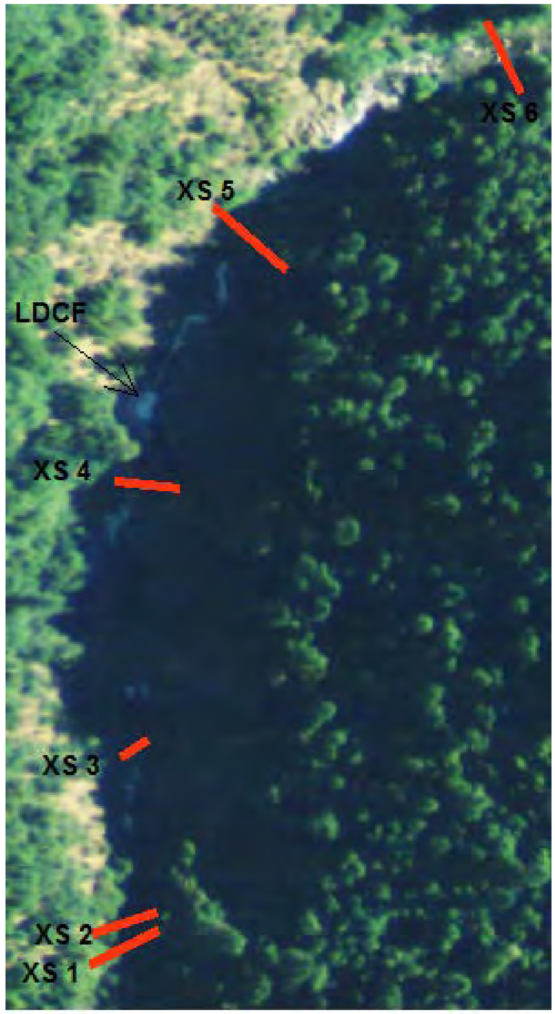

Figure 9
Lower Deer Creek Falls Transects

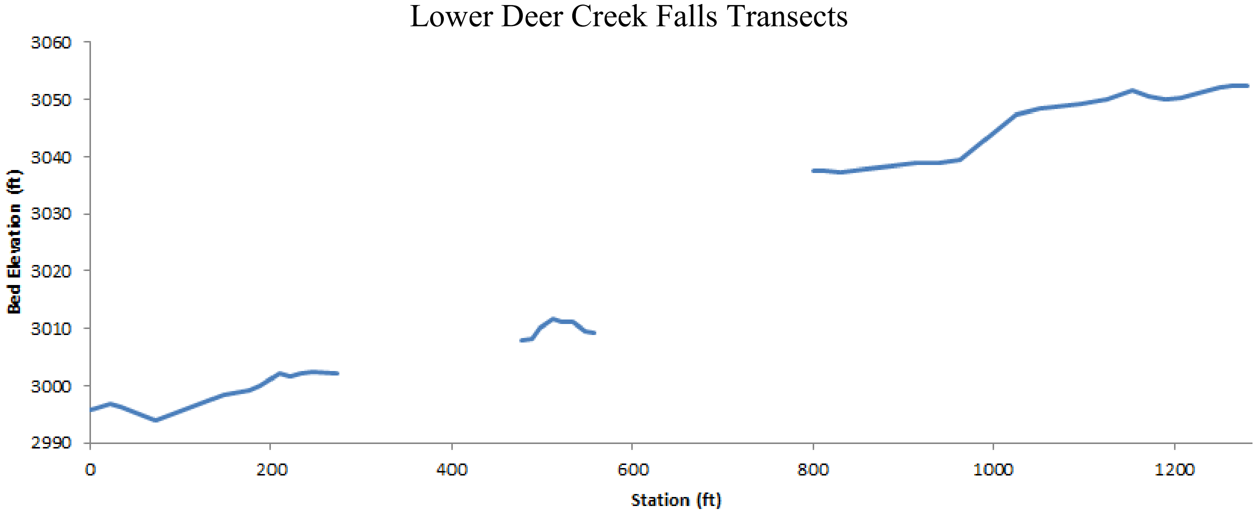

Figure 10
Lower Deer Creek Falls Longitudinal Profile. The falls and fish ladder are at Station 600.

Table 9
Lower Deer Creek Falls Pebble Count Data[8]

Section	D16, inches	D50, inches	D84, inches	D100, inches
1	2.4	10.1	> 14.3	Bedrock
2	3.5	10.1	Bedrock	Bedrock
3	1.8	5.0	> 14.3	Bedrock
4	2.4	5.0	> 14.3	Bedrock
5	3.5	10.1	> 14.3	Bedrock
6	0.3	5.0	> 14.3	Bedrock

Deer Creek Irrigation District Dam Roughened Channel Pre-restoration Monitoring

Methods

The goal of this task was to collect baseline information to assess geomorphic changes to Deer Creek resulting from the future installation of a fish passage improvement project such as a roughened channel downstream of the Deer Creek Irrigation District Diversion Dam. In the summer of 2016, we surveyed a total of 6 transects (three upstream of Deer Creek Irrigation District Diversion Dam and three downstream of Deer Creek Irrigation District Diversion Dam, Figure 11). Bed elevation profiles were measured for each transect using standard surveying techniques (differential leveling), and a tape to record stations. We also conducted a pebble count at each of the 6 transects to provide baseline conditions to estimate how the grain size distribution on the creek bed near the monitoring sections will change as a result of the installation of a roughened channel to provide upstream passage at Deer Creek Irrigation District Diversion Dam, and took 4 pre-restoration photographs (looking from left bank to right bank, looking from right bank to left bank, looking upstream, and looking downstream) of each of the 6 transects. A minimum of 100 pebbles (Harrelson et al. 1994) were counted per cross-section. We used our RTK GPS equipment to survey a longitudinal profile of the study area. The transect data were entered into an Excel spreadsheet to generate bed elevation profiles.

Results

The longitudinal profile is shown in Figure 12, while the pebble count data are given in Table 10. Cross-section profiles and photographs are shown in Appendix D. The lowermost transect is below the bottom of where the roughened channel will start.

[8] Sections 1-4 are downstream of Lower Deer Creek Falls and Sections 5-6 are upstream of Lower Deer Creek Falls.

Figure 11
Deer Creek Irrigation District Dam Transects

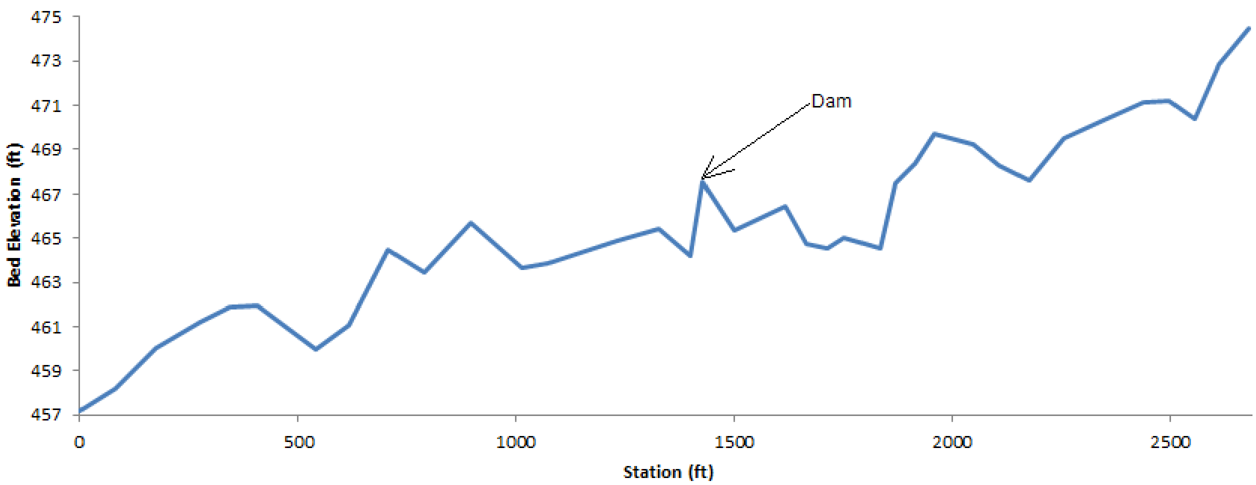

Figure 12
Deer Creek Irrigation District Diversion Dam Longitudinal Profile

Discussion

The data that we collected will serve as a good baseline to assess the effects of a fish passage improvement project such as a roughened channel downstream of Deer Creek Irrigation District Diversion Dam. The plan is to re-measure the transects and conduct new pebble counts and longitudinal surveys after the first, second and third high flows.

Table 10
Deer Creek Irrigation District Diversion Dam Pebble Count Data[9]

Section	D16, inches	D50, inches	D84, inches	D100, inches
1	7.1	10.1	14.3	> 14.3
2	3.5	10.1	14.3	Bedrock
3	0.16	5.0	7.1	> 14.3
4	5.0	10.1	14.3	Bedrock
5	0.16	3.5	7.1	> 14.3
6	5.0	10.1	> 14.3	Bedrock

Mill Creek Upper Dam Fish Ladder Pre-restoration Monitoring

Methods

The goal of this task was to collect baseline information to assess geomorphic changes to Mill Creek resulting from the installation of a new fish ladder at the Mill Creek Upper Diversion Dam. In the summer of 2016, we surveyed a total of 6 transects (three upstream of Mill Creek Upper Diversion Dam and three downstream of Mill Creek Upper Diversion Dam, Figure 13). Bed elevation profiles were measured for each transect using standard surveying techniques (differential leveling), and a tape to record stations. We also conducted a pebble count at each of the 6 transects to provide baseline conditions to estimate how the grain size distribution on the creek bed near the monitoring sections will change as a result of the installation of a new fish ladder at Mill Creek Upper Diversion Dam, and took 4 pre-restoration photographs (looking from left bank to right bank, looking from right bank to left bank, looking upstream, and looking downstream) of each of the 6 transects. A minimum of 100 pebbles (Harrelson et al. 1994) were counted per cross-section. We used our RTK GPS equipment to survey a longitudinal profile of the study area. The transect data were entered into an Excel spreadsheet to generate bed elevation profiles.

Results

The longitudinal profile is shown in Figure 14, while the pebble count data are given in Table 11. Cross-section profiles and photographs are shown in Appendix E.

Discussion

The data that we collected will serve as a good baseline to assess the effects of the new fish ladder at Mill Creek Upper Diversion Dam. The plan is to re-measure the transects and conduct new pebble counts and longitudinal surveys after the first, second and third high flows.

[9] Sections 1-3 are downstream of Deer Creek Irrigation District Diversion Dam and Sections 4-6 are upstream of Deer Creek Irrigation District Diversion Dam.

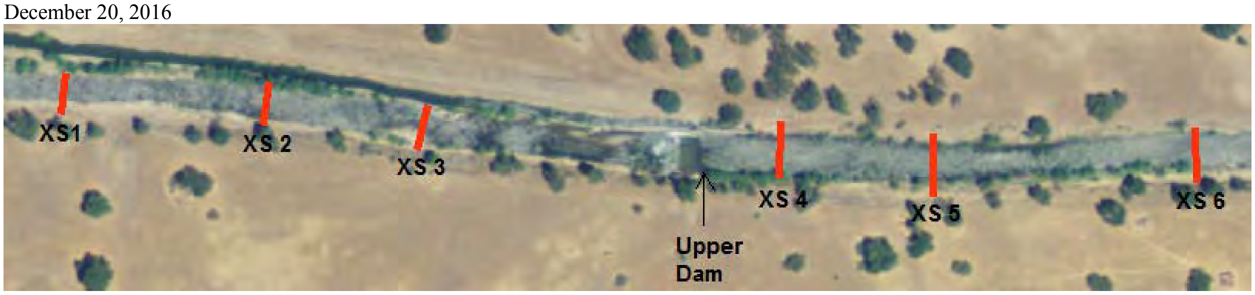

Figure 13
Mill Creek Upper Diversion Dam Transects

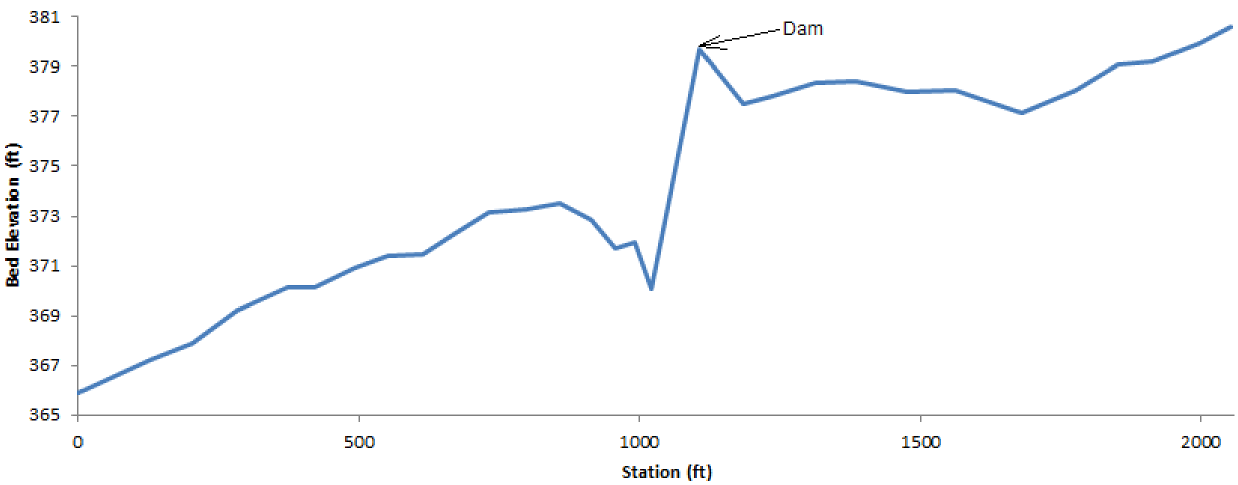

Figure 14
Mill Creek Upper Diversion Dam Longitudinal Profile

Table 11
Mill Creek Upper Diversion Dam Pebble Count Data[10]

Section	D16, inches	D50, inches	D84, inches	D100, inches
1	5.0	10.1	14.3	Bedrock
2	5.0	10.1	< 14.3	Bedrock
3	3.5	7.1	14.3	Bedrock
4	1.3	2.4	7.1	Bedrock
5	1.3	3.5	5.0	Bedrock
6	3.5	7.1	14.3	Bedrock

[10] Sections 1-3 are downstream of Mill Creek Upper Diversion Dam and Sections 4-6 are upstream of Mill Creek Upper Diversion Dam.

Mill Creek Ward Dam Fish Ladder Passage Assessment

Methods

The goal of this task was to develop a solution to the upstream passage impediment caused by the deposition of a large gravel bar[11] upstream of the new 2015 Ward Dam fish ladder. On July 27, 2016, we resurveyed three HEC-RAS cross-sections that crossed the gravel bar, measured discharges above and below the dam, and collected topography data upstream of Ward Dam using a survey-grade RTK GPS unit. We also collected substrate and cover data (Tables 12 and 13) for each topographic point collected with the total station and survey-grade RTK GPS unit. A River2D model was developed from the HEC-RAS cross-sections and topography data using the same methods given above for the Feather River Sunset Pumps investigation, and was run at a design flow of 432 cfs with a downstream boundary condition from the HEC-RAS model. Bed files were developed for two alternatives: 1) excavating a small channel through the gravel bar along with installing a rock barb to keep additional material from depositing; and 2) removal of the gravel bar. River2D models were run for both of these alternatives at 432 cfs. After the second alternative was implemented in August 2016, we collected additional topography data on September 1, 2016 and measured a discharge above the dam. This topography data will be used in FY-17 to model the as-built conditions and develop a long-term solution to gravel deposition upstream of Ward Dam. Additional information about the gravel bar deposition is given in NHC (2016).

Results

Under existing conditions (Figure 15), only 2.2 percent of Mill Creek flows were entering the Ward Dam Fish Ladder at the design flow of 432 cfs, as compared to the minimum of 10 percent required by NMFS fish ladder criteria. With the first proposed alternative (Figure 16), 9.5 percent of Mill Creek flows would enter the Ward Dam fish ladder at the design flow of 432 cfs. With the second proposed alternative (Figure 17), 15 percent of Mill Creek flows would enter the Ward Dam fish ladder at the design flow of 432 cfs.

Discussion

The hydraulic modeling indicated that the selected alternative will provide a short-term solution to upstream fish passage at Ward Dam. Video monitoring of upstream fish passage by CDFW in the fall of 2016 will serve to confirm this analysis. Hydraulic modeling of the as-built conditions and additional structural measures, such as a rock barb, in FY-17 should help in developing a long-term solution to upstream fish passage at Ward Dam.

[11] The gravel bar seems to have been formed during a five-year flow event in March 2016.

Table 12
Substrate Descriptors and Codes

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 – 1
1.2	Medium Gravel	1 – 2
1.3	Medium/Large Gravel	1 – 3
2.3	Large Gravel	2 – 3
2.4	Gravel/Cobble	2 – 4
3.4	Small Cobble	3 – 4
3.5	Small Cobble	3 – 5
4.6	Medium Cobble	4 – 6
6.8	Large Cobble	6 – 8
8	Large Cobble	8 – 10
9	Boulder/Bedrock	> 12
10	Large Cobble	10 – 12

Table 13
Cover Coding System

Cover Category	Cover Code
No cover	0.1
Cobble	1
Boulder	2
Fine woody vegetation (< 1" diameter)	3
Fine woody vegetation + overhead	3.7
Branches	4
Branches + overhead	4.7
Log (> 1' diameter)	5
Log + overhead	5.7
Overhead cover (> 2' above substrate)	7
Undercut bank	8
Aquatic vegetation	9
Aquatic vegetation + overhead	9.7
Rip-rap	10

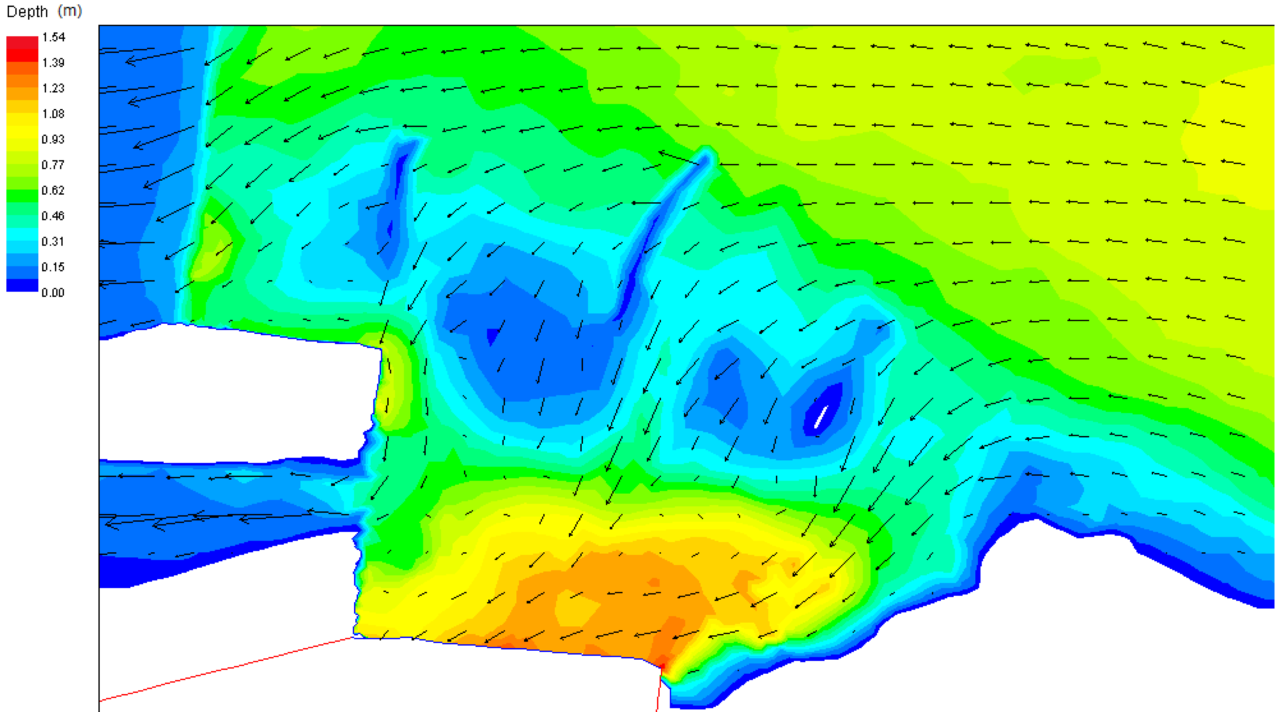

Figure 15
Mill Creek Ward Dam Existing Conditions Prior to Gravel Bar Removal

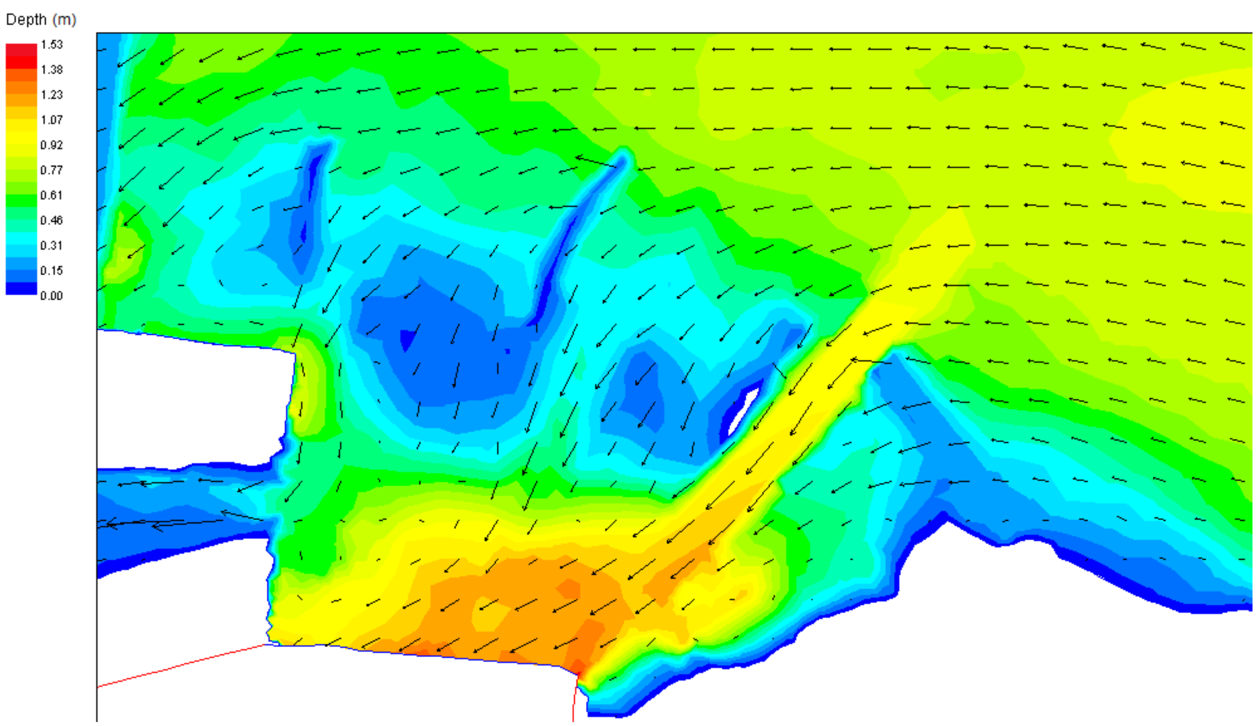

Figure 16
Mill Creek Ward Dam Proposed Conditions 1

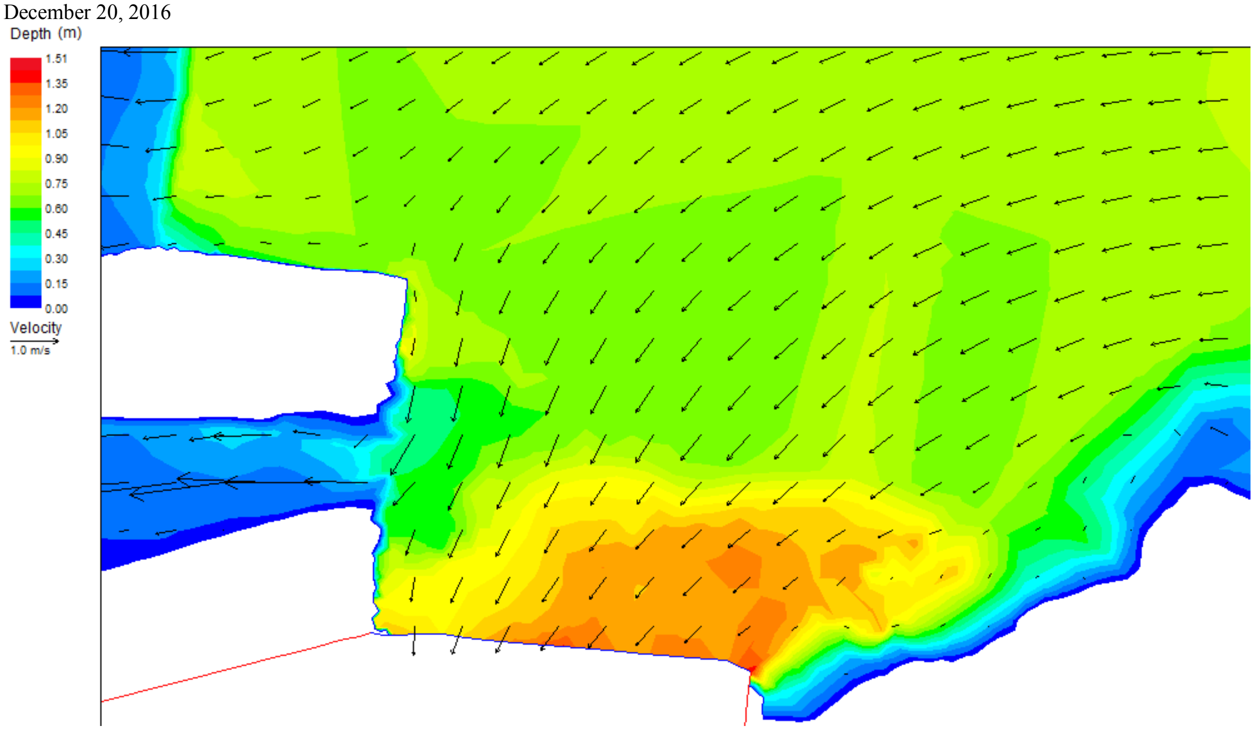

Figure 17
Mill Creek Ward Dam Proposed Conditions 2

Antelope Creek Lower Slab Upstream Passage Assessment

Methods

The goal of this task was to develop a solution to the barrier to upstream passage of adult spring-run Chinook salmon caused by the Antelope Creek lower slab (Figure 18), also known as Facht's Place crossing. A River2D model developed for the site with data collected in 2014 indicated that the slab would be an upstream passage barrier for flows of less than 441.5 cfs, which are only exceeded 5% of the time during the migration period for adult spring-run Chinook salmon. A field visit on November 18, 2015 indicated that there had been significant channel changes in the vicinity of the lower slab (Figure 19) so that river left is no longer a barrier, with the dominant flow path being down the length of the slab, rather than across the slab. As a result, we collected additional topography data in the vicinity of the slab on May 25, 2016 to update the hydraulic model to use in developing a solution to the upstream passage barrier. Topographic data were collected using a total station and a survey-grade RTK GPS unit. We also collected substrate and cover data for each topographic point collected with the total station and survey-grade RTK GPS unit.

A design flow of 85.5 cfs was selected, since this was the lowest flow at which the riffle at the upstream end of the original site had a maximum depth of 0.9 feet. Topography points from the original River2D bed file within the area sampled in 2016 were deleted, and then the new topography data was added to the bed file. Additional breaklines were added to the bedfile to

Figure 18
Antelope Creek lower slab pre 2014 high flows

Figure 19
Antelope Creek lower slab post 2014 high flows

refine the topography in the area sampled in 2016. In addition, the bed elevations at the upstream end of the north channel and downstream end of the south channel were raised to reflect the current flow patterns observed at the site. The revised bedfile was opened up in R2D_Mesh with the original mesh file. We then modified the internal boundary of the original mesh to reflect the reduced size of the upstream island, deleted mesh breaklines within the area sampled in 2016, and added additional mesh breaklines coinciding with the new breaklines added to the bed file. The resulting modified mesh was used in River2D to simulate depths and velocities at the design flow of 85.5 cfs.

During the field visit on November 18, 2015, a solution was selected for solving the upstream passage barrier, namely adding a 6 inch high and 2 foot wide rubber pre-made speed bump, that would be bolted onto the slab, crossing the slab to increase depths on the slab. Other possible solutions, such as a roughened channel downstream of the slab, or replacing the slab with box culverts, were judged to not be feasible due to the substantial channel changes that are likely to occur at the site in the future with high flows. The selected solution was simulated in River2D by modifying the bed file by adding points on both sides of the slab which increased the height of the slab by six inches, connecting these points with a breakline, and adding points with the original slab height at 1 foot on either side of the first two points, and connecting these points with breaklines. Different locations were tried for the simulated speed bump to see what location would produce the best upstream passage conditions (ideally a path traversing the slab with depths greater than 0.9 feet). The design bed files were opened up with the modified River2D file to simulate the depths with the speed bump at the design flow of 85.5 cfs.

Results

The River2D simulations at 85.5 cfs (Figures 20 and 21) captured the changes in the dominant flow paths at the site. Namely, in 2014 most of the flow went down the north channel and crossed the slab. As a result of high flows in the winter of 2014, the upstream end of the north channel and downstream end of the south channel were blocked off, with the flow all now going down the south channel upstream of the slab, then flowing along the length of the slab, then flowing down the north channel downstream of the slab. At 85.5 cfs for the existing 2016 conditions, the minimum depth along the passage route going down the slab was 0.6 feet deep. With the simulated speed bump, this depth was increased to 0.7 feet. The best location for the speed bump was on line with the thalweg just downstream of the slab (Figure 22).

Discussion

While the hydraulic model captured the dominant flow paths, it likely underestimated the degree to which flow went down the length of the slab. As a result, it likely underestimated the benefit of adding a speed bump to the slab. Additional monitoring is needed after the speed bump is installed to assess whether it will result in the upstream passage criterion being met.

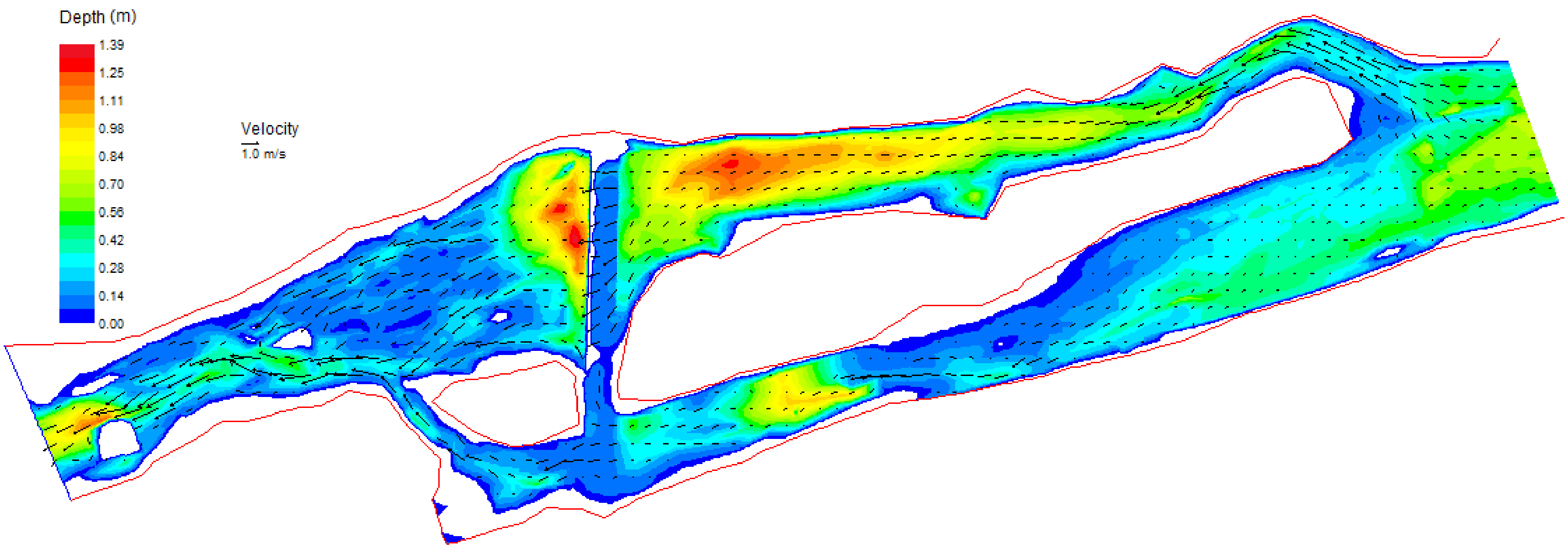

Figure 20
Lower Slab Site 2014 Flow Paths at 85.5 cfs[12]

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[12] The direction of the black arrows indicates the direction of flow, which the length of each arrow indicate the magnitude of the velocity at that location. The white areas enclosed within the red lines are the islands upstream and downstream of the slab. Flow is from right to left.

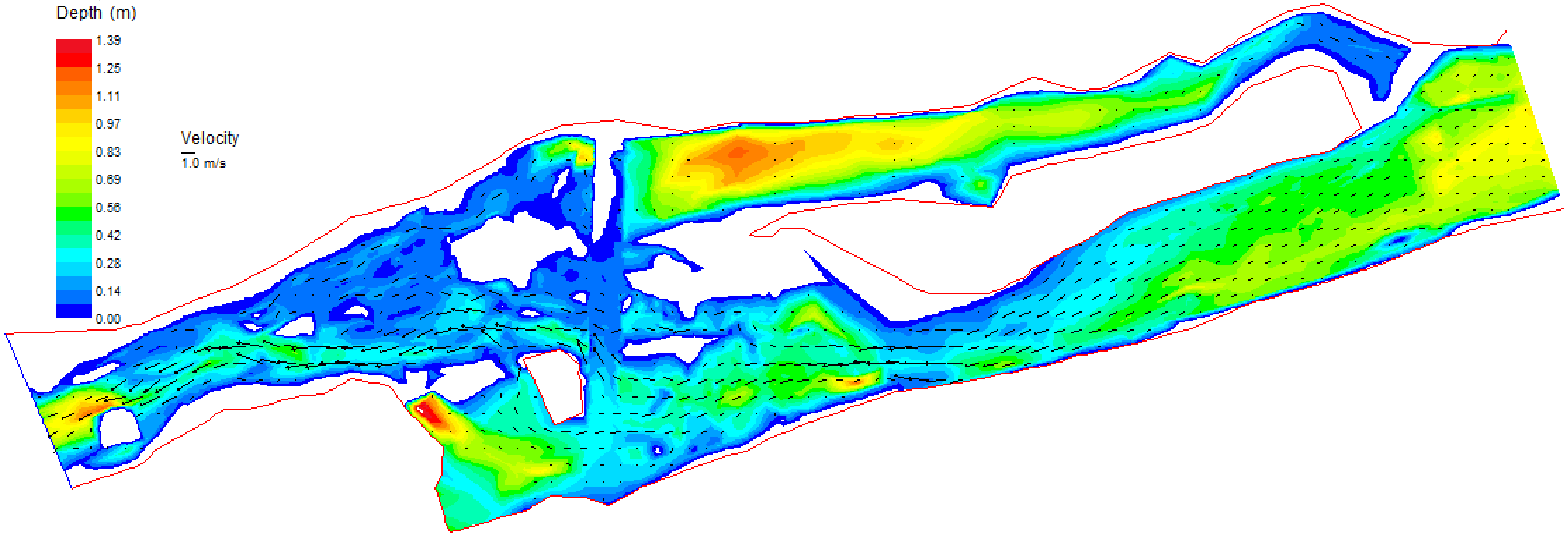

Figure 21
Lower Slab Site 2016 Flow Paths at 85.5 cfs. Flow direction is from right to left.

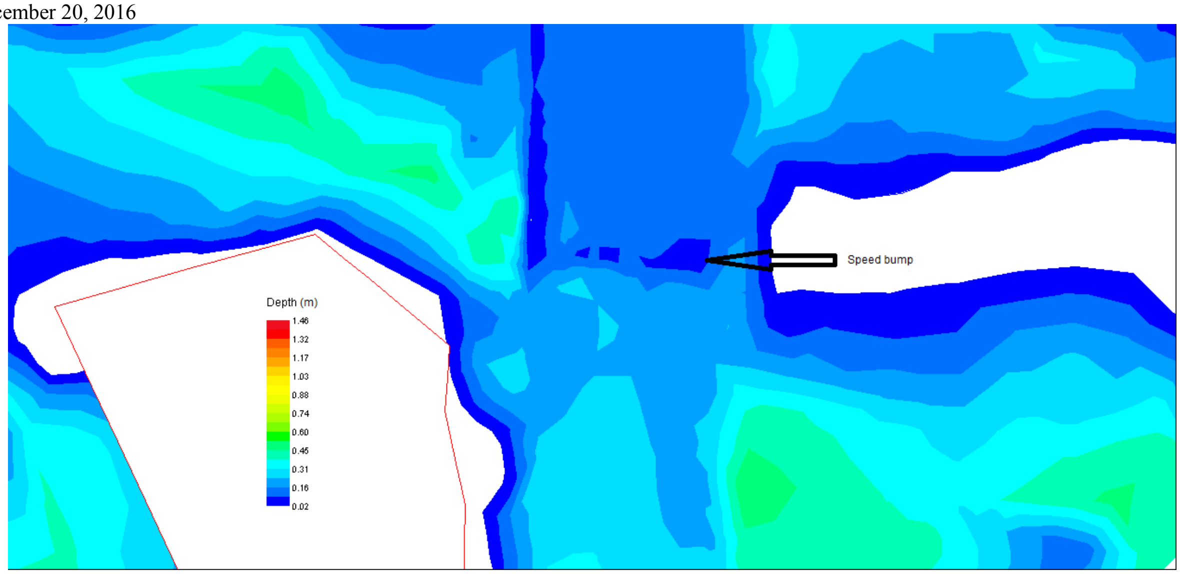

Figure 22
Location of Proposed Speed Bump

Antelope Creek Floodplain Feasibility Study

Methods

The goal of this task was to develop a HEC-RAS model to assess the current extent of floodplain inundation in the Antelope Creek watershed and to develop alternatives to improve aquatic and terrestrial habitat while developing feasible solutions to the flooding problem on Antelope Creek that are sensitive to the needs and values of the local landowners. HEC-RAS models are typically developed using a combination of in-channel cross-sections and Light Detection and Ranging (LIDAR) data. The resulting HEC-RAS model is then used with LIDAR data to generate floodplain inundation. The first step in this task was to determine what existing sources of data were available. Inquiries with CDWR, CALTRANS and FEMA indicated that there were no existing HEC-RAS models for Antelope Creek. We obtained LIDAR data from CDWR, but this data was limited to the portion of the watershed downstream of Cone Grove Road. USGS Digital Elevation Model (DEM) data was used for a preliminary representation of the topography upstream of Cone Grove Road[13]. The geographic extent of the Antelope Creek HEC-RAS model will be from the Sacramento River to upstream of all distributaries (Figure 23). Antelope Creek has four distributaries: Butler Slough, Craig Creek, Mill Race Creek and New Creek (Stillwater Sciences et al. 2011). In turn, Mill Race and New Creeks are tributaries of Salt Creek. Antelope Creek, Butler Slough, Craig Creek and Salt Creek flow directly into the Sacramento River. Little Antelope Creek will be treated in the HEC-RAS model as an additional flow source to Antelope Creek. The number of river miles for each stream in the HEC-RAS model are shown in Table 14.

[13] USGS DEM data has limited utility for floodplain delineation because the vertical accuracy is 5 ft and the horizontal resolution is 25 ft. In contrast, LIDAR data typically has a vertical accuracy of 0.5 ft and a horizontal resolution of 3 ft.

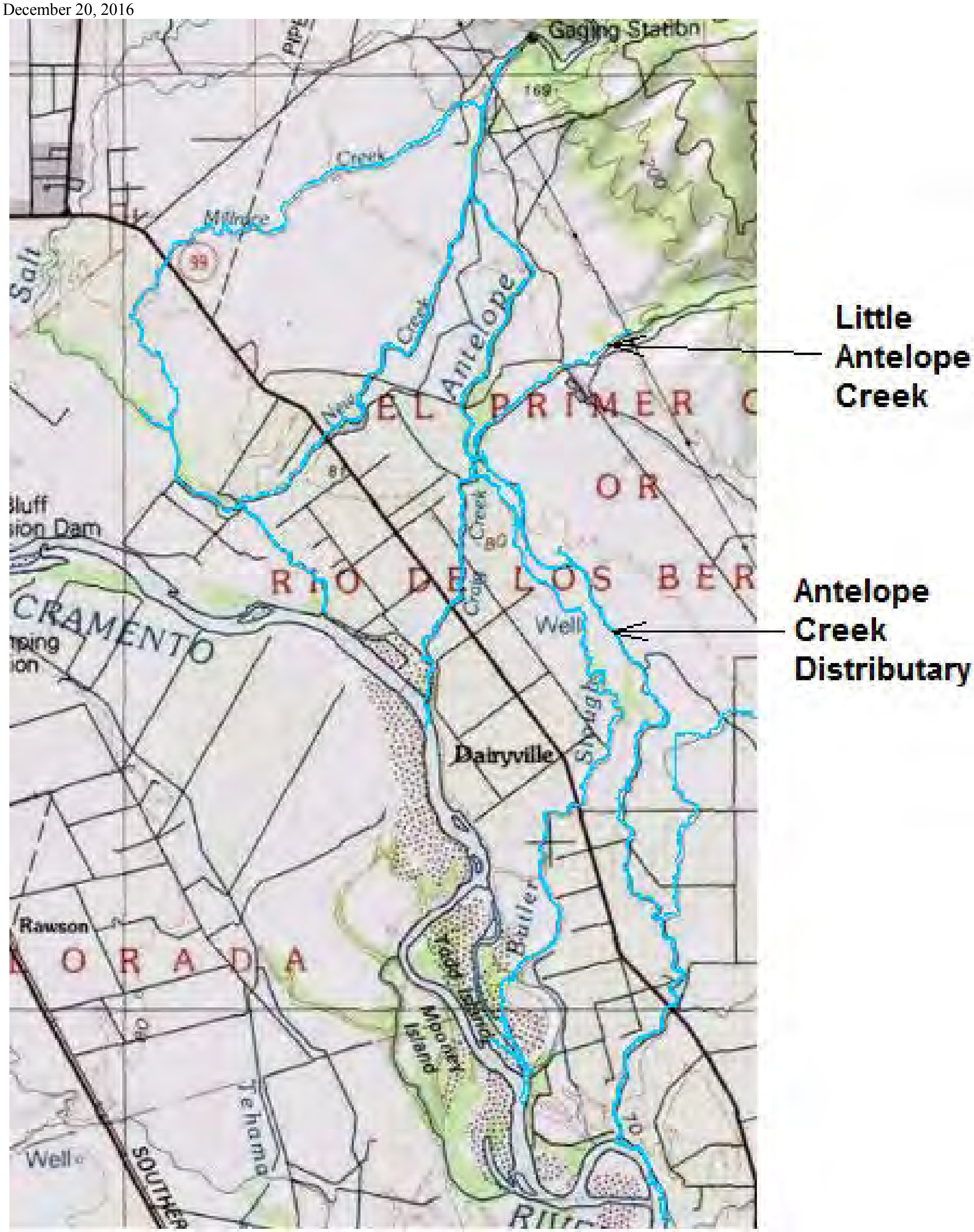

Figure 23
Geographic Extent of Antelope Creek HEC-RAS Model

Our investigations indicated that there were limited sources of in-channel cross-sections for the Antelope Creek watershed, specifically: 1) as-built surveys for bridge crossings; 2) topography data that we collected in 2012 at the Antelope Creek/Craig Creek junction; and 3) cross-section data currently being collected by Stillwater Sciences for a critical riffle study of Antelope and Craig Creeks. We obtained as-built surveys from CALTRANS and the Tehama County Department of Public Works. For the Stillwater Science data to be usable for a HEC-RAS model, we needed to shoot in their controls with our RTK-GPS equipment. We can use the LIDAR data as a data source for the Mill Race Creek in-channel cross-sections, since Mill Race Creek was entirely dry at the time that the LIDAR data was collected. We sent out letters to all of the landowners on Antelope, Craig, New and Salt Creeks and Butler Slough requesting permission for access to collect in-channel cross-sections.

Table 14
Length of Streams to be Modeled for Antelope Creek HEC-RAS model

Stream	**Stream Length (Miles)**
Antelope Creek	10
Butler Slough	5.4
Craig Creek	2
Mill Race Creek	4.3
New Creek	3.2
Salt Creek	2

Bed elevation profiles were measured for each cross-section using standard surveying techniques (differential leveling), and a tape to record stations. We used our RTK GPS unit to establish vertical control for each transect, as well as to record the horizontal locations of the ends of the cross-sections. Additional data that were recorded for each cross-section were the main channel left bank and right bank stations and the Manning's n values for the left overbank, main channel and right overbank.

Results

As of the end of FY-16, we have received permission for access from 58 of 172 parcels, and have permission to access the stream channel for another 28 parcels. Only three landowners have denied us access. In FY-17, we will follow up with phone calls to the remaining landowners to see if they will grant access. In FY-16, we collected data for a total of 39 cross-sections. In combination with the other data sources, we now have in-channel data for a total of seven miles, with 19.6 miles remaining for data collection in FY-17 and beyond.

Discussion

FEMA requires a minimum of 500 feet spacing between cross-sections for HEC-RAS models. As a result, we would need to collect data for another 207 cross-sections to be able to complete a HEC-RAS model for the Antelope Creek watershed. Based on our sampling in FY-16, this would require an additional seven weeks of fieldwork to complete. Another factor in completing a HEC-RAS model is whether we are able to get sufficient access from landowners to complete the cross-section data collection. LIDAR data may be collected in FY-17 for the portion of the watershed upstream of Cone Grove Road through the USGS 3DEP program, but would likely require $1,000 of CVPIA seed funding. Additional progress on this task will depend on the priority of this task, relative to other tasks in FY-17.

Sacramento River Juvenile Green Sturgeon Habitat Mapping

Methods

The goal of this task is to support the AFRP funded Juvenile Green Sturgeon Overwintering Migration project by providing in-river physical rearing habitat data prior to juvenile migration to the Delta. These data will be used to conduct habitat suitability analyses for the in-river portion of the juvenile life-history phase, of which little information is known. Future efforts may focus on quantifying available suitable juvenile rearing habitat for green sturgeon within and/or outside the Sacramento River. We mapped the topography, depths and velocities at one additional site (Rkm 370) where the Red Bluff Fish and Wildlife Office has captured juvenile green sturgeon. These parameters were mapped using a combination of an Acoustic Doppler Current Profiler (ADCP) and a survey-grade RTK GPS unit. For each traverse with the ADCP, the RTK GPS was used to record the horizontal location and WSEL at the starting and ending location of each traverse, while the ADCP provided depths, velocities and distances across the traverse. The WSEL of each ADCP traverse is then used together with the depths from the ADCP to determine the bed elevation of each point along the traverse. The site was sampled once on October 28, 2015 at a flow of 6,273 cfs.

Results

The bed topography of the study site is shown in Figure 24, while the depths and velocities at the study site are shown in Figures 25 to 26.

Discussion

The next step in this analysis would be to determine the depths and velocities within the subsection of the sites that were actually sampled for juvenile green sturgeon. This subset of depths and velocities would then provide a starting point to quantify microhabitat use requirements for juvenile green sturgeon.

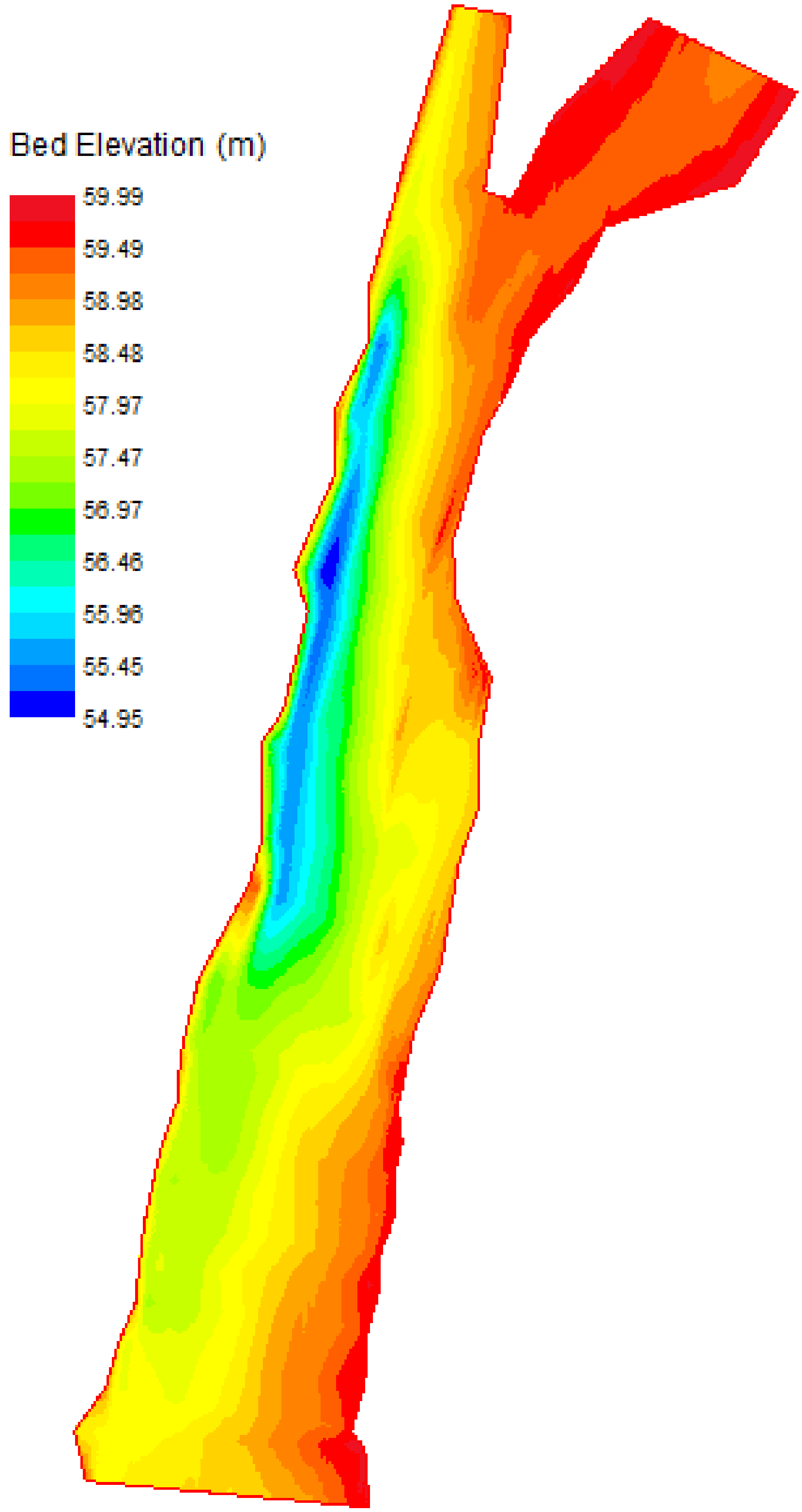

Figure 24
Rkm 370 Bed Topography. Flow is from top to bottom.

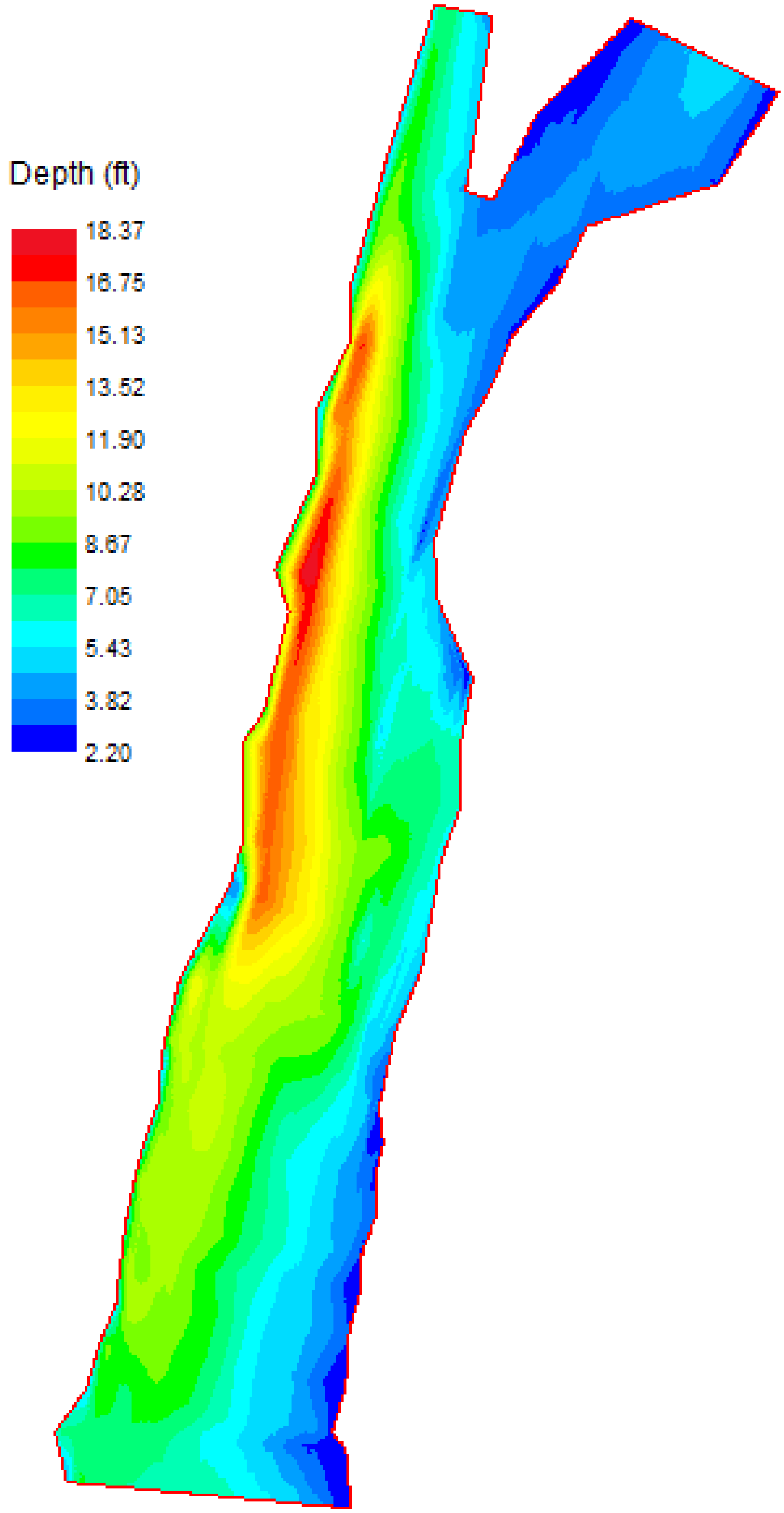

Figure 25
Rkm 370 Depths

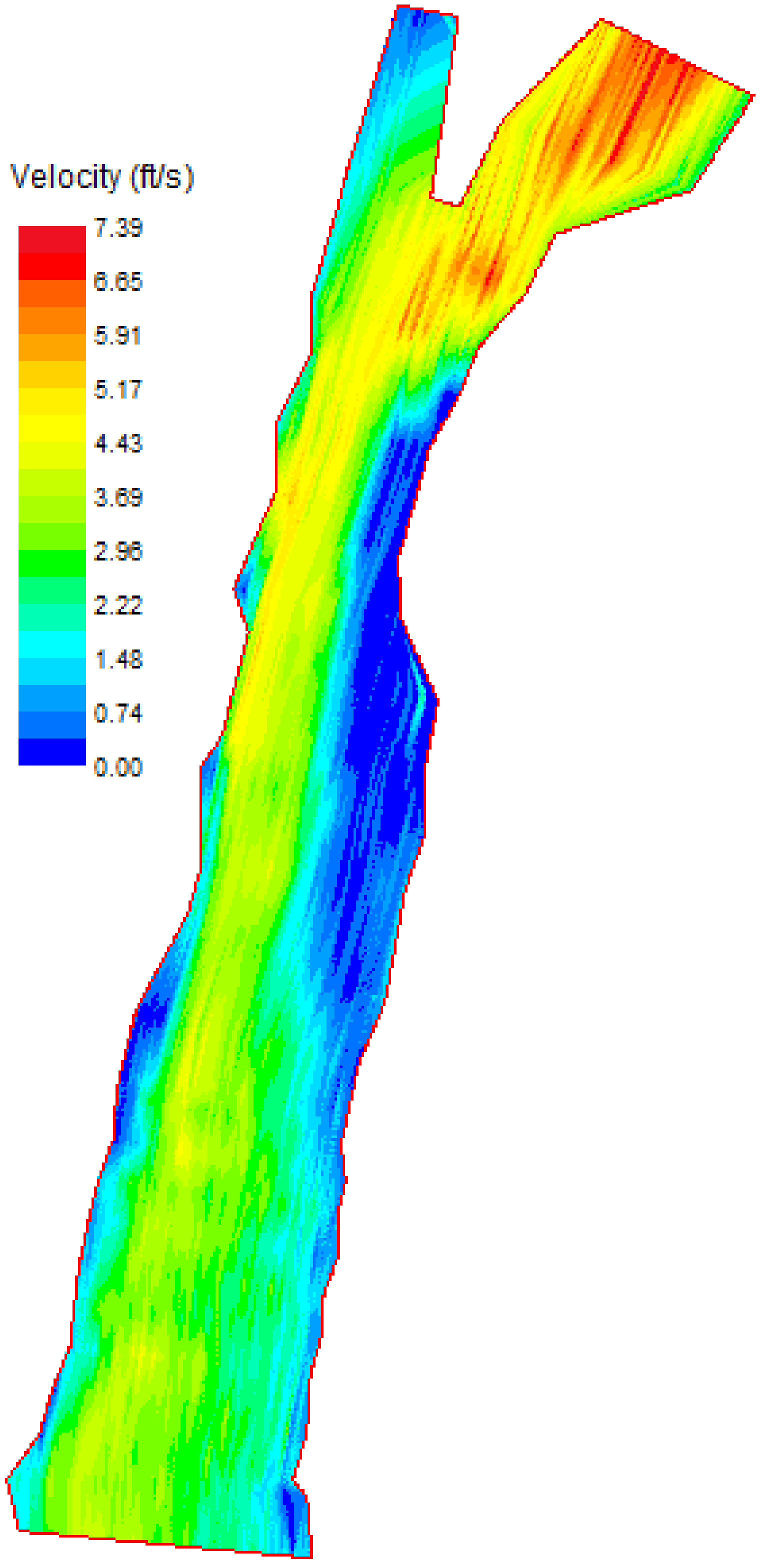

Figure 26
Rkm 370 Velocities

San Joaquin River White Sturgeon Spawning Habitat Mapping

Methods

The goal of this task is to support the AFRP funded San Joaquin River White Sturgeon Spawning project by providing in-river physical spawning habitat data. These data will be used to conduct habitat suitability analyses for the spawning life-history phase. We mapped the topography, depths and velocities at 3 sites (Rkm 142.5, 140.4 and 118.4) where the Lodi Fish and Wildlife Office has captured white sturgeon eggs. These parameters were mapped using the same methods described above for the Sacramento River green sturgeon rearing task. The Rkm 142.5 site was sampled once on March 11, 2016 at a flow of 2,285 cfs. The Rkm 140.4 site was sampled once on April 18, 2016 at a flow of 423 cfs. The Rkm 118.4 site was sampled once on April 27, 2016 at a flow of 2,657 cfs.

Results

The bed topography of the study sites are shown in Figures 27-29, while the depths and velocities at the study site are shown in Figures 30 to 35.

Discussion

We were unable to sample the portion of the Rkm 142.5 site under Grayson Bridge due to interference of the bridge with GPS signals. However, by collecting data just upstream and downstream of the bridge, we were able to maintain the same spacing of ADCP traverses that we had for the remainder of the site. Accordingly, the inability to sample under Grayson Bridge did not affect the mapping of depths and velocities at this site.

The next step in this analysis would be to determine the depths and velocities within the subsection of the sites that were actually sampled for white sturgeon spawning. This subset of depths and velocities would then provide a starting point to quantify microhabitat use requirements for white sturgeon spawning in the San Joaquin River.

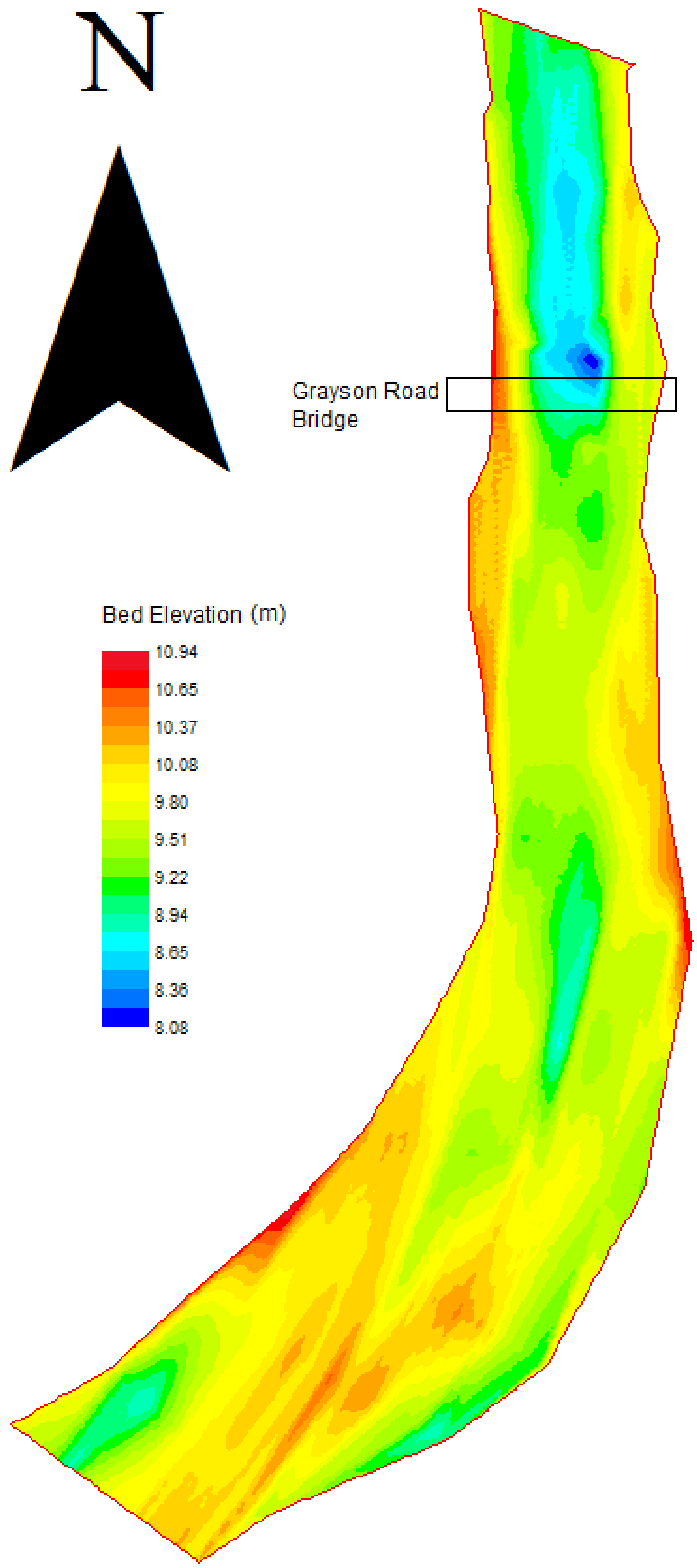

Figure 27
Rkm 142.5 Bed Topography

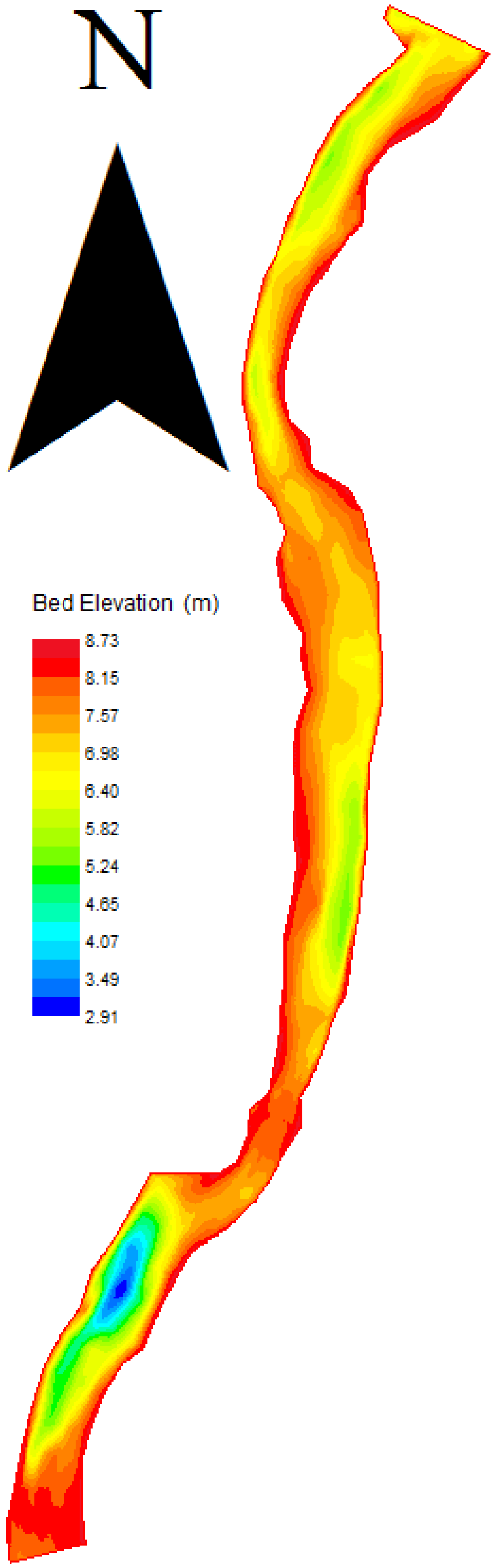

Figure 28
Rkm 140.4 Bed Topography

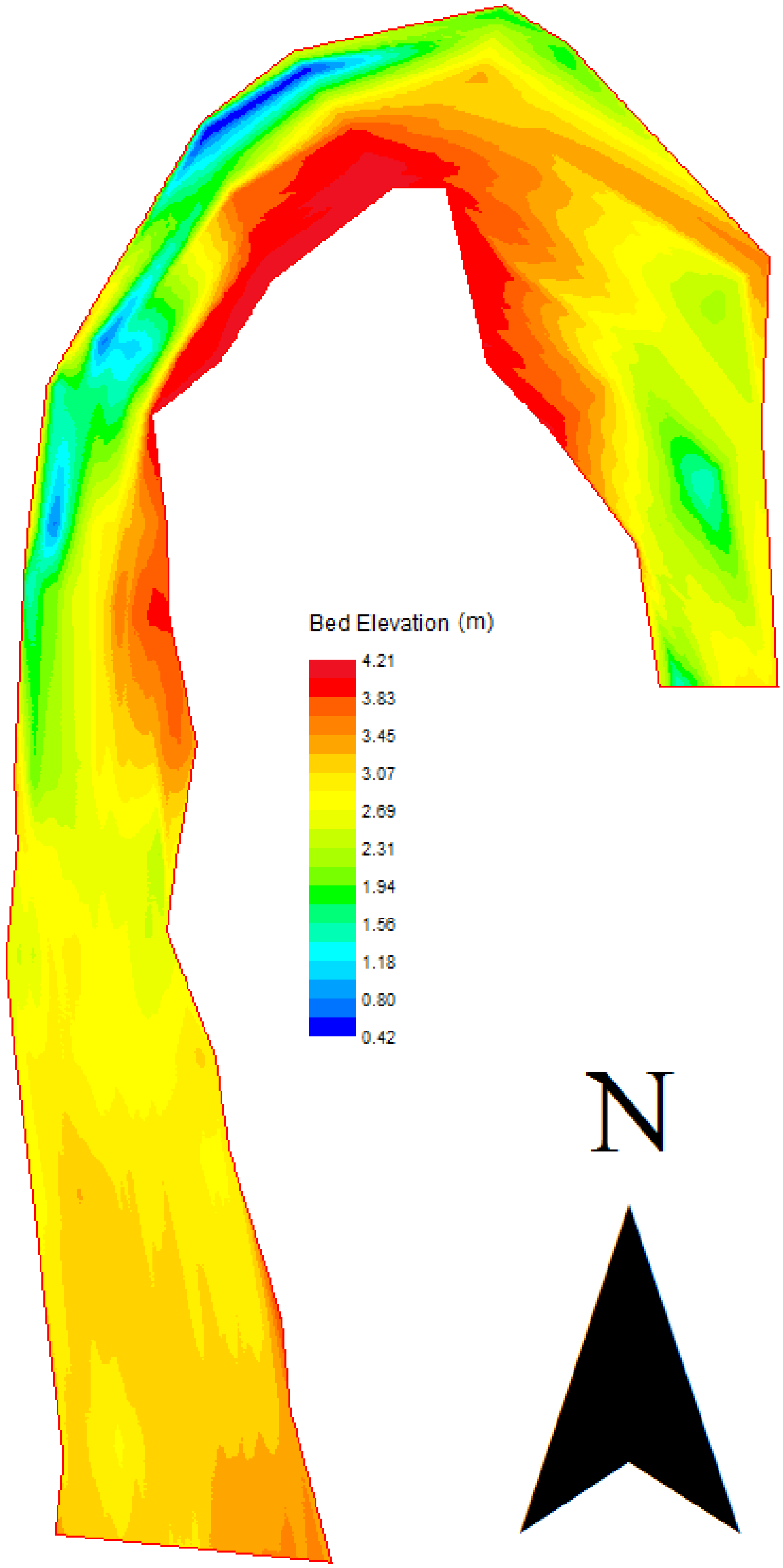

Figure 29
Rkm 118.4 Bed Topography

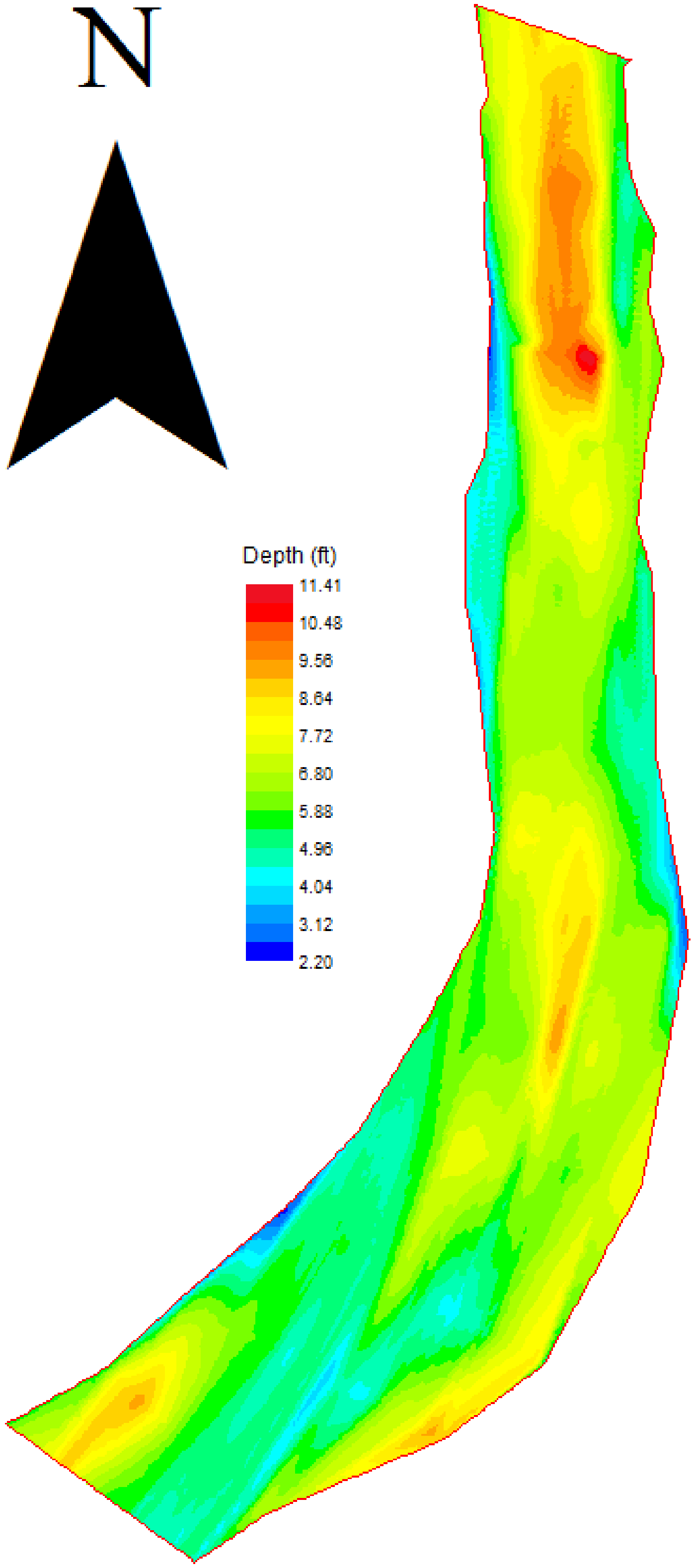

Figure 30
Rkm 142.5 Depths

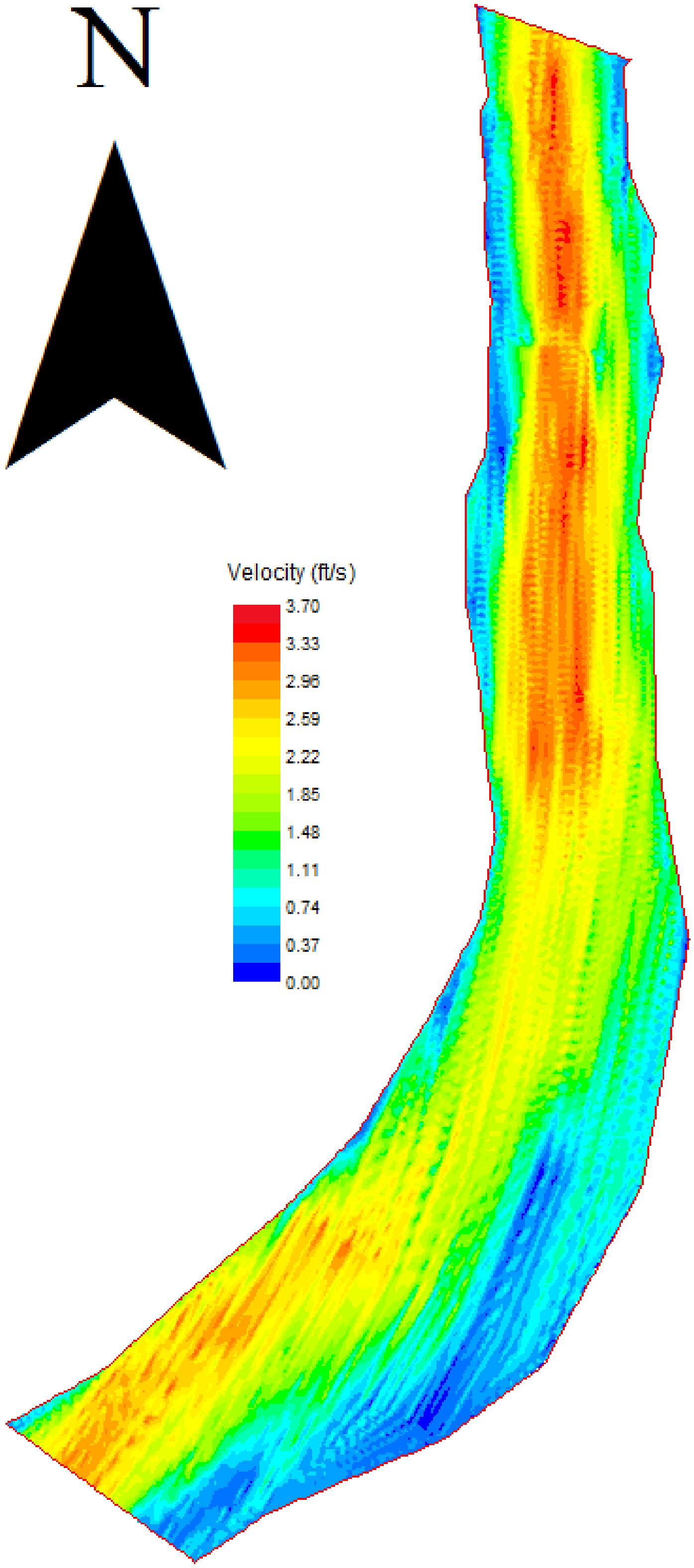

Figure 31
Rkm 142.5 Velocities

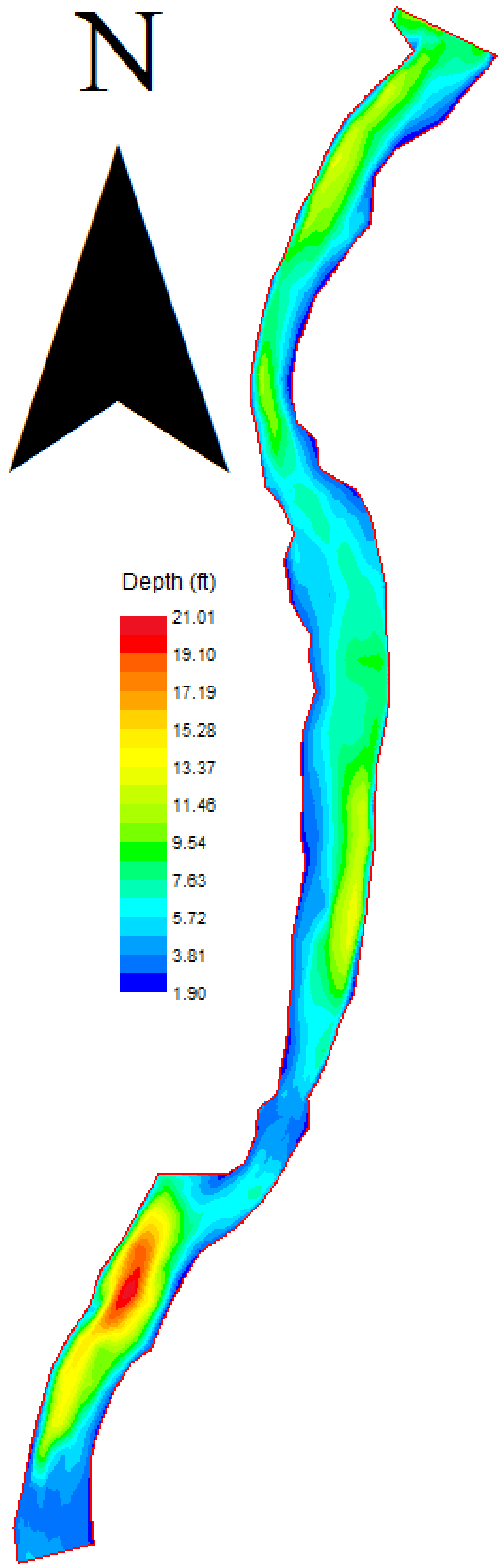

Figure 32
Rkm 140.4 Depths

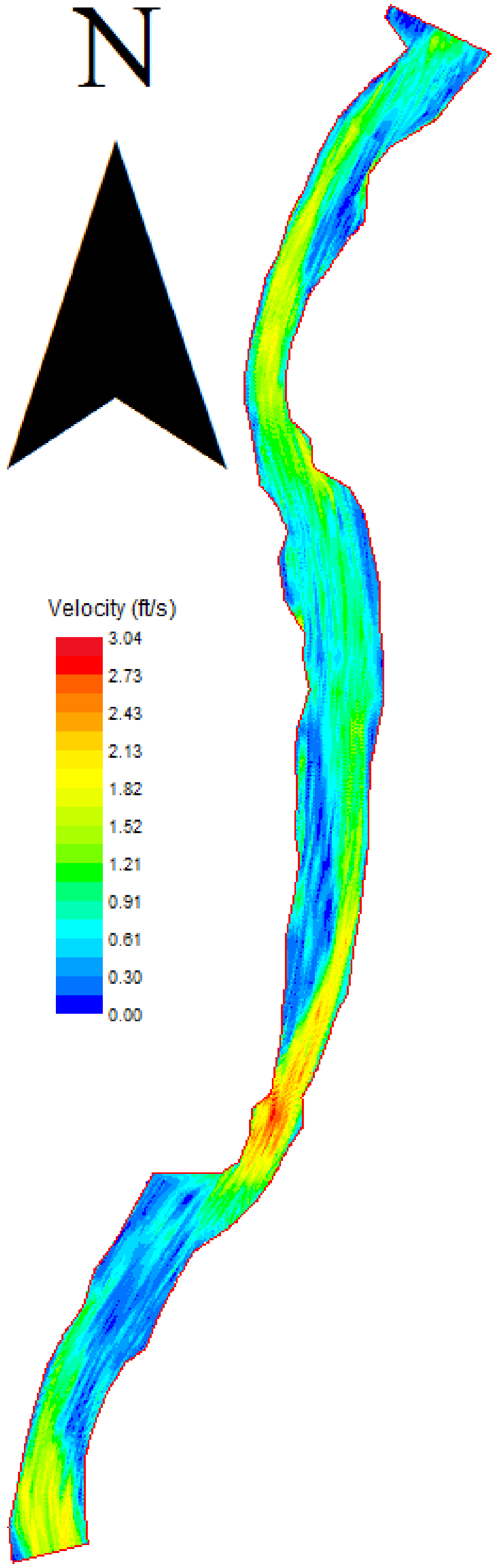

Figure 33
Rkm 140.4 Velocities

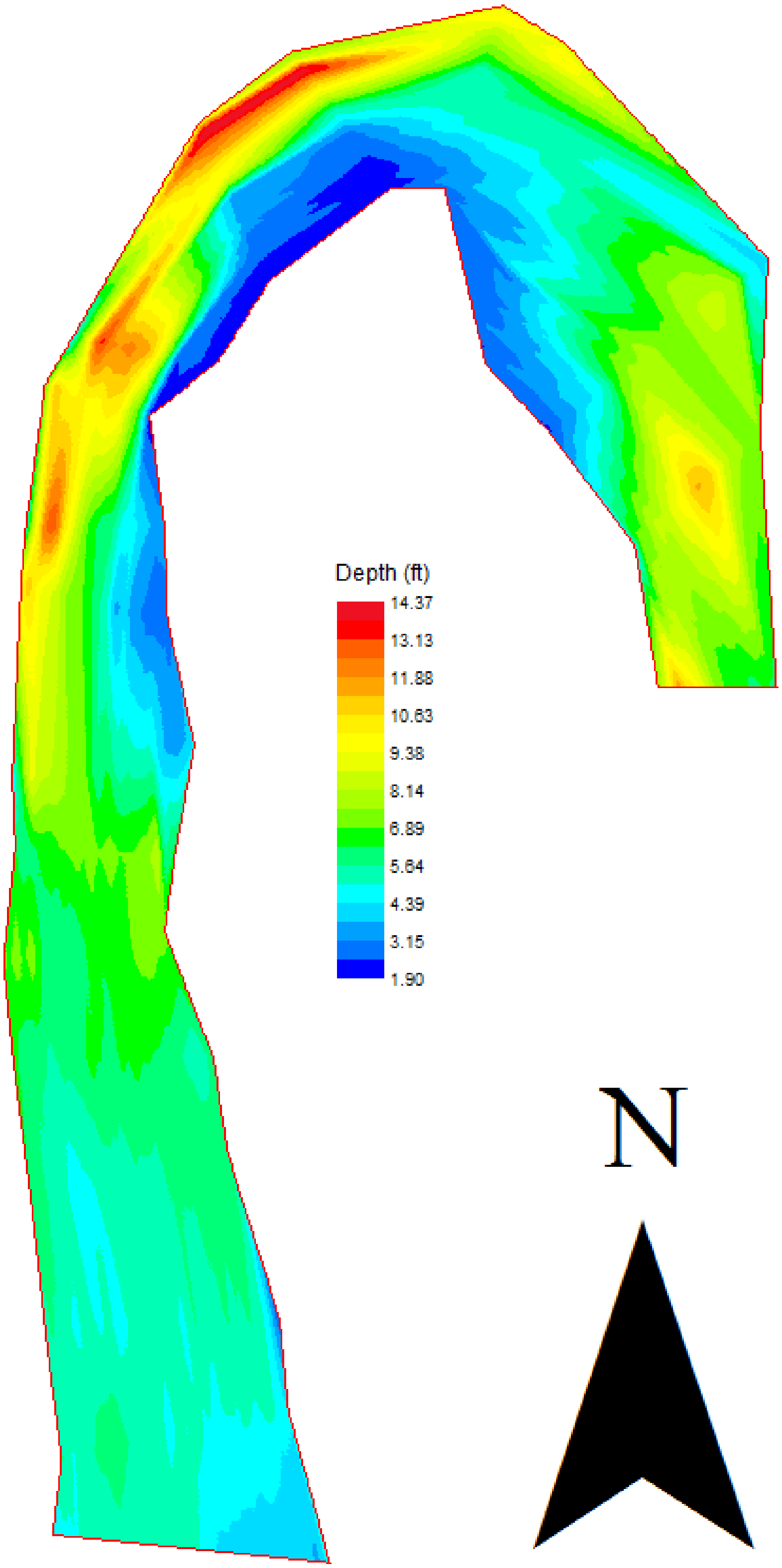

Figure 34
Rkm 118.4 Depths

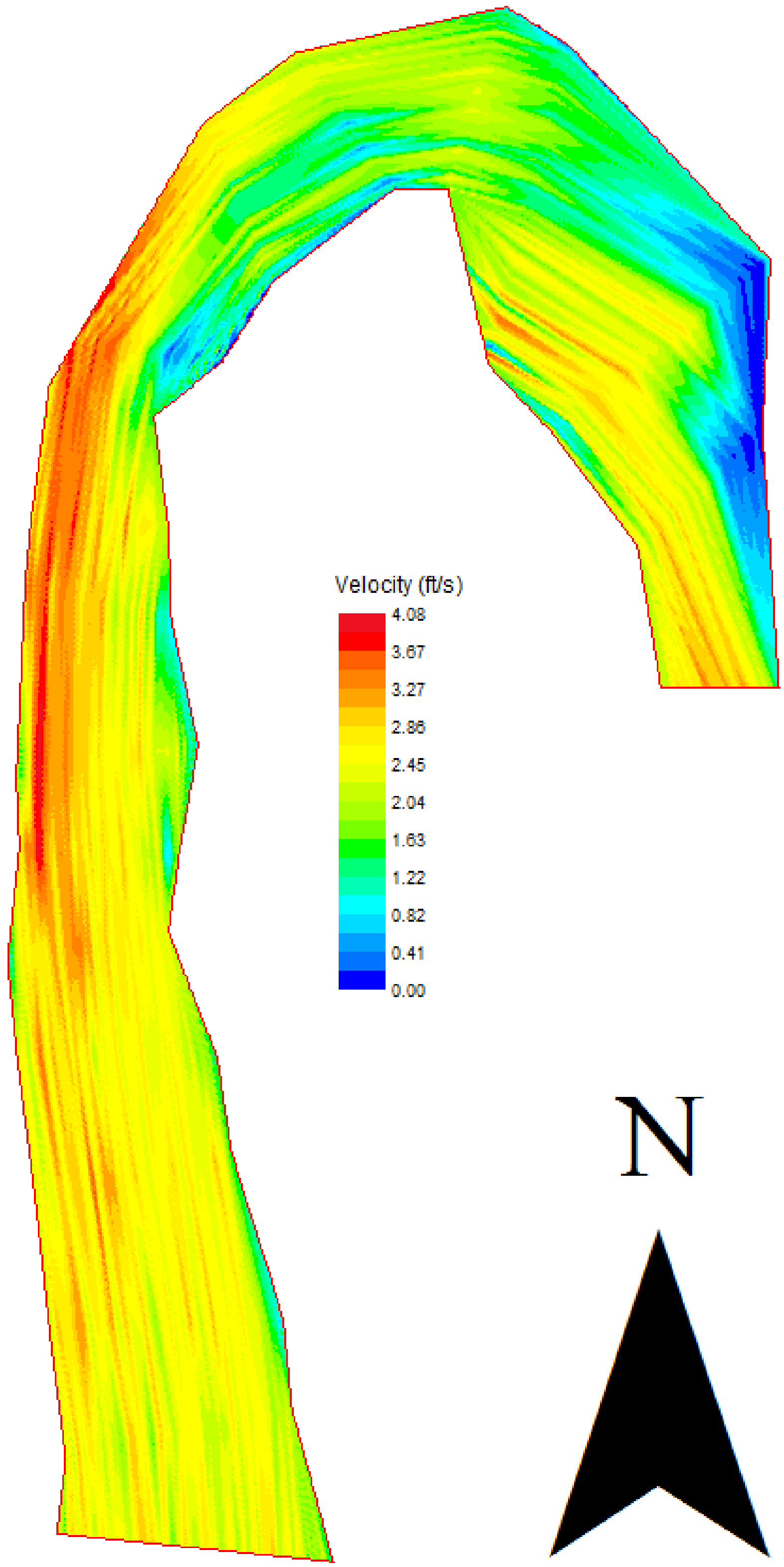

Figure 35
Rkm 118.4 Velocities

Stanislaus River Upstream Passage Assessment

Methods

The purpose of this task was to assess a potential upstream barrier to white sturgeon passage at RM 2.0 (Figure 36). Depths and velocities were mapped using the same methods described above for the Sacramento River green sturgeon rearing task. Mapping was conducted on October 26, 2015 at a flow of 973 cfs and on November 18, 2015 at a flow of 238 cfs. For the latter mapping, portions of the passage barrier that were too shallow to be sampled with the ADCP were measured with a combination of a RTK GPS unit (for horizontal position) and stadia rod (for depth). Upstream passage was assessed using the same criteria given above for Sunset Pumps. The site was snorkeled on June 24, 2016 at a flow of 355 cfs to confirm that there was sufficient clearance for sturgeon to pass under a large woody debris pile that was just upstream of the barrier. In addition, depths across the critical passage location (determined from the earlier mapping) were measured with a tape and stadia rod.

Results

Depths at the barrier are shown in Figures 37 and 38. The maximum velocity measured in the vicinity of the barrier was 4.71 ft/s at 973 cfs and 3.34 ft/s at 238 cfs. At 973 cfs, the minimum width with a depth greater than 3 feet was 14 feet. Although the minimum width at the barrier with a depth greater than 3 feet was 7.5 feet at 238 cfs, there were locations upstream and downstream of the barrier at that flow where the entire channel width had depths of less than 3 feet. At 355 cfs, the minimum width with a depth greater than 3 feet was 19 feet. Acoustic tagging data from adult white sturgeon documented upstream migration past the barrier at a flow of 755 cfs, on April 20, 2015. Snorkeling indicated that there was sufficient deep passage under the woody debris pile.

Figure 36
Stanislaus River Potential Upstream Migration Barrier

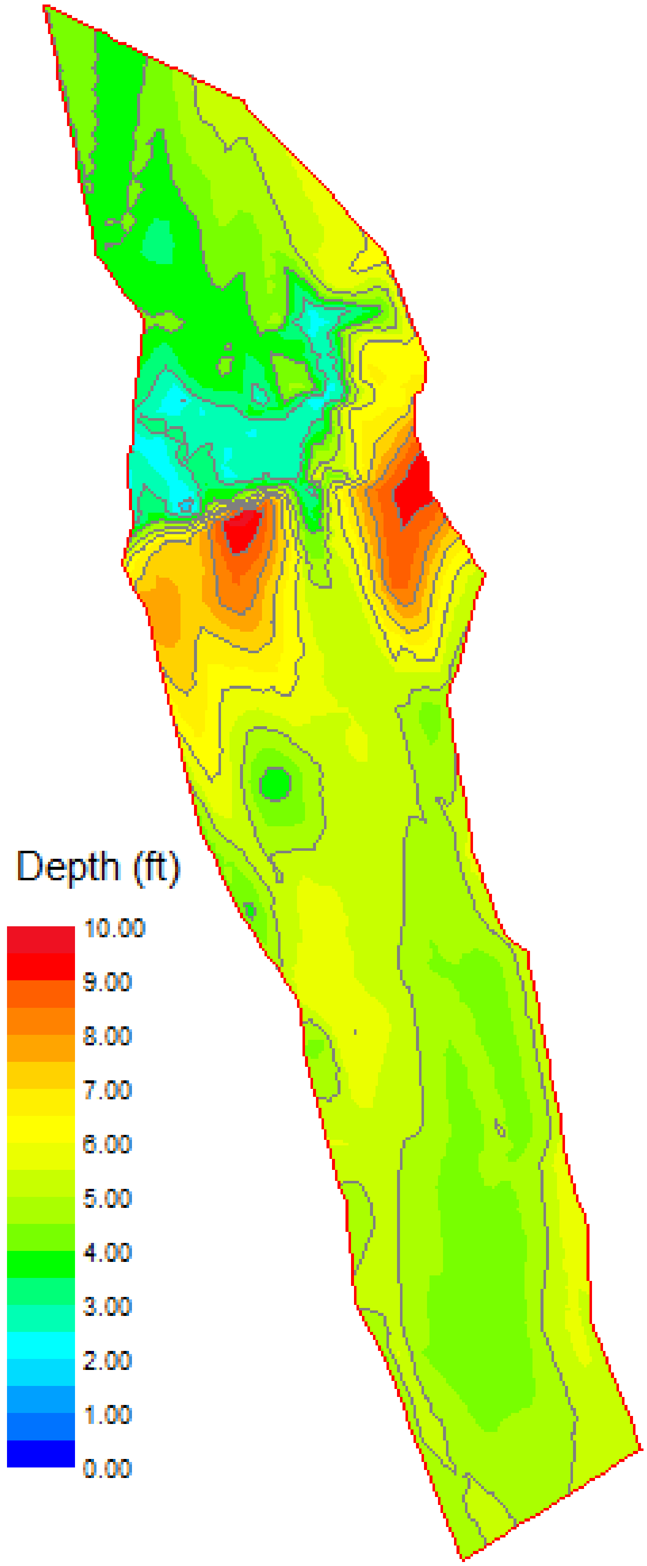

Figure 37
Stanislaus River Potential Upstream Migration Barrier Depths at 973 cfs

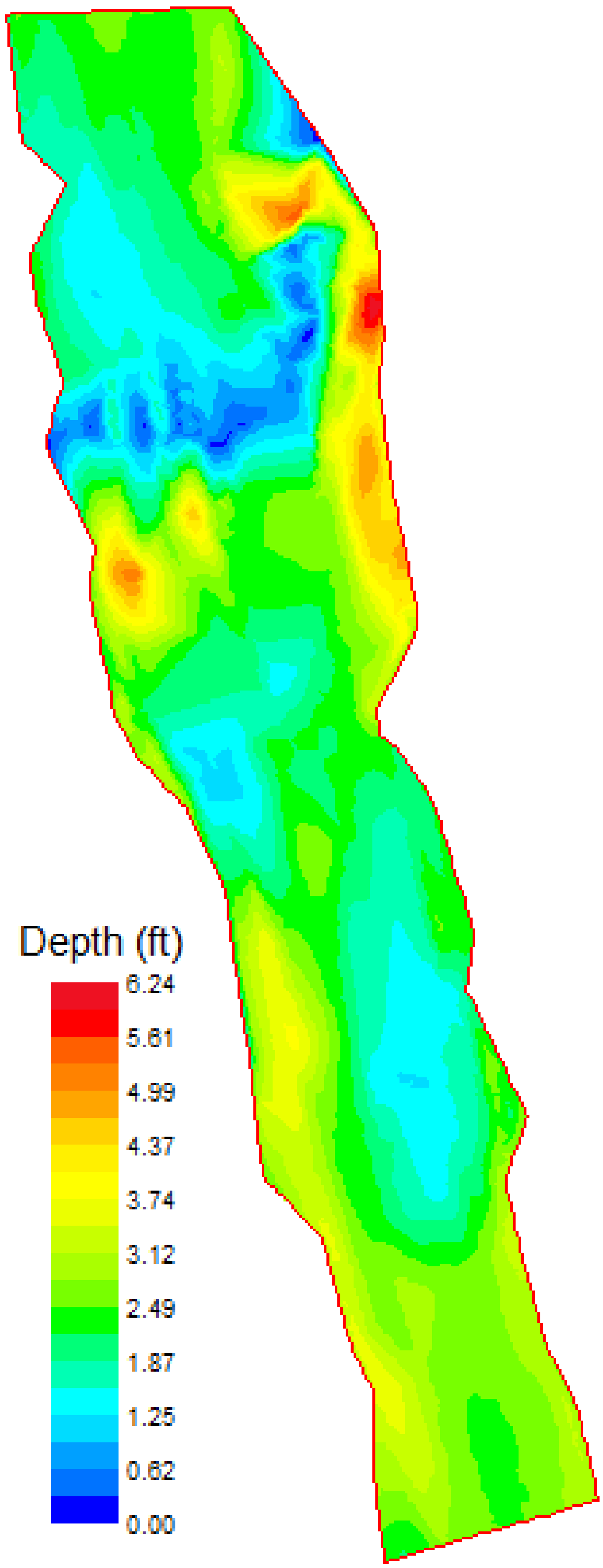

Figure 38
Stanislaus River Potential Upstream Migration Barrier Depths at 238 cfs

Discussion

Based on the measurements at the two lower flows, the actual minimum width with a depth greater than 3 feet at 973 cfs was greater than 19 feet. At this higher flow, we were unable to sample the entire width that had depths greater than 3 feet due to obstructions from brush. The evaluation indicated that this location is not a barrier to upstream migration of adult white sturgeon. Although the rip-rap piled across the channel to raise the stage for an upstream diversion would appear to be a barrier to upstream migration of adult white sturgeon, the deep gap between the rip-rap and the east bank has a continuous wide and deep enough channel to enable adult white sturgeon to pass upstream without delay or blockage.

Hammon Bar Velocity Validation

Methods

The purpose of this task was to validate the velocities predicted by a habitat model of the Hammon Bar riparian restoration site. Mean column velocities were to be measured at two flows that inundate the Hammon Bar plantings with a wading rod and a Marsh-McBirney[R] model 2000 velocity meter. Depth was recorded to the nearest 0.1 foot and average water column velocity was recorded to the nearest 0.01 ft/s. The horizontal location of each velocity measurement was recorded with a survey-grade RTK GPS unit. Measurements were made downstream of both pod and stinger plantings, with at least 100 measurements made for each type of planting at each of the two flows. The River2D model of the post second year plantings, created in FY-14, would be run at the two flows, and the measured velocities were compared to the velocities simulated by River2D at the horizontal locations recorded with the survey-grade RTK GPS unit.

Results

An attempt was made to collect the data on March 15 and 16, 2016, at flows of, respectively, 15,485 and 13,329 cfs. Unfortunately, we were unable to collect any data due to equipment failure. Visual observation indicated that the plantings were not entirely inundated even at 15,485 cfs.

Discussion

We plan to try again in FY-17 to collect this data; this will require Yuba River flows exceeding 15,500 cfs.

North Fork Cottonwood Creek Flows Investigation

Methods

The purpose of this task was to identify opportunities for restoration or negotiations on flow management in North Fork Cottonwood Creek to improve summer water temperatures for spring-run Chinook salmon adult holding. Existing flow and water temperature data on North Fork Cottonwood Creek, including diversions from the Igo/Ono diversion, were assembled. In addition, water temperature profiles in Rainbow Lake were to be collected.

Results

Water temperature data have been collected just downstream of the barrier for anadromous salmonids in North Fork Cottonwood Creek (Figure 39) by CDFW staff, starting on September 18, 2012. The maximum water temperature observed thus far at that location was 80.0 ° F. Maximum daily water temperatures exceeded 76 ° F[14] for four days in 2013, 15 days in 2014 and 16 days in 2015. Water temperature data were also collected by the timber harvest company, Crane Mills, downstream of the confluence of Moon Fork and North Fork Cottonwood Creek (just downstream of Rainbow Lake) from June 16 to November 3, 1999[15]. For this data and date range, the maximum water temperature was 68.15 ° F (on July 26). Flow data is available for the period of October 1, 1975 through September 29, 1994 for a CDWR gage on North Fork Cottonwood Creek[16]. Currently, a CDWR gage on North Fork Cottonwood Creek upstream of Rainbow Lake only records stage. Mean monthly flows and diversion rates from the Igo/Ono diversion, as per SWRCB (2015), are shown in Table 15. A tributary, Jerusalem Creek, enters the study reach (Figure 39). The only flow data available for Jerusalem Creek was a measurement we made on August 15, 2012. On that date, Jerusalem Creek flows were 18 percent of the total North Fork Cottonwood Creek flows at the waterfall. We were unable to collect water temperature profiles in Rainbow Lake due to lack of landowner approval. Rainbow Lake has an area of 113 acres and a capacity to the spillway crest of 3,600 acre-feet. Releases from Rainbow Lake to the North Fork of Cottonwood Creek are from the bottom of the reservoir (J. Schreder, landowner, personal communication).

[14] This is the highest daily maximum water temperature where adult spring-run are observed holding in Beegum Creek, a tributary to Middle Fork Cottonwood Creek (D. Killam, CDFW, personal communication).
[15] This was the only water temperature data collected by Crane Mills downstream of Rainbow Lake; the remaining data were collected either in North Fork Cottonwood Creek upstream of Rainbow Lake or in Moon Fork Cottonwood Creek upstream of North Fork Cottonwood Creek.
[16] Gage A03545 - Cottonwood Creek, North Fork, near Igo. Lat: 40.442134 Long: -122.550846.

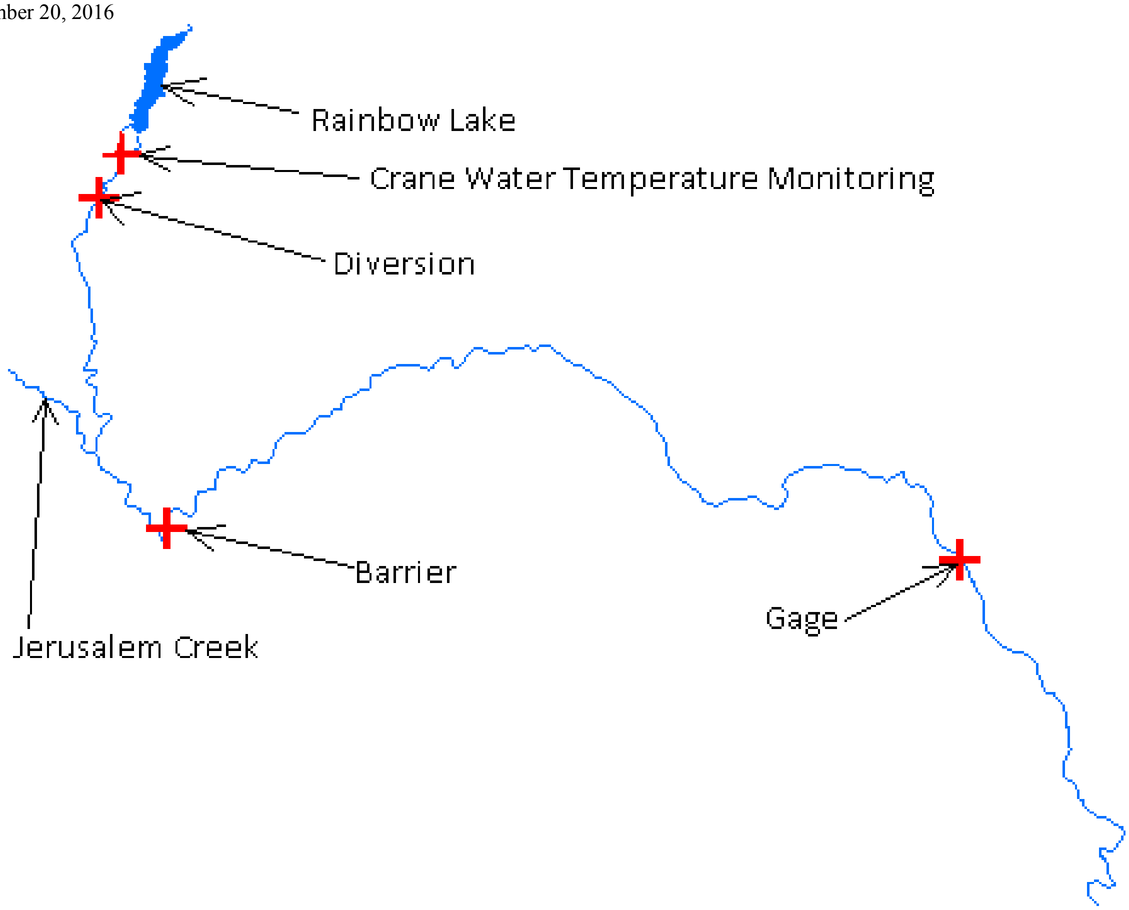

Figure 39
North Fork Cottonwood Creek Flows Investigations Map

Table 15
North Fork Cottonwood Creek Mean Monthly Flows and Diversions

Month	Mean Monthly Flows (cfs)	Mean Monthly Diversions (cfs)
January	224.3	0
February	311.3	0
March	390.9	0
April	203.0	8.4
May	113.2	8.9
June	53.7	8.4
July	19.8	8.9
August	9.2	8.9
September	11.5	8.8
October	19.4	8.7
November	72.9	0
December	161.4	0

Discussion

This data should provide a good starting point for developing a water temperature model of North Fork Cottonwood Creek in FY-17. The mean monthly flows in Table 15 were measured below the diversion, and thus represent impaired flows.

Feather Water District Hydraulic Evaluation

Methods

The purpose of this task was to conduct a hydraulic evaluation of the new cone screens at the Feather Water District diversions. Ambient velocities in the vicinity of the screens were measured as described above for the Sacramento River juvenile green sturgeon habitat mapping. A SonTek 16 MHz Acoustic Doppler Velocimeter (ADV) was planned to be used to measure near-screen velocities in three dimensions: X, Y, and Z. The ADV is positioned such that approach velocity is measured directly by the X component of the probe. Sweeping velocities are calculated as the resultant of Y and Z measured values. Raw data for each location are stored in separate files and processed with WinADV, a program developed by the U.S. Bureau of Reclamation. Point-average velocities are processed with Microsoft Excel to produce charts and graphs. Total discharge for each screen is calculated based on screen area and approach velocities as a quality control procedure. The formula to calculate the total discharge is as follows:

$$\text{Total Discharge} = \Sigma \text{ screen area}_{\text{depth position } i} \times \text{average approach velocity}_{\text{depth position } i}$$

Results

Ambient velocities were measured on May 18, 2016 at Feather River flows of 4,564 cfs. The average ambient velocity near the Feather Water District South screens was 1.26 ft/s, while the average ambient velocity near the Feather Water District North screens was 1.44 ft/s. At this flow, the tops of the screens were 5 feet deep. Using the rating curve for the Feather River at Boyd's Landing gage, we determined that Feather River flows would need to be lower than 1,800 cfs to measure approach and sweeping velocities on the screens. Feather River flows stayed above 3,200 cfs through the end of FY-16. As a result, our collection of approach velocity data has been delayed until FY-17.

Discussion

Conical screens were originally developed to operate in tidal and backwater areas where water depths are shallow and there is no dominant current in the water body. More recently, pie baffle systems have been employed to allow cone screens to be used in a riverine environment. The NMFS and CDFW criterion for approach velocities is 0.33 ft/s. Our hydraulic evaluation of the Red Bluff cone screens, which did not have a pie baffle system, found approach velocities as high as 1.9 ft/s in a location where we estimate that the ambient velocities were in the range of

2 to 2.5 ft/s. Hanna (2011), with a pie baffle system, had a maximum approach velocity of 0.5 ft/s with an ambient velocity of 1.69 ft/s. In FY-17, we will be able to determine what the maximum approach velocity is for the ISI pie baffle system on the Feather Water District screens with the ambient velocity to be measured concurrently.

Central Valley Structured Decision Model Evaluation

Methods

The purpose of this task was to develop new sources of data to improve the parameterization of the Central Valley Structured Decision Model (Peterson et al. 2014). Efforts on this task in FY-16 focused on spawning, rearing and floodplain habitat for the 26 streams in the Structured Decision Model (SDM). The original SDM had spawning, rearing and floodplain habitat values that were largely based on expert opinion and did not vary with flow. We identified spawning and rearing flow-habitat relationships from instream flow studies. In addition, we used simplified HEC-RAS models that were extracted from the CDWR Central Valley Flood Evaluation and Delineation (CVFED) Program HEC-RAS models (CDWR 2015) to develop flow-floodplain area relationships. We also sought out other sources of HEC-RAS models to develop flow-floodplain area relationships for streams that were not modeled by the CVFED program.

Results

We assembled flow-habitat relationships from existing IFIM studies to parameterize the relationship between spawning habitat and flow for the following watersheds: American River, Battle Creek, Bear River, Butte Creek, Calaveras River, Clear Creek, Cottonwood Creek, Feather River, Merced River, Mokelumne River, Stanislaus River, Tuolumne River, Upper-mid Sacramento River and Yuba River. We also assembled flow-habitat relationships from existing IFIM studies to parameterize the relationship between in-channel rearing habitat and flow for the following watersheds: American River, Battle Creek, Bear River, Butte Creek, Calaveras River, Clear Creek, Cottonwood Creek, Cow Creek, Feather River, Merced River, Mokelumne River, Stanislaus River, Tuolumne River, Upper-mid Sacramento River and Yuba River. In FY-16, we completed flow-floodplain area relationships for the following watersheds: American River, Bear River, Big Chico Creek, Butte Creek, Deer Creek, Elder Creek, Feather River, Mid-Sacramento River (Woodson Bridge to Feather River), Stanislaus River, Tuolumne River and Yuba River. We also started developing a flow-floodplain area relationship for the San Joaquin River. In FY-17, we will complete the flow-floodplain area relationship for the San Joaquin River and develop flow-floodplain area relationship for the Delta Sacramento, Lower Sacramento, Merced River, and Upper Sacramento Rivers. The Upper Sacramento River (Keswick to Woodson Bridge) flow-floodplain area relationship will be developed from the CDWR Comprehensive Study HEC-RAS model. We requested HEC-RAS models from FEMA for the remaining 26 Central Valley SDM streams, but they were unable to locate any HEC-RAS models for those streams.

Discussion

This information should be useful to the CVPIA fisheries Science Integration Team in their efforts to refine the Central Valley structured decision model.

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Appendix A
Clover Creek Critical Riffle Study Photos and Regressions

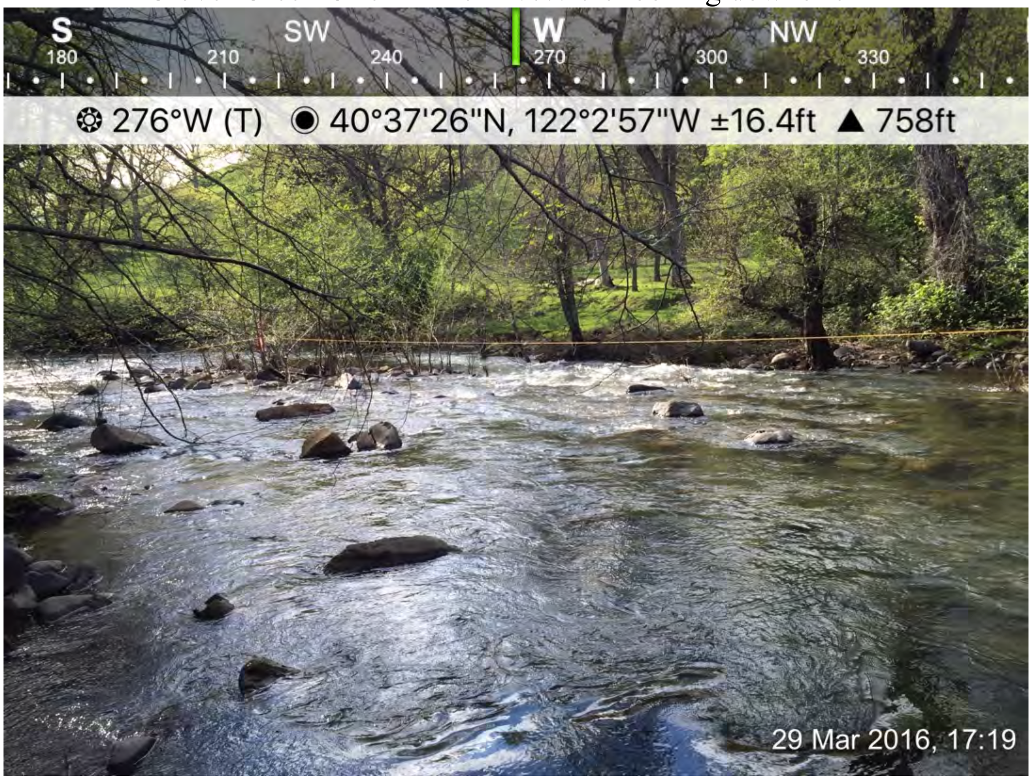
Clover Creek Riffle 4 at 65.8 cfs looking downstream

Clover Creek Riffle 4 at 12.1 cfs looking upstream

Clover Creek Riffle 22 at 65.8 cfs looking upstream

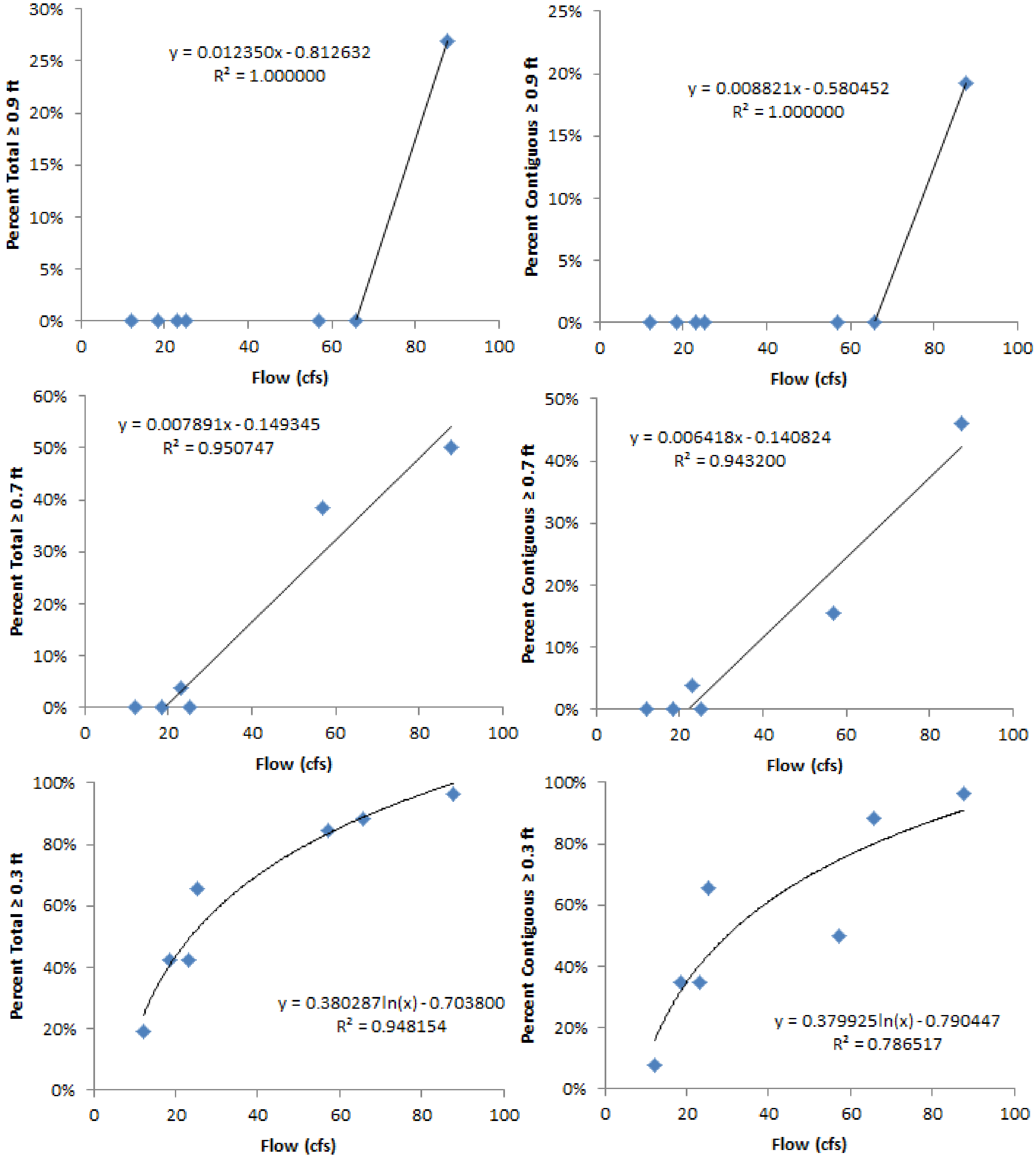
Clover Creek Riffle 22 at 12.1 cfs looking upstream

Clover Creek Oiler Riffle at 87.6 cfs looking downstream

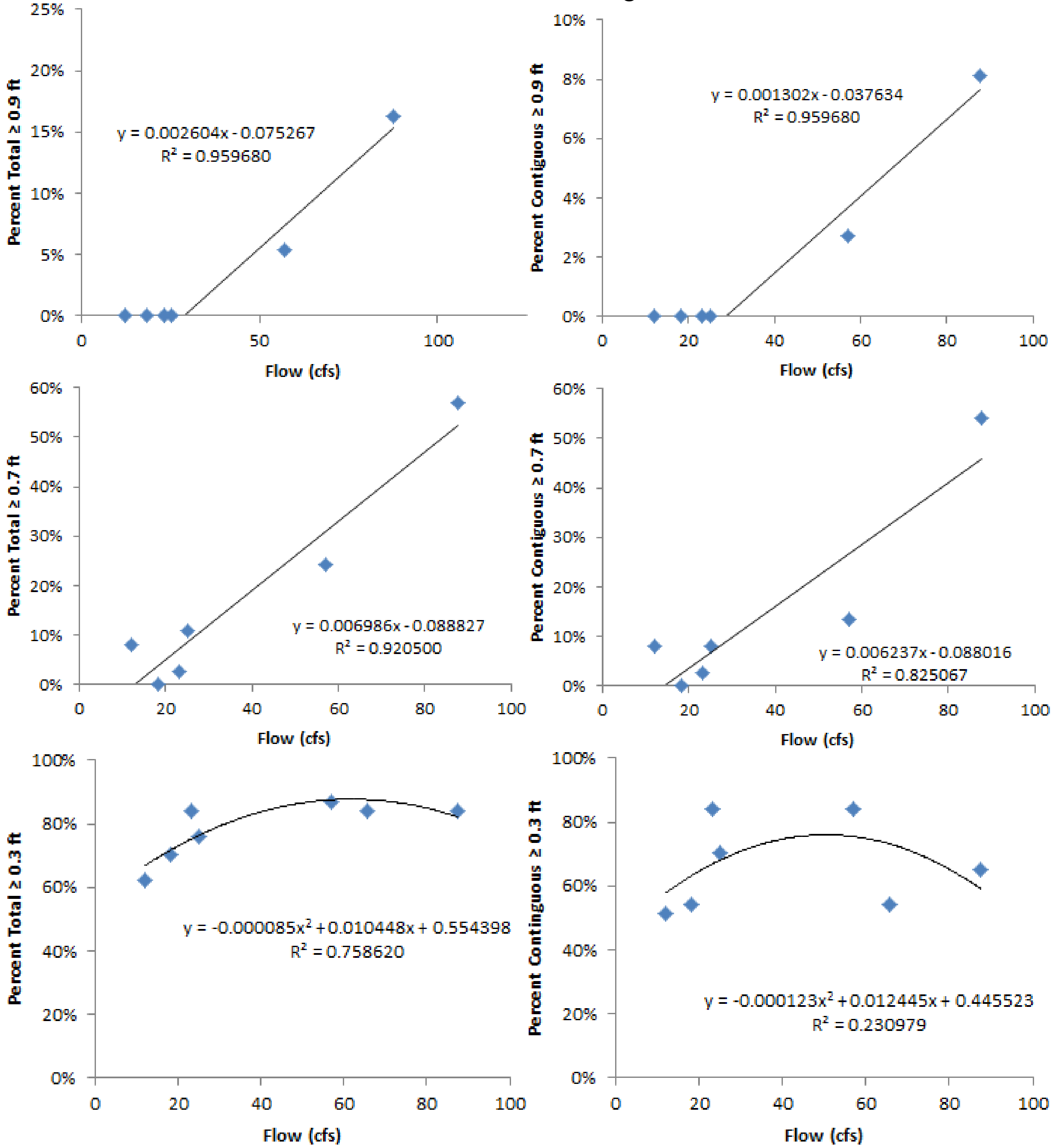


Clover Creek Oiler Riffle at 20.7 cfs looking downstream

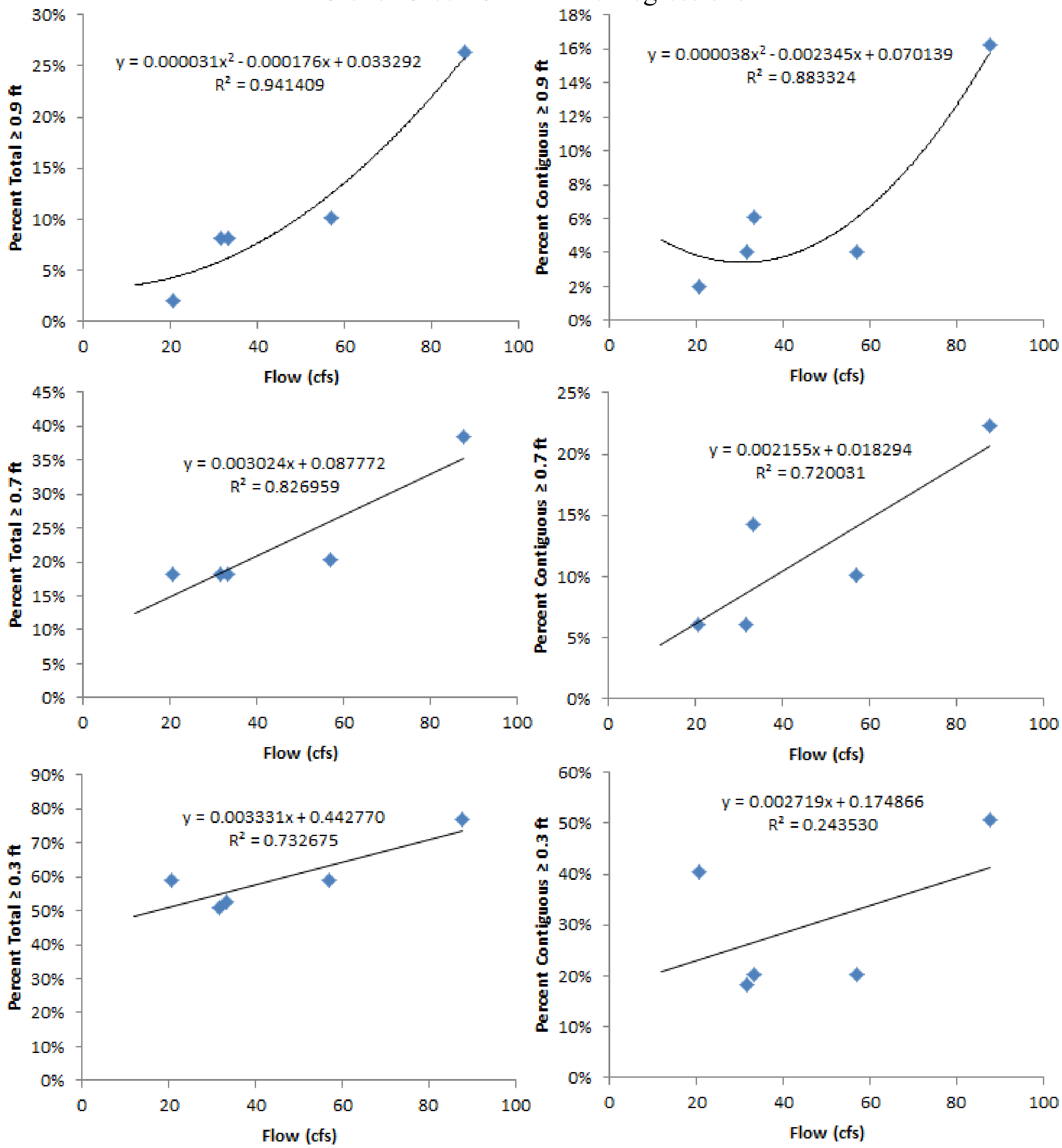
Clover Creek Riffle 4 Regressions



Clover Creek Riffle 22 Regressions



Clover Creek Oilar Riffle Regressions



Appendix B
Bear Creek Critical Riffle Study Photos and Regressions

Bear Creek Riffle 1 at 61.1 cfs looking upstream

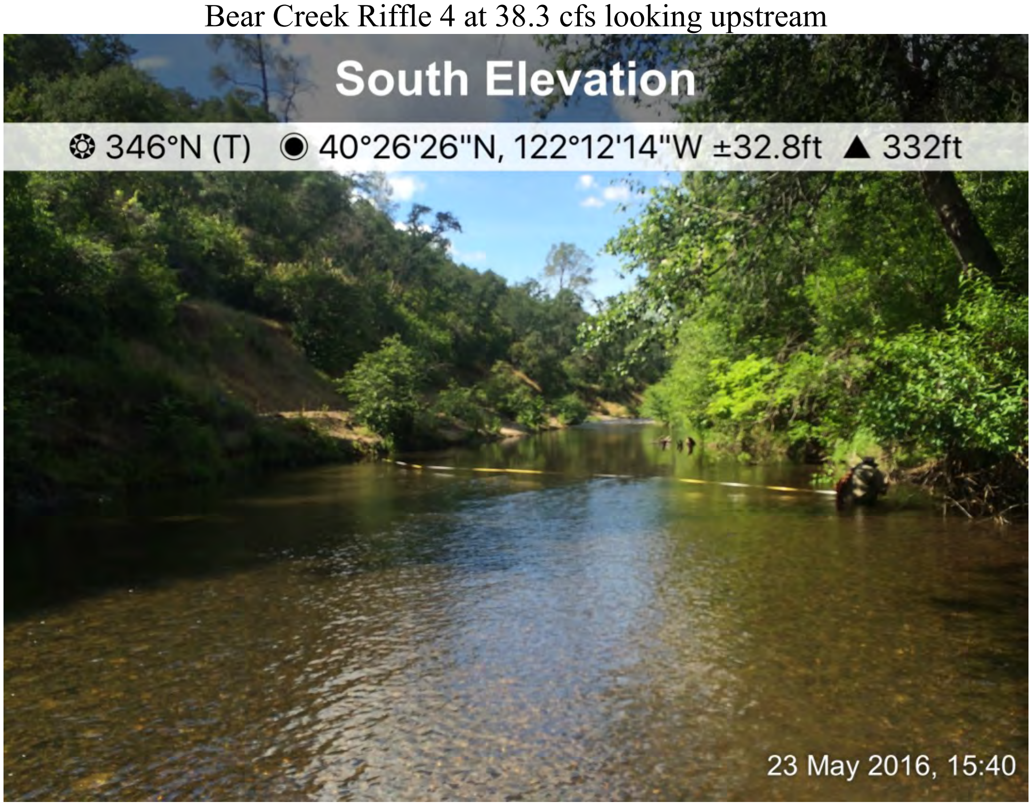
Bear Creek Riffle 1 at 38.3 cfs looking upstream

Bear Creek Riffle 2 at 61.1 cfs looking upstream

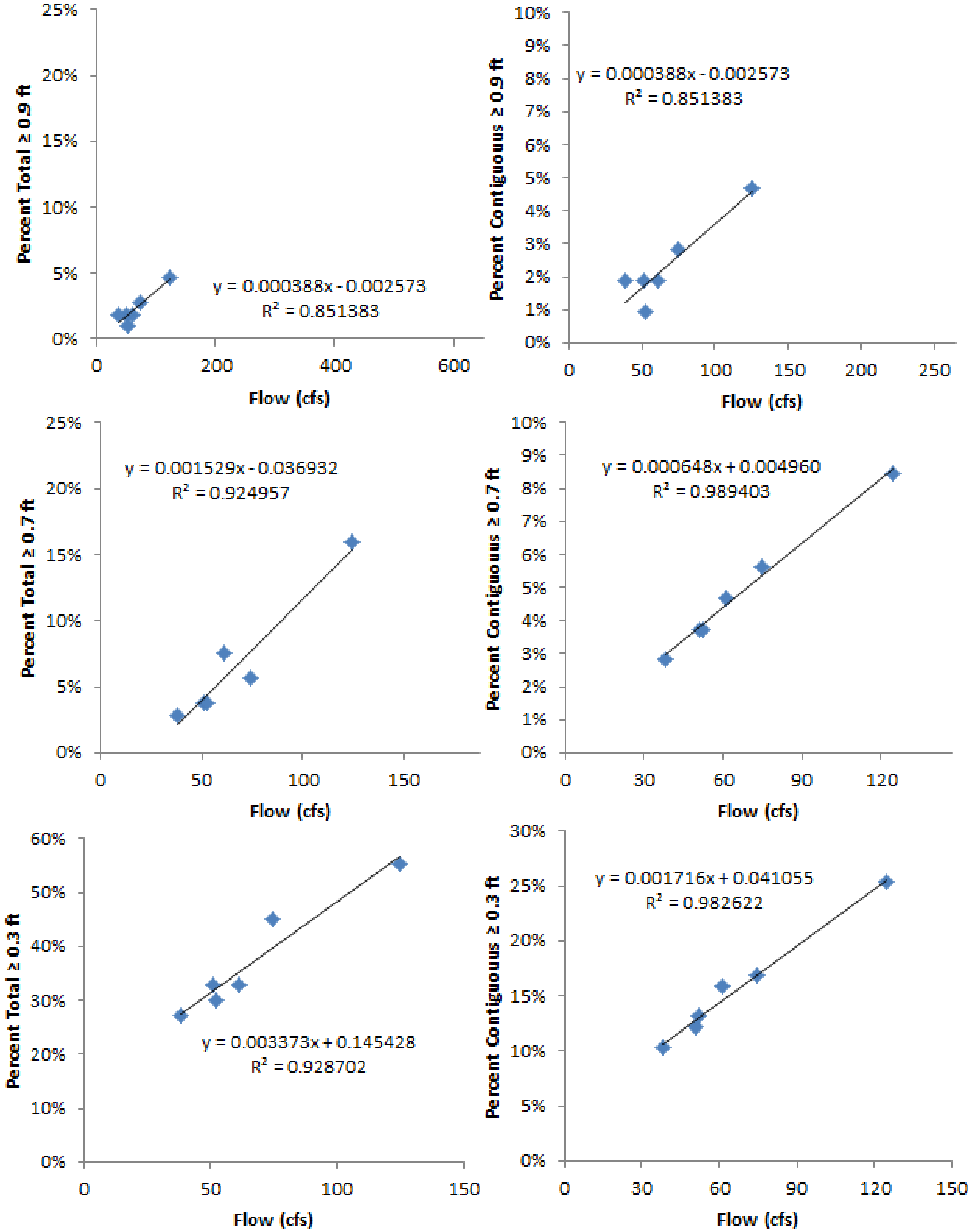
Bear Creek Riffle 2 at 38.3 cfs looking upstream

Bear Creek Riffle 4 at 61.1 cfs looking upstream

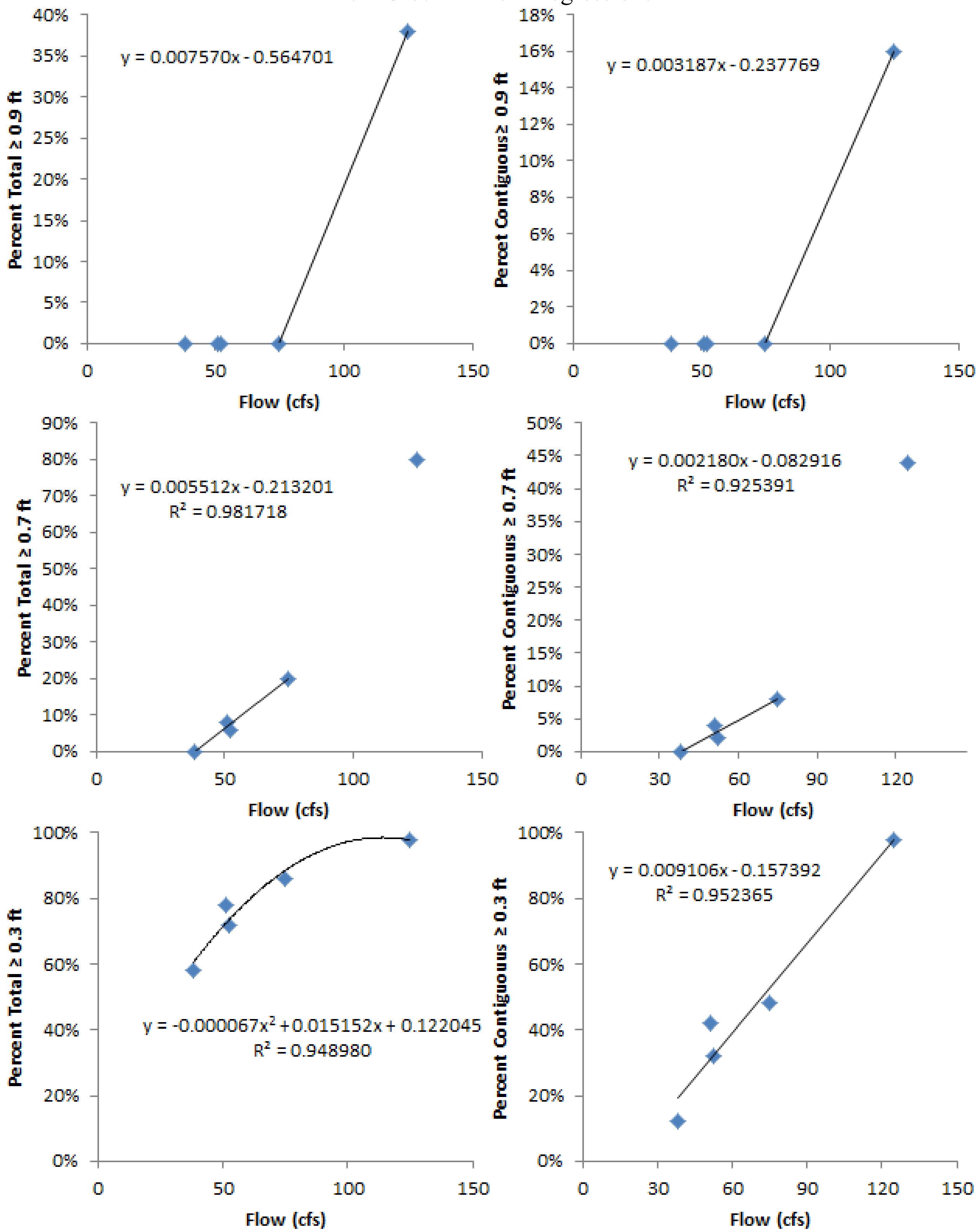
Bear Creek Riffle 4 at 38.3 cfs looking upstream



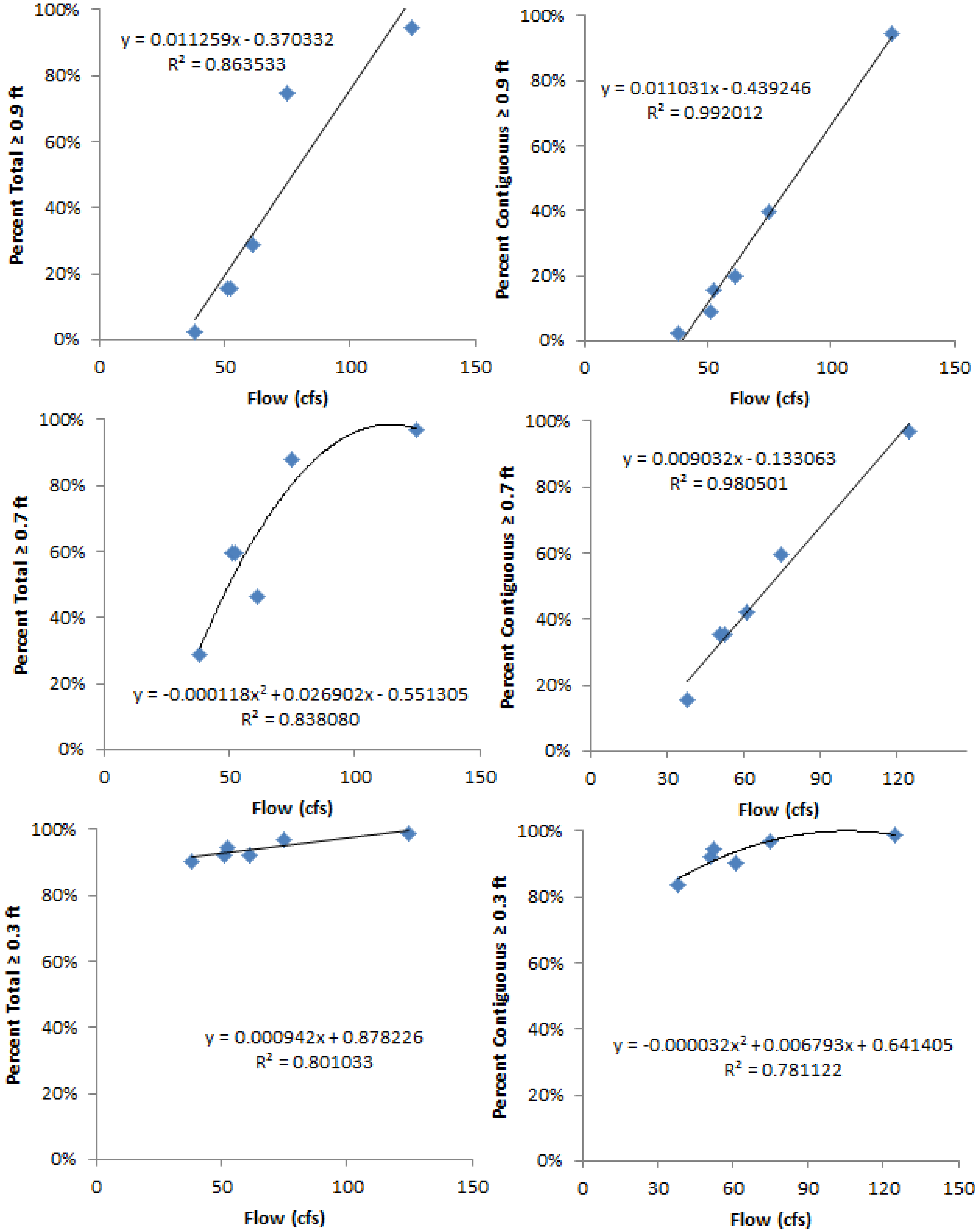
Bear Creek Riffle 1 Regressions



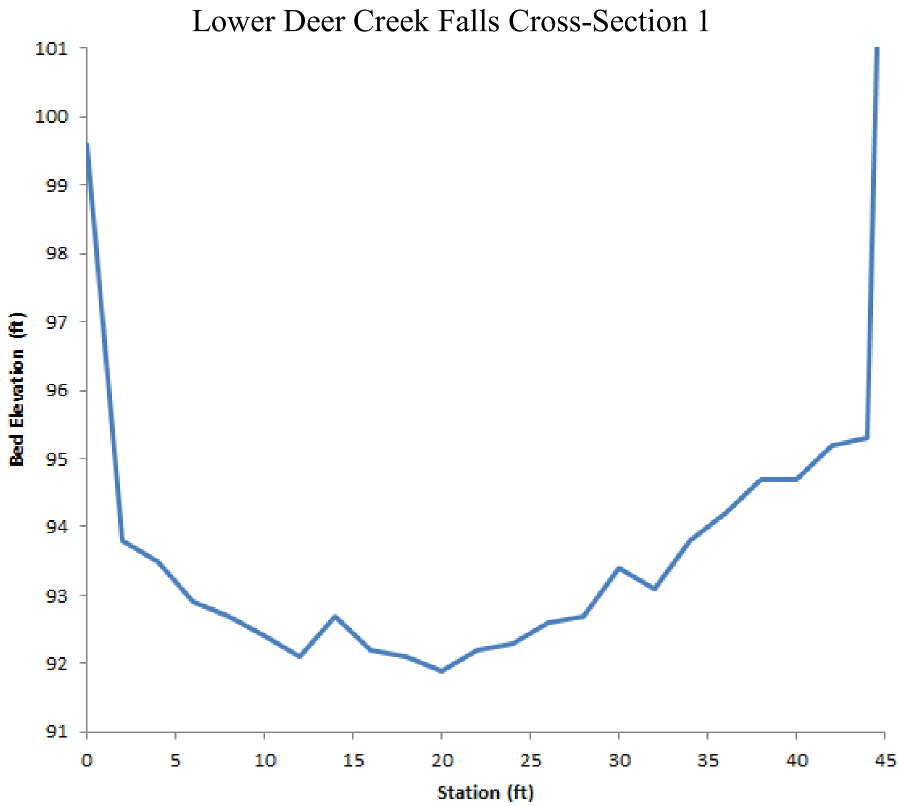
Bear Creek Riffle 2 Regressions

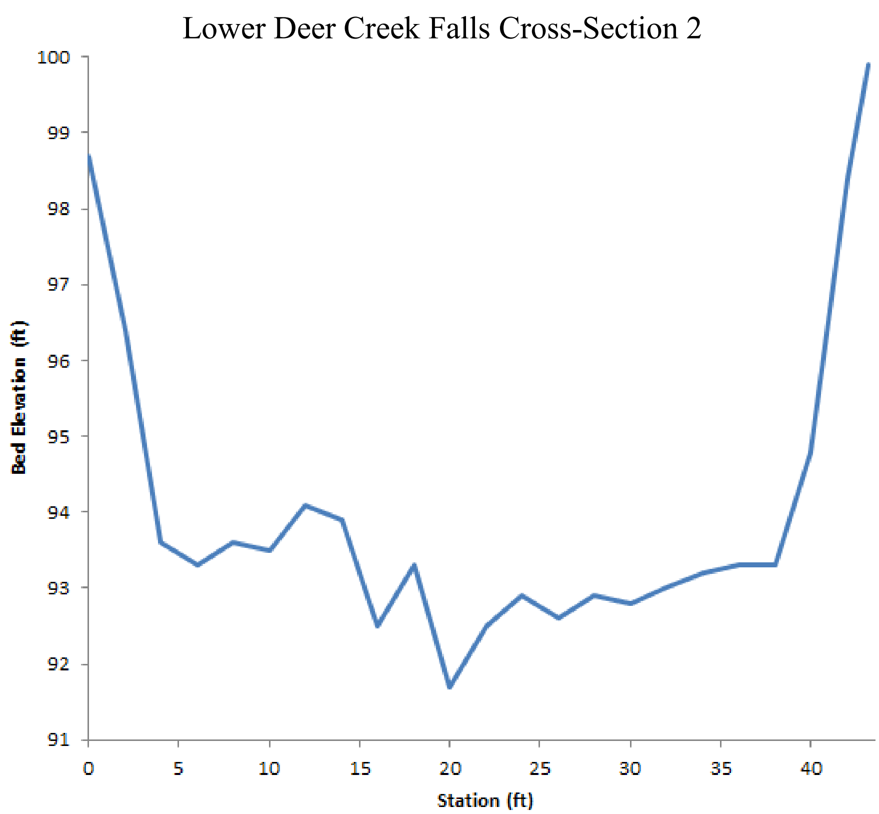


Bear Creek Riffle 4 Regressions

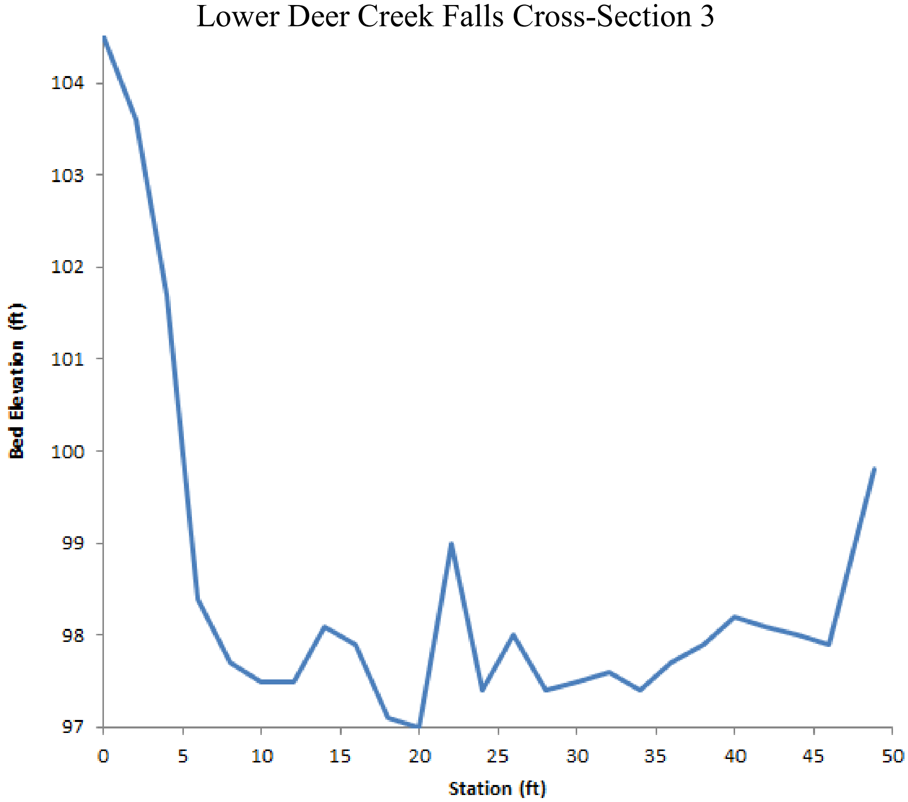


Appendix C
Lower Deer Creek Falls Cross-sectional Profiles and Photos

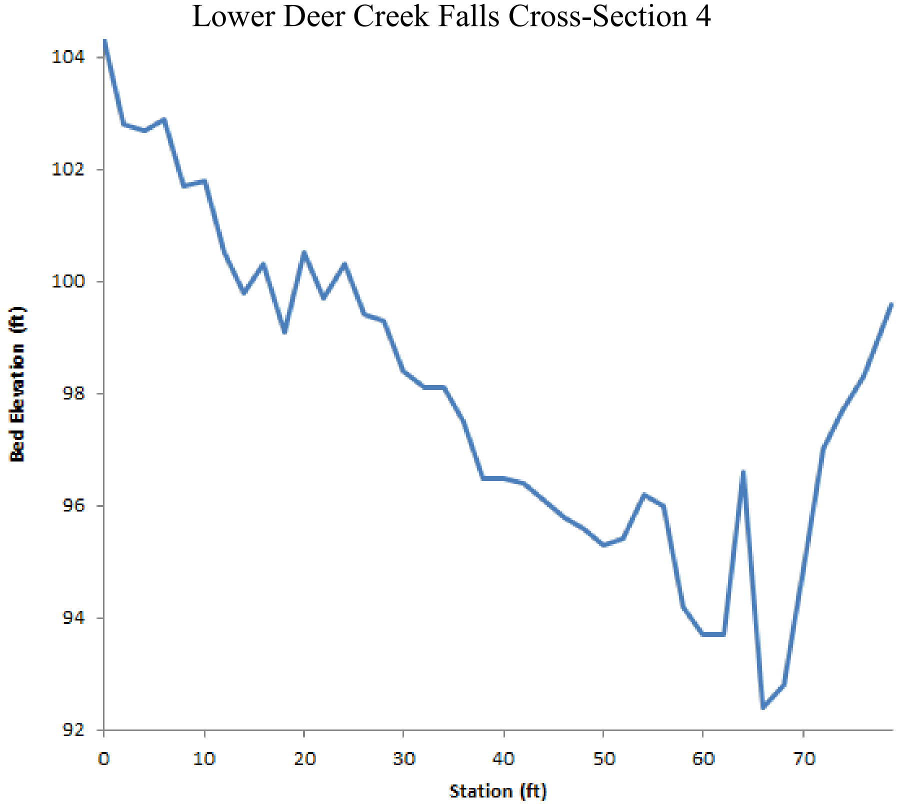

Lower Deer Creek Falls Cross-Section 1
Bed Elevation (ft)
Station (ft)
101
100
99
98
97
96
95
94
93
92
91
0
5
10
15
20
25
30
35
40
45


Lower Deer Creek Falls Cross-Section 2
Bed Elevation (ft)
Station (ft)
100
99
98
97
96
95
94
93
92
91
0
5
10
15
20
25
30
35
40

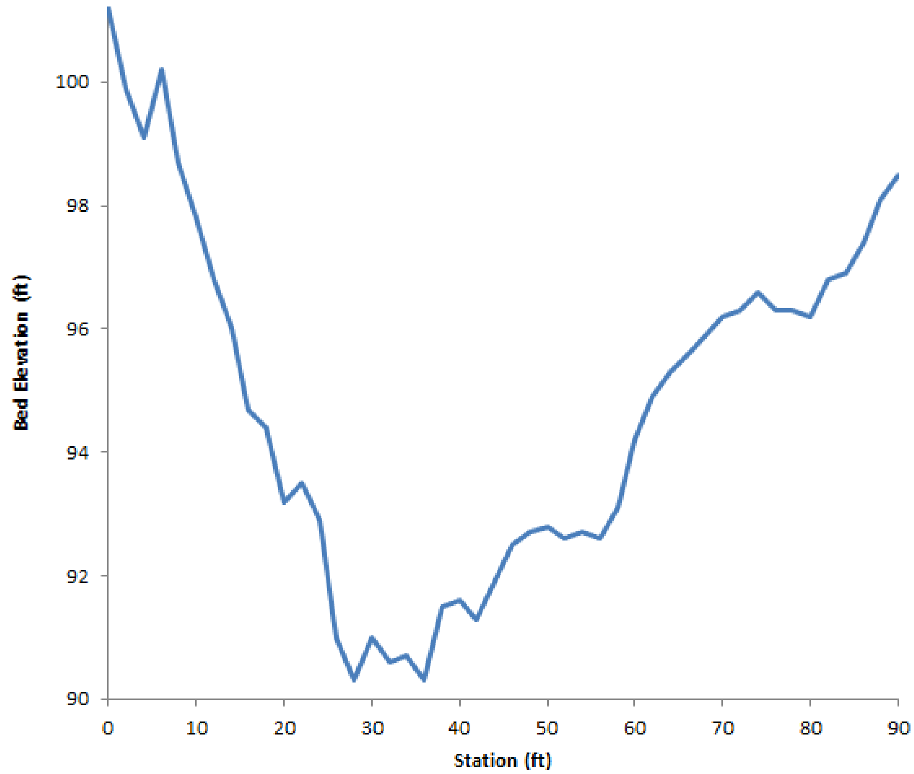
Lower Deer Creek Falls Cross-Section 3



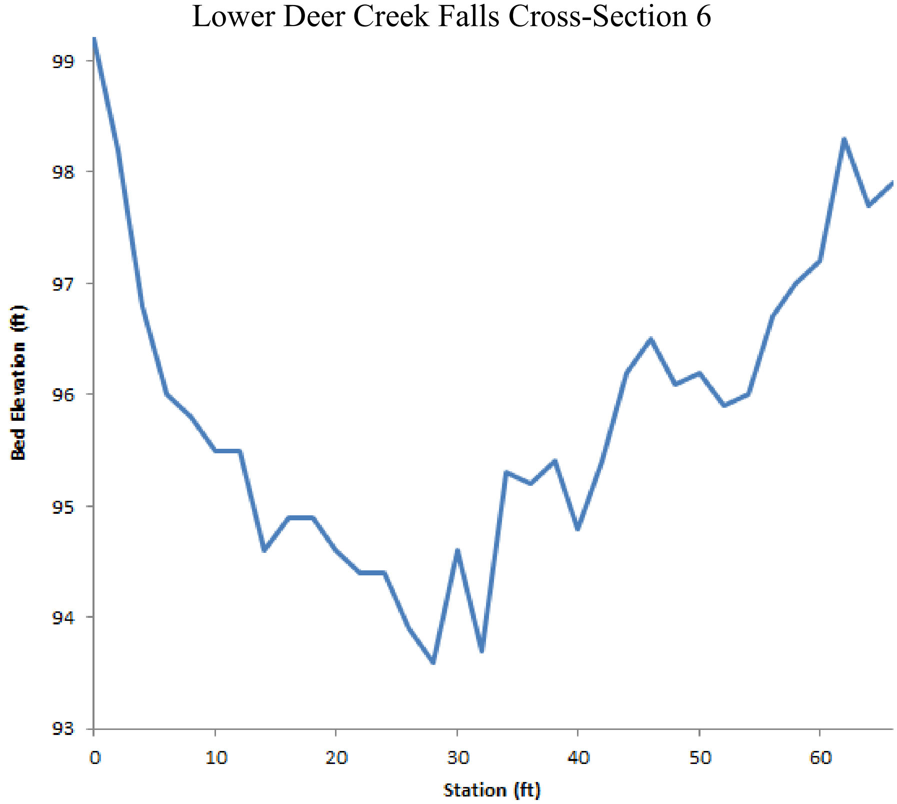
Lower Deer Creek Falls Cross-Section 4



Lower Deer Creek Falls Cross-Section 5

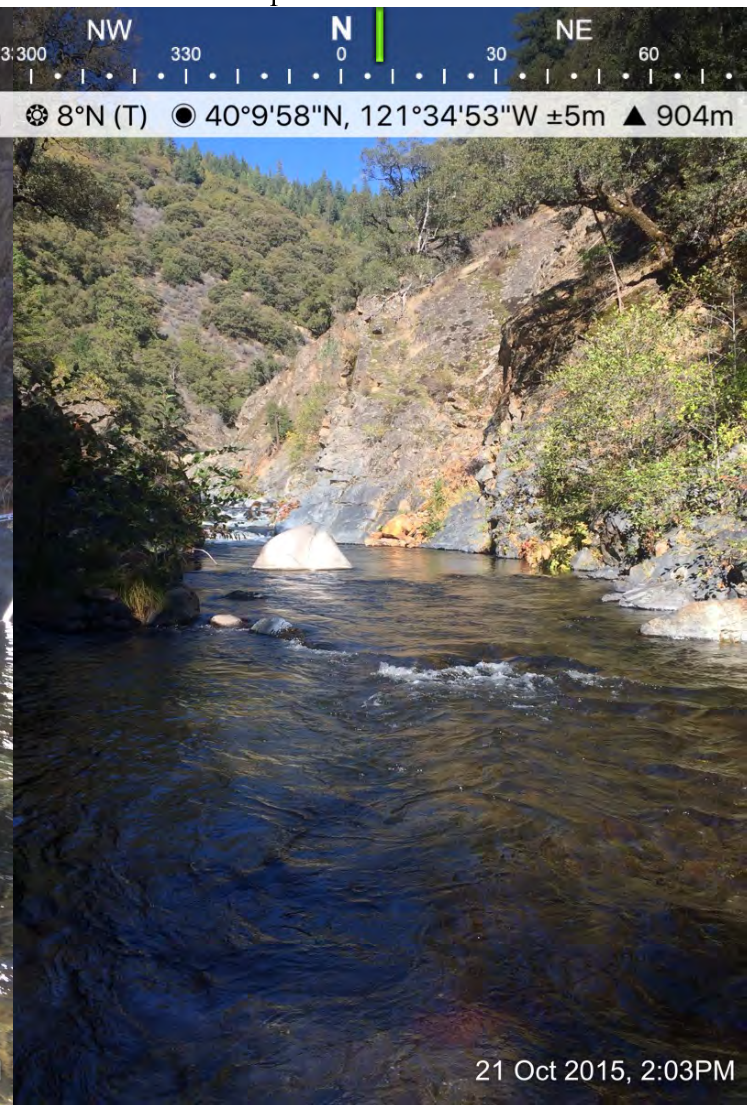


Lower Deer Creek Falls Cross-Section 6



Lower Deer Creek Falls Section 1
View of Left Bank from Right Bank

Lower Deer Creek Falls Section 1
View of Upstream from Mid-channel



Lower Deer Creek Falls Section 1
View of Downstream from Mid-channel

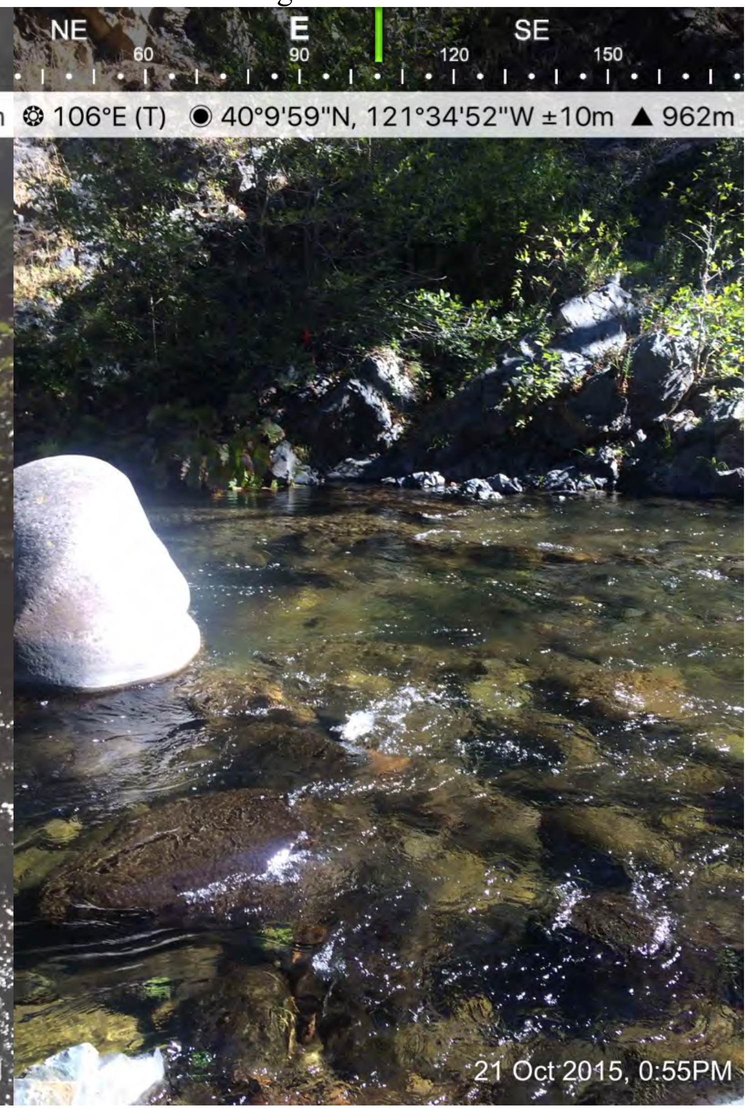
Lower Deer Creek Falls Section 1
View of Right Bank from Left Bank

Lower Deer Creek Falls Section 2
View of Left Bank from Right Bank

Lower Deer Creek Falls Section 2
View of Upstream from Mid-channel

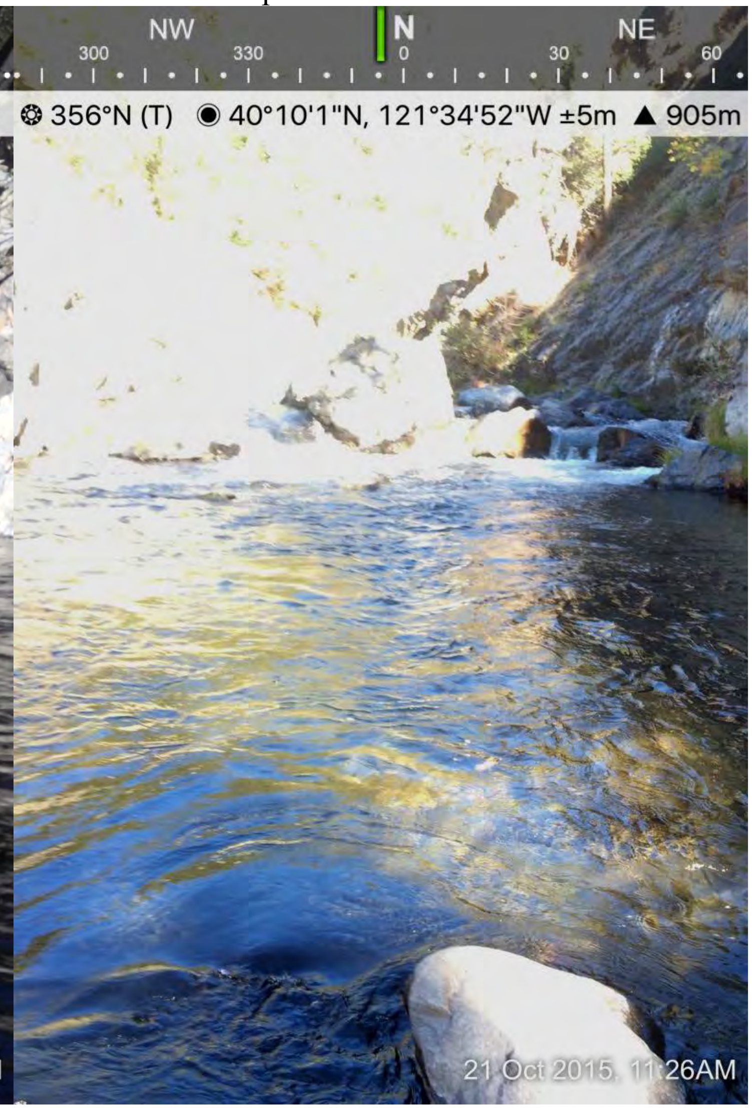
Lower Deer Creek Falls Section 2
View of Downstream from Mid-channel

Lower Deer Creek Falls Section 2
View of Right Bank from Left Bank

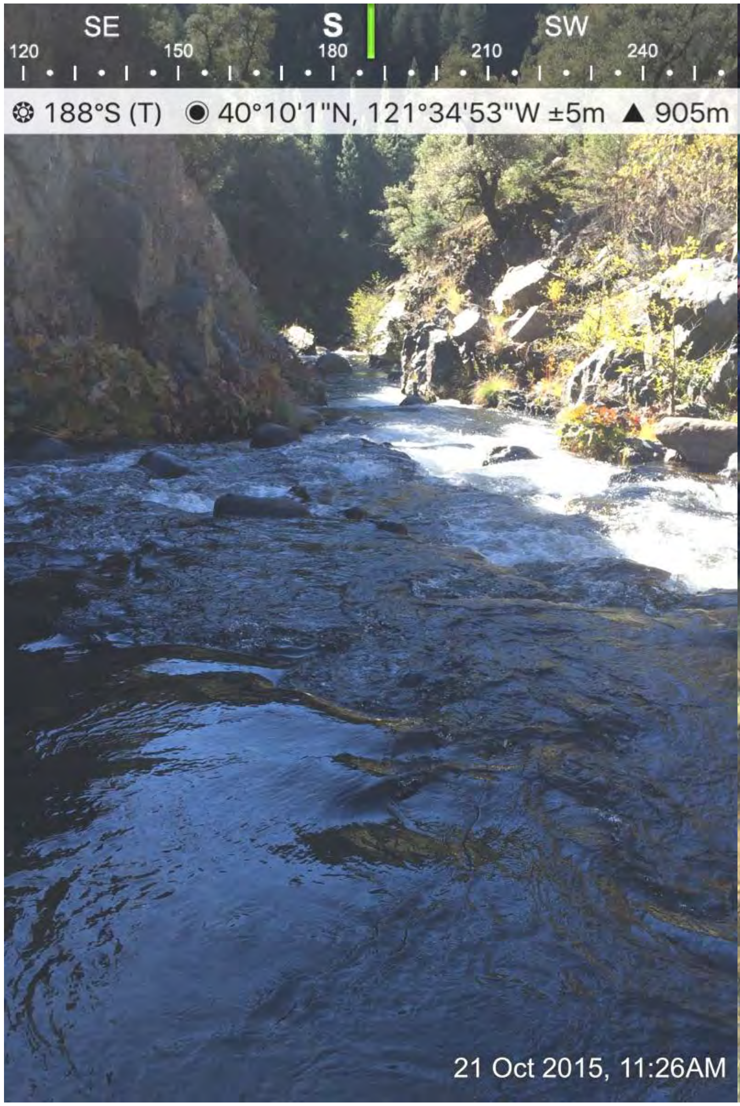


Lower Deer Creek Falls Section 3
View of Left Bank from Right Bank

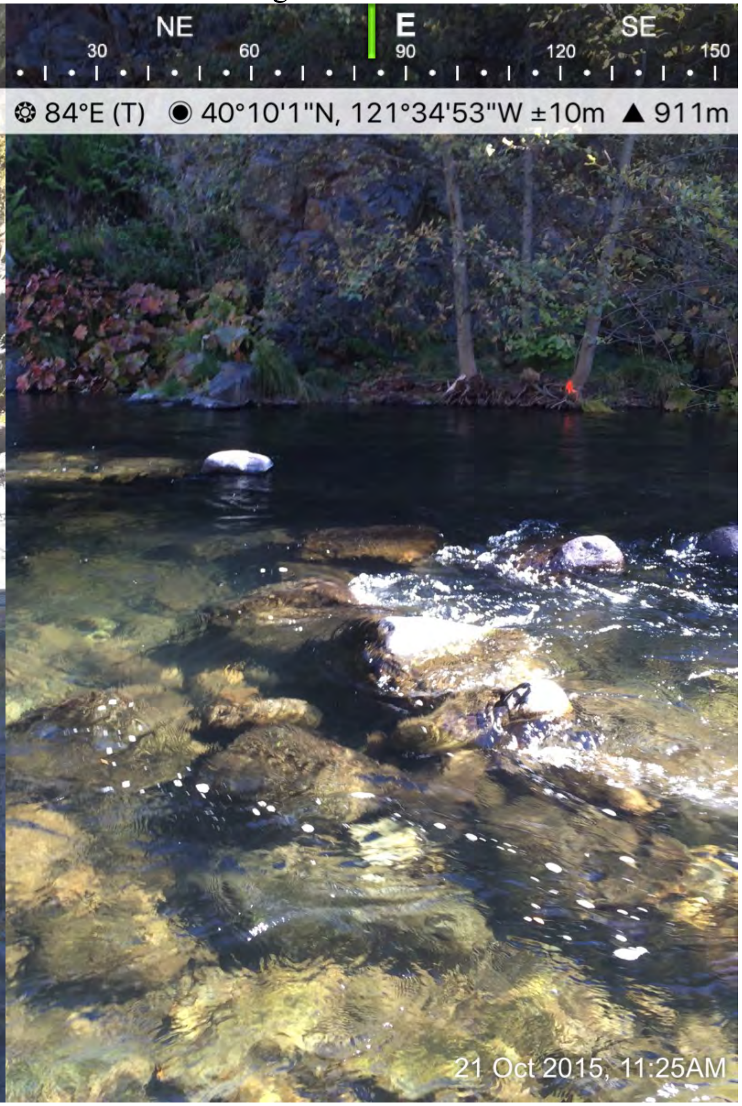
Lower Deer Creek Falls Section 3
View of Upstream from Mid-channel



Lower Deer Creek Falls Section 3
View of Downstream from Mid-channel



Lower Deer Creek Falls Section 3
View of Right Bank from Left Bank

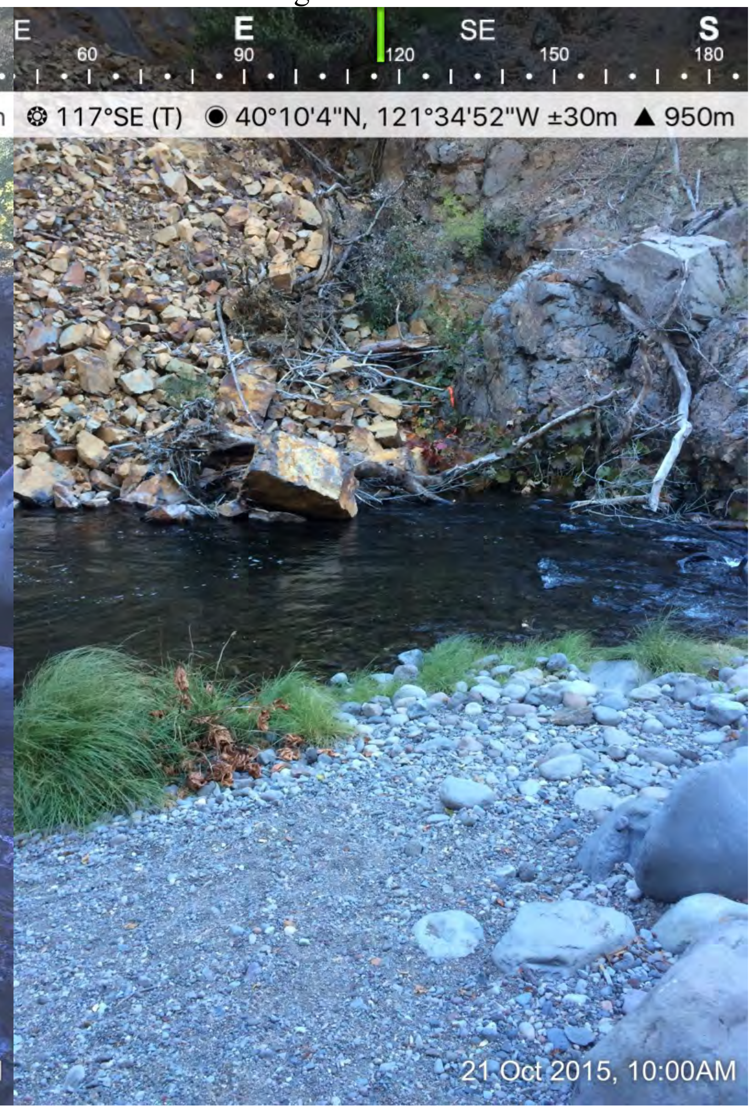


Lower Deer Creek Falls Section 4 – View of Left Bank from Right Bank

Lower Deer Creek Falls Section 4 – View of Upstream from Mid-channel

Lower Deer Creek Falls Section 4
View of Downstream from Mid-channel

Lower Deer Creek Falls Section 4
View of Right Bank from Left Bank

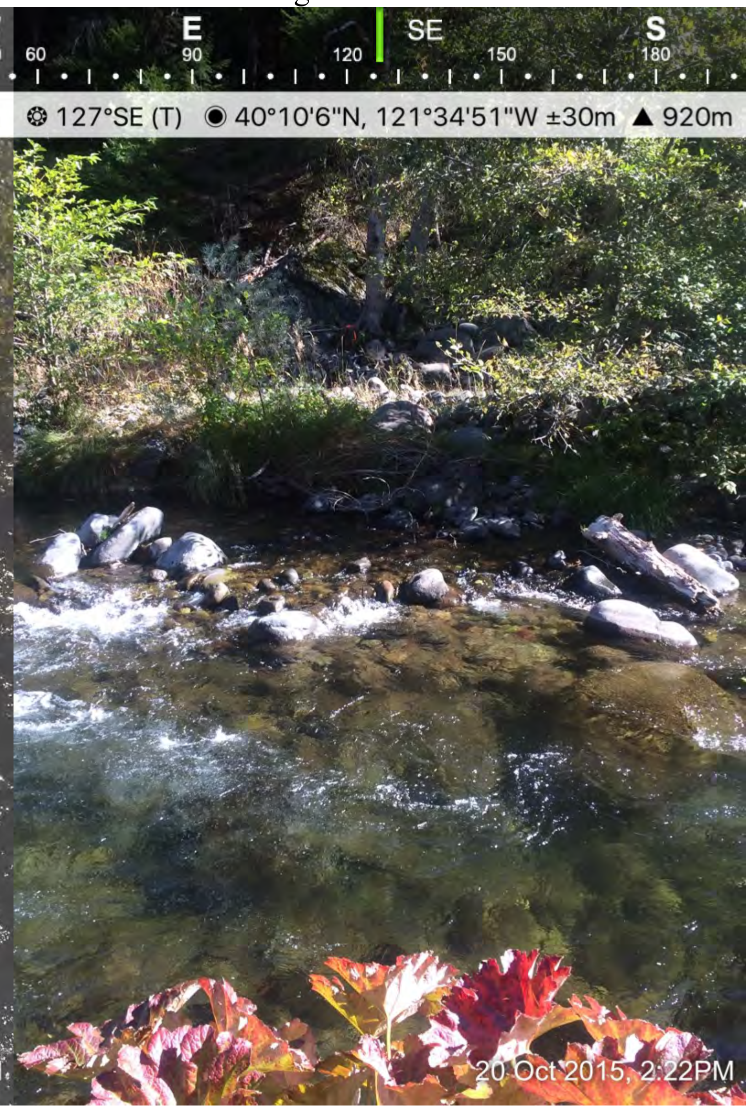


Lower Deer Creek Falls Section 5
View of Left Bank from Right Bank

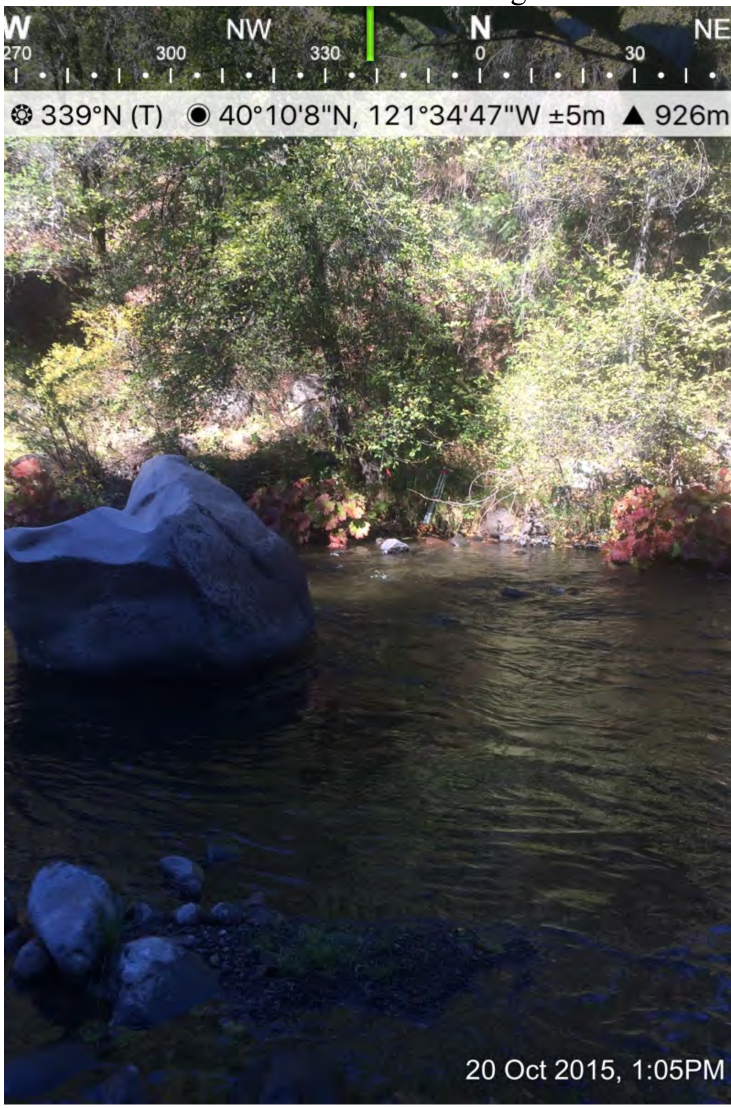
Lower Deer Creek Falls Section 5
View of Upstream from Mid-channel

Lower Deer Creek Falls Section 5
View of Downstream from Mid-channel

Lower Deer Creek Falls Section 5
View of Right Bank from Left Bank



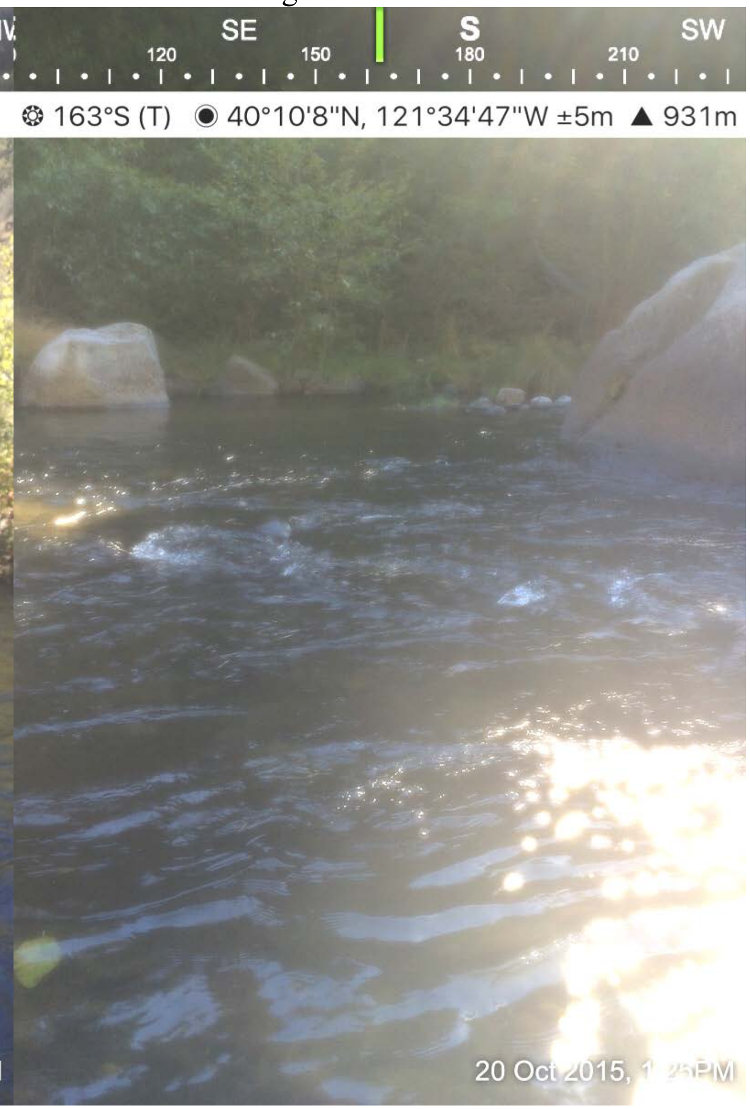
Lower Deer Creek Falls Section 6
View of Left Bank from Right Bank



Lower Deer Creek Falls Section 6
View of Upstream from Mid-channel

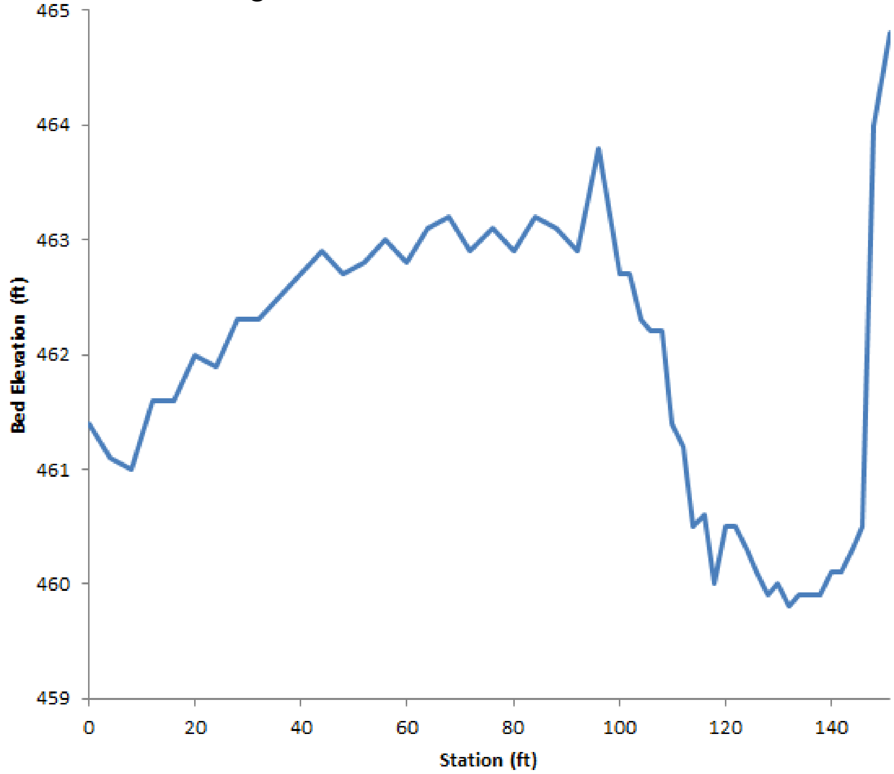
Lower Deer Creek Falls Section 6
View of Downstream from Mid-channel

Lower Deer Creek Falls Section 6
View of Right Bank from Left Bank

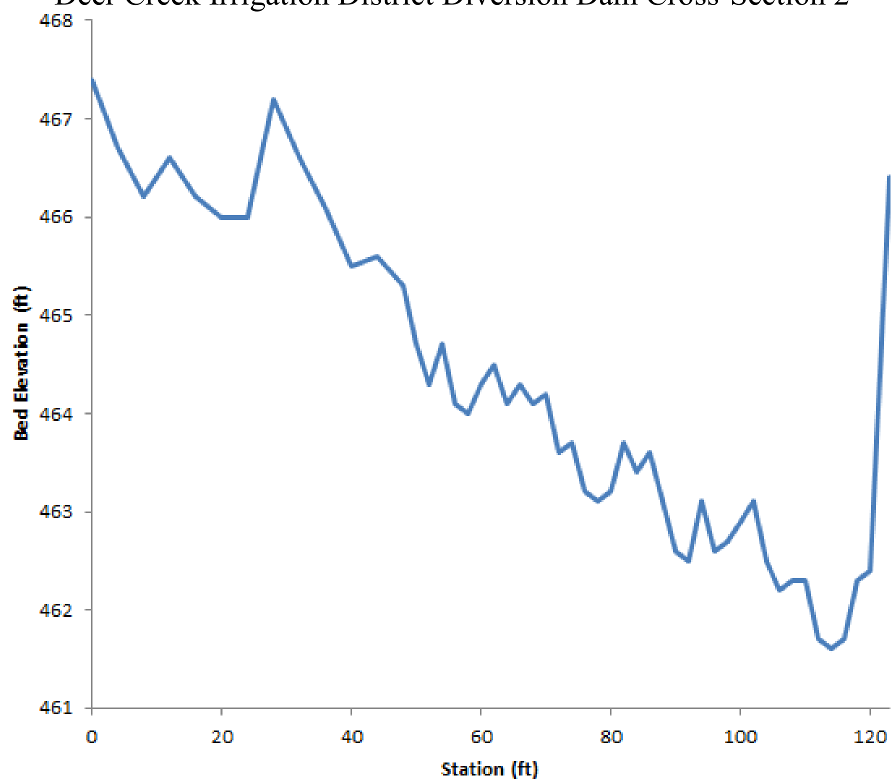


Appendix D
Deer Creek Irrigation District Diversion Dam Cross-sectional Profiles and Photos

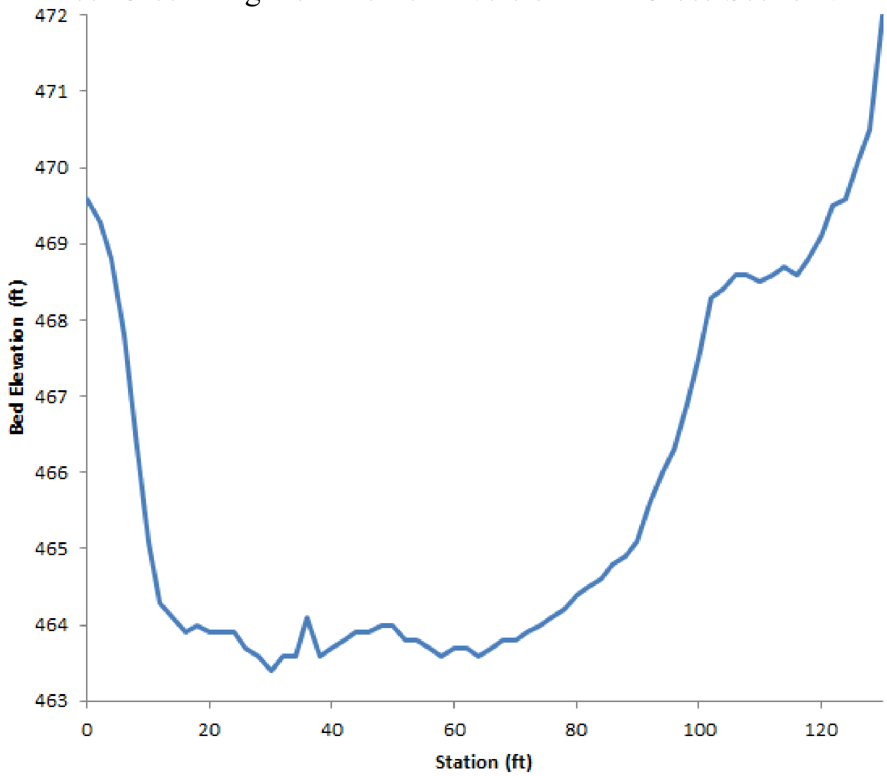
Deer Creek Irrigation District Diversion Dam Cross-Section 1



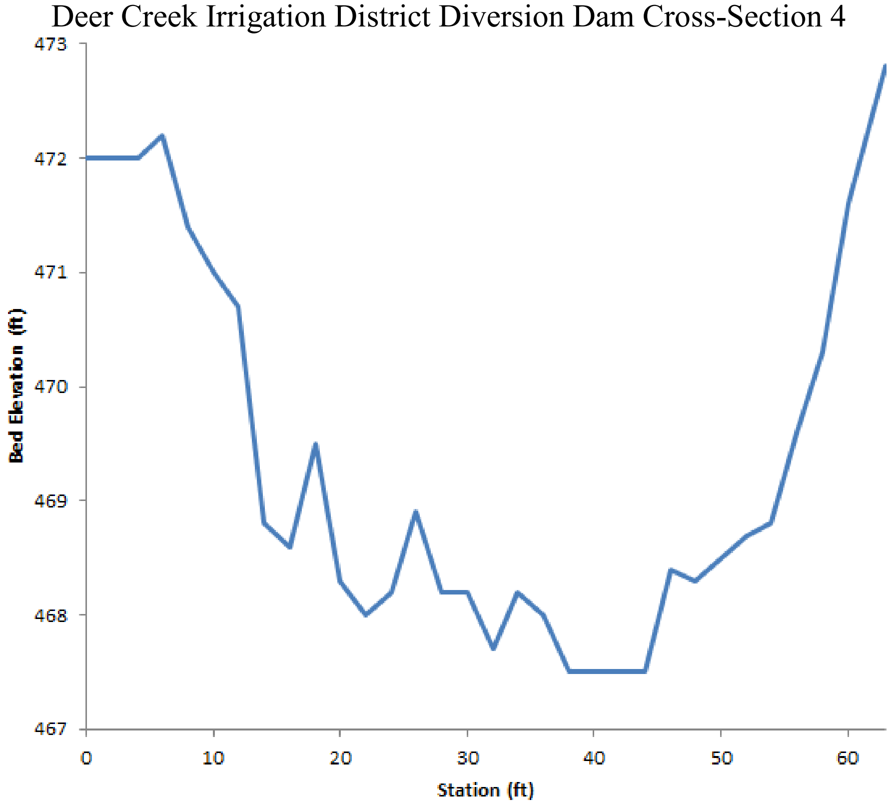
Deer Creek Irrigation District Diversion Dam Cross-Section 2



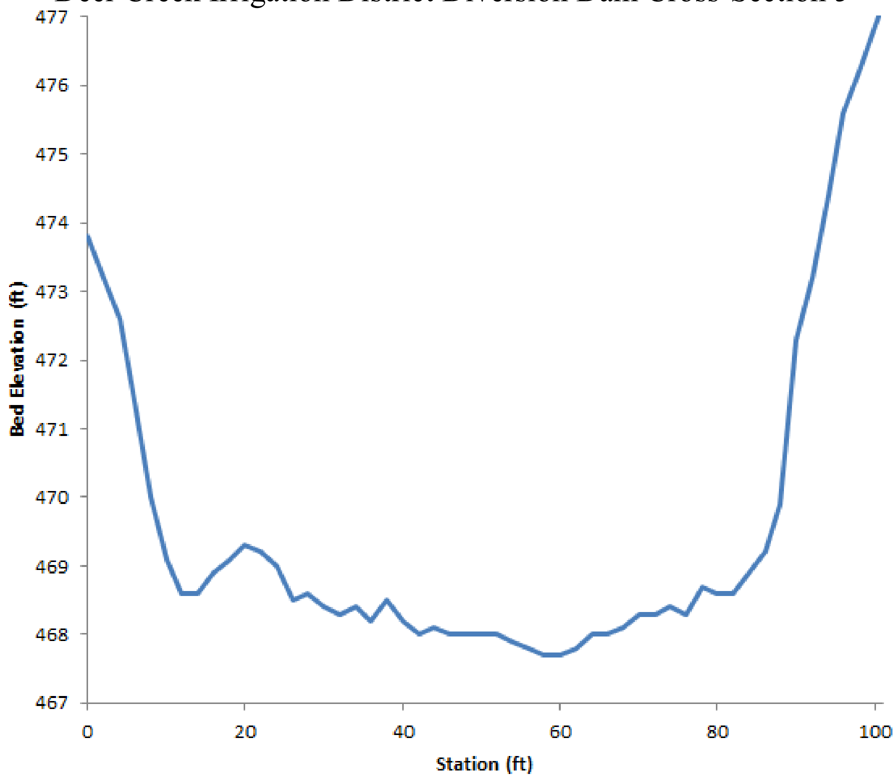
Deer Creek Irrigation District Diversion Dam Cross-Section 3



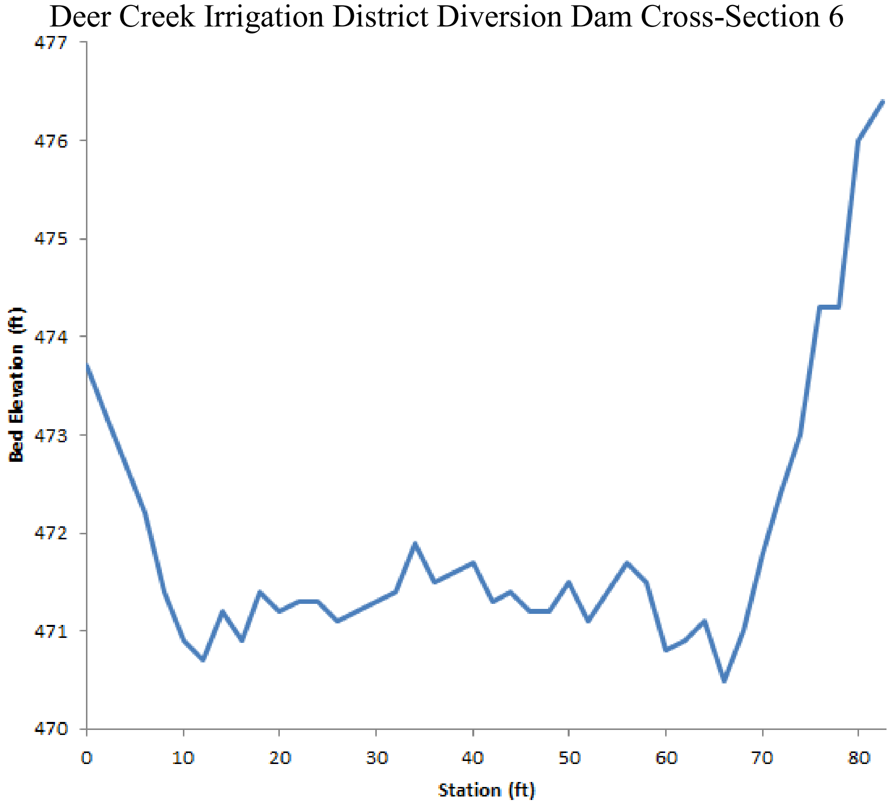
Deer Creek Irrigation District Diversion Dam Cross-Section 4



Deer Creek Irrigation District Diversion Dam Cross-Section 5



Deer Creek Irrigation District Diversion Dam Cross-Section 6

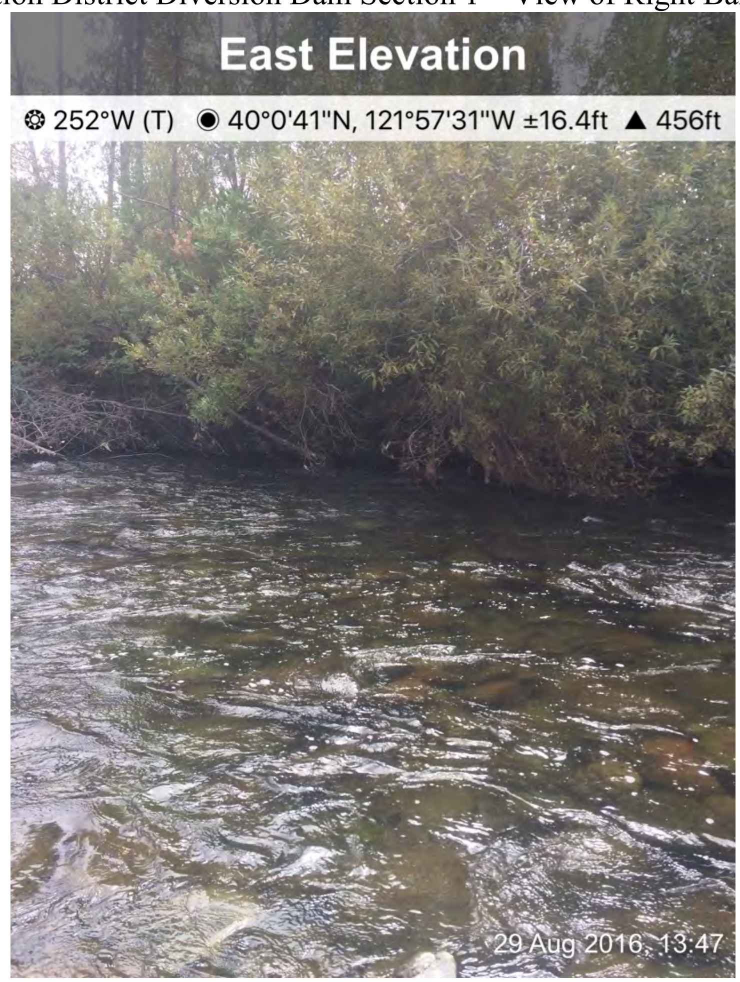


Deer Creek Irrigation District Diversion Dam Section 1 – View of Left Bank from Right Bank

Deer Creek Irrigation District Diversion Dam Section 1 – View of Upstream from Mid-channel

Deer Creek Irrigation District Dam Section 1 – View of Downstream from Mid-channel

Deer Creek Irrigation District Diversion Dam Section 1 – View of Right Bank from Left Bank

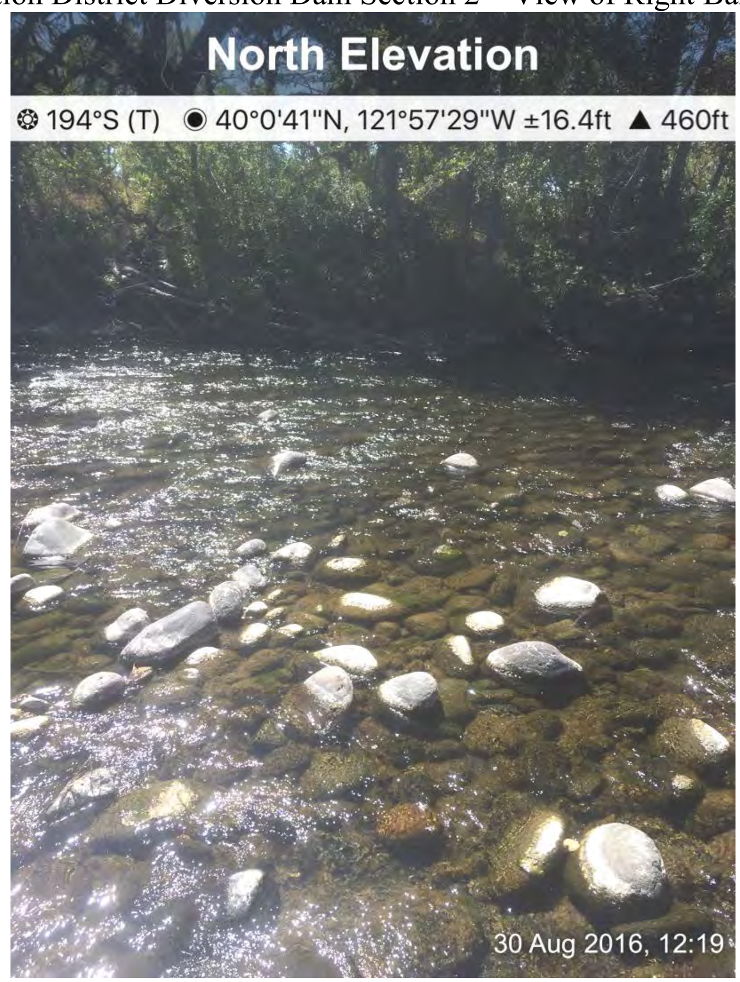


Deer Creek Irrigation District Diversion Dam Section 2 – View of Left Bank from Right Bank

Deer Creek Irrigation District Diversion Dam Section 2 – View of Upstream from Mid-channel

Deer Creek Irrigation District Dam Section 2 – View of Downstream from Mid-channel

Deer Creek Irrigation District Diversion Dam Section 2 – View of Right Bank from Left Bank



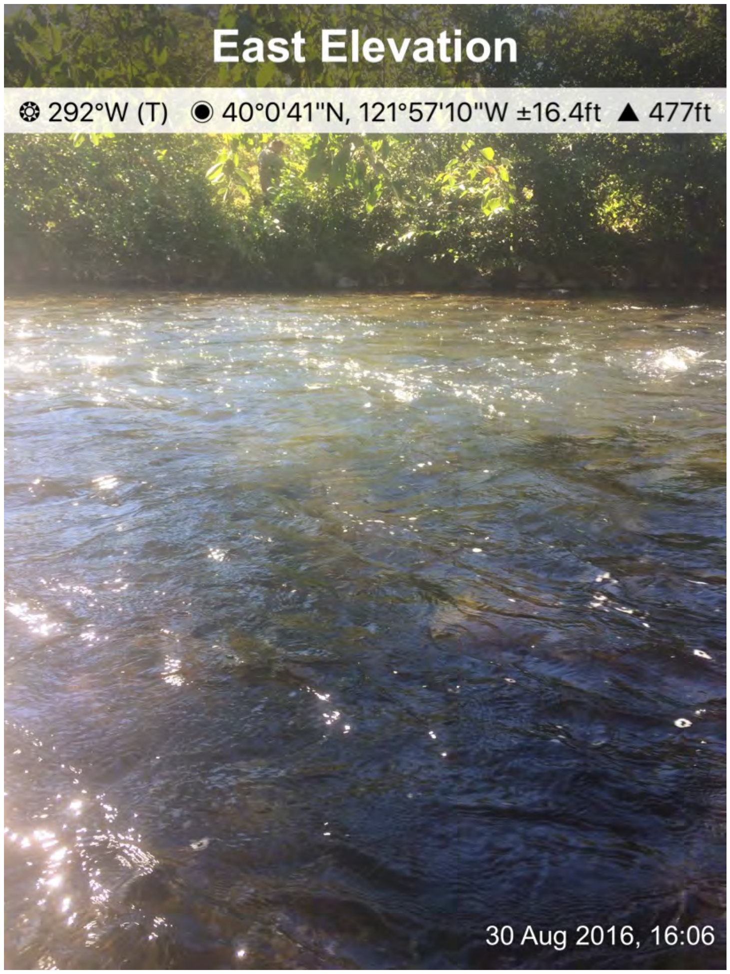
Deer Creek Irrigation District Diversion Dam Section 3 – View of Left Bank from Right Bank

Deer Creek Irrigation District Diversion Dam Section 3 – View of Upstream from Mid-channel

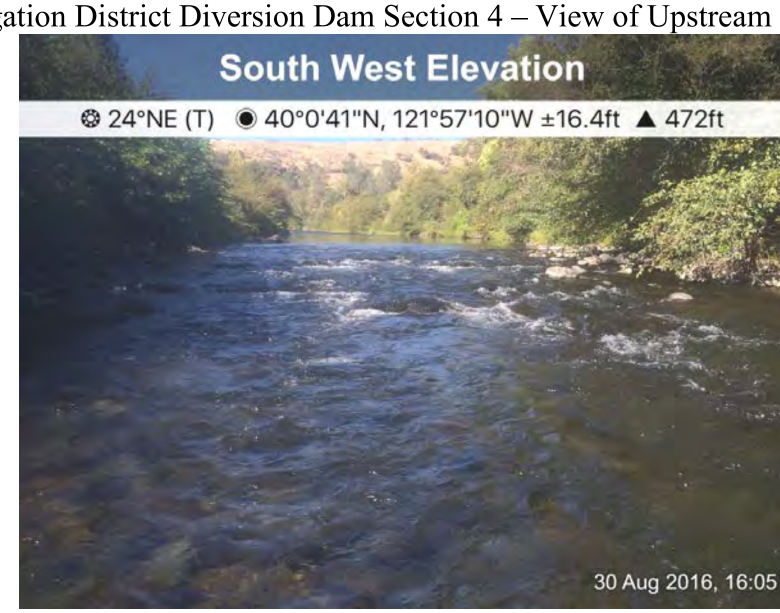
Deer Creek Irrigation District Dam Section 3 – View of Downstream from Mid-channel

Deer Creek Irrigation District Diversion Dam Section 3 – View of Right Bank from Left Bank

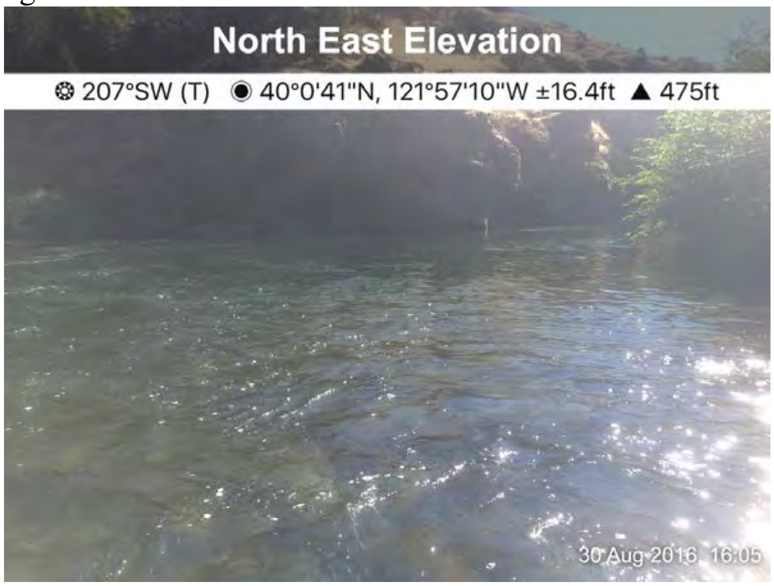
Deer Creek Irrigation District Diversion Dam Section 4 – View of Left Bank from Right Bank



Deer Creek Irrigation District Diversion Dam Section 4 – View of Upstream from Mid-channel

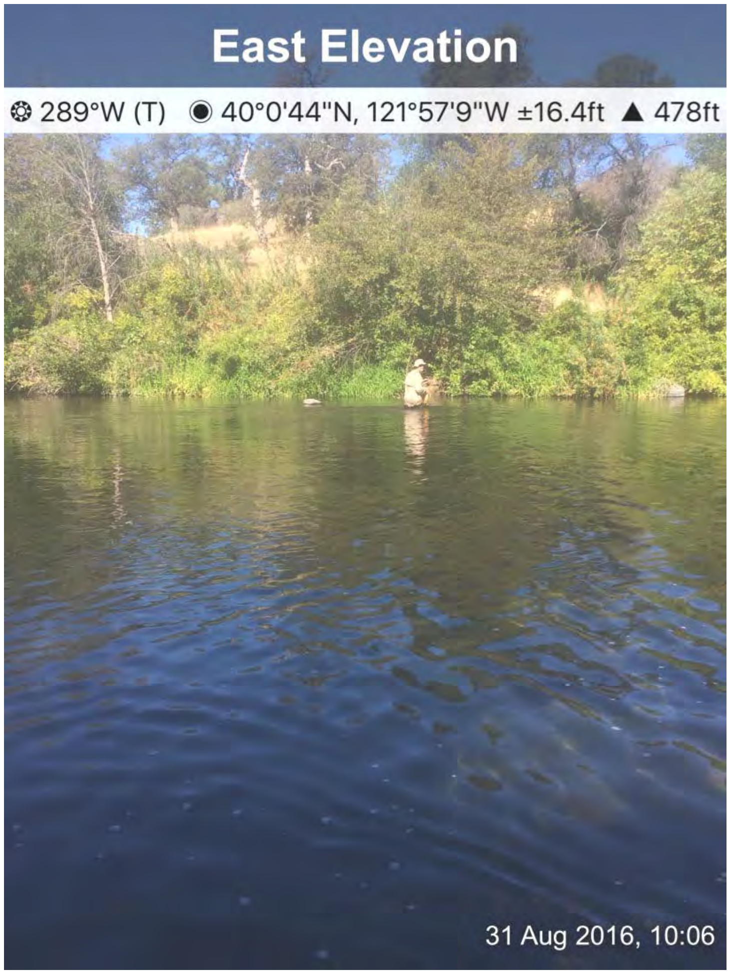


Deer Creek Irrigation District Dam Section 4 – View of Downstream from Mid-channel



Deer Creek Irrigation District Diversion Dam Section 4 – View of Right Bank from Left Bank

Deer Creek Irrigation District Diversion Dam Section 5 – View of Left Bank from Right Bank



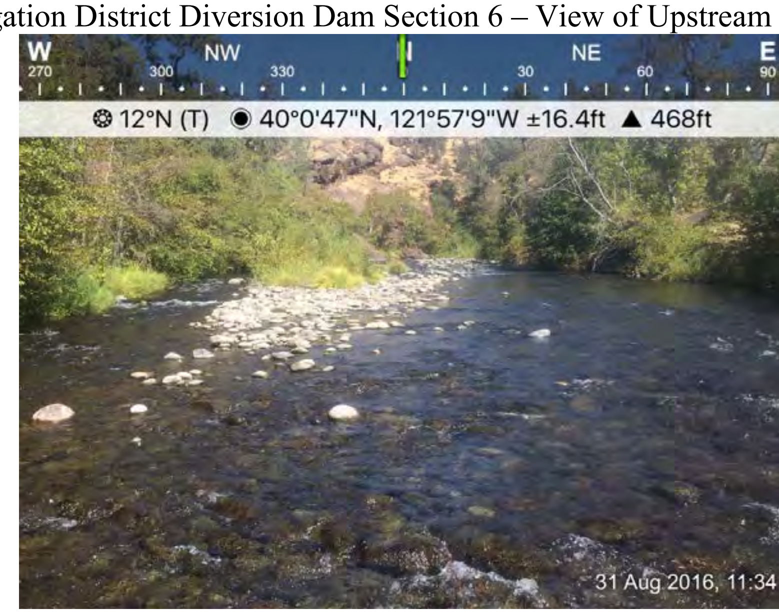
Deer Creek Irrigation District Diversion Dam Section 5 – View of Upstream from Mid-channel

Deer Creek Irrigation District Dam Section 5 – View of Downstream from Mid-channel

Deer Creek Irrigation District Diversion Dam Section 5 – View of Right Bank from Left Bank

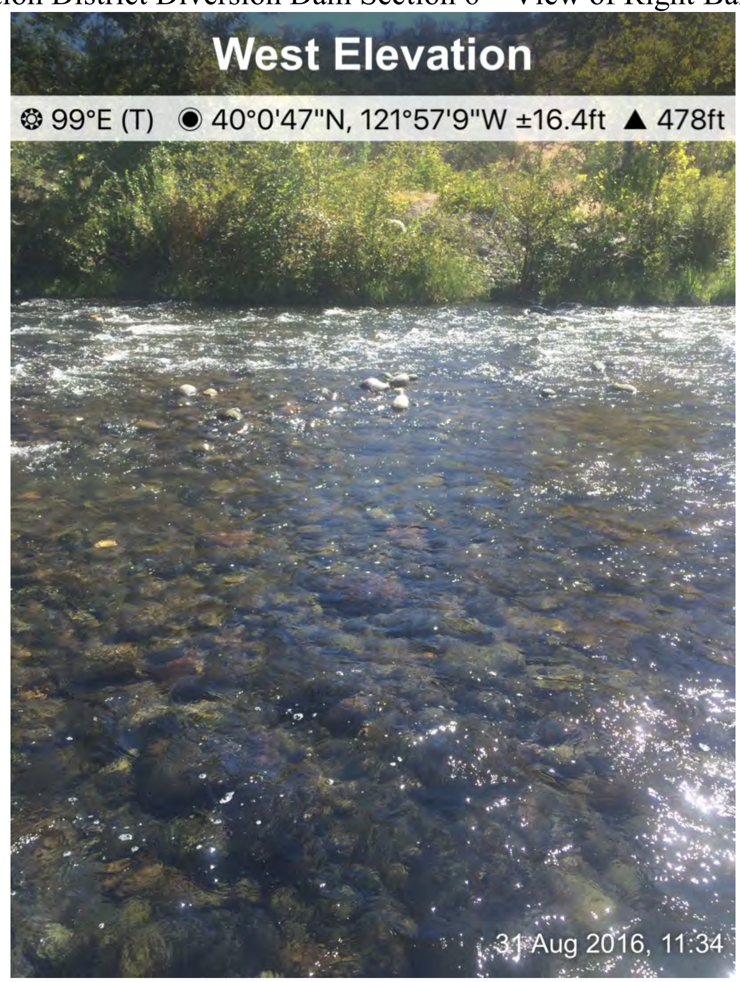
Deer Creek Irrigation District Diversion Dam Section 6 – View of Left Bank from Right Bank

Deer Creek Irrigation District Diversion Dam Section 6 – View of Upstream from Mid-channel



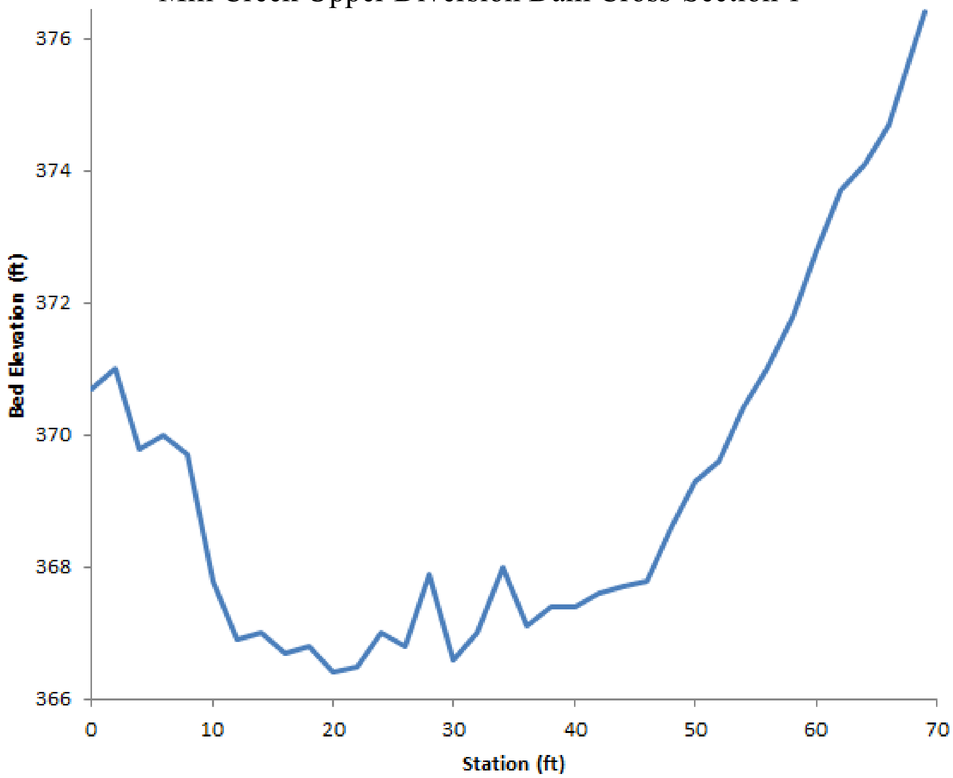
Deer Creek Irrigation District Dam Section 6 – View of Downstream from Mid-channel

Deer Creek Irrigation District Diversion Dam Section 6 – View of Right Bank from Left Bank

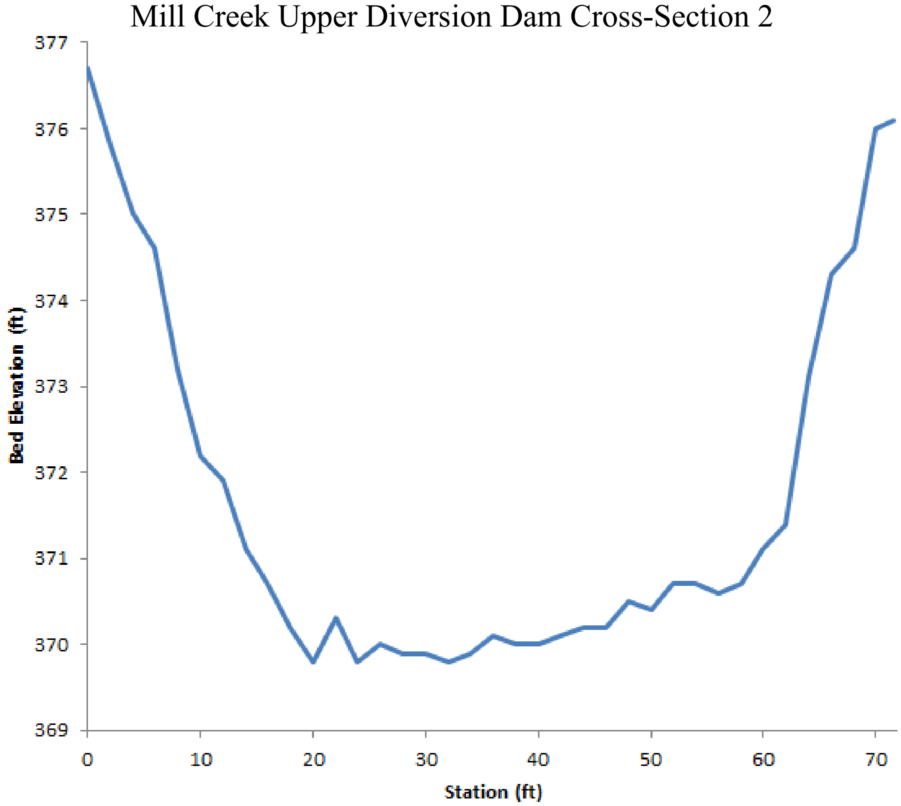


Appendix E
Mill Creek Upper Diversion Dam Cross-sectional Profiles and Photos

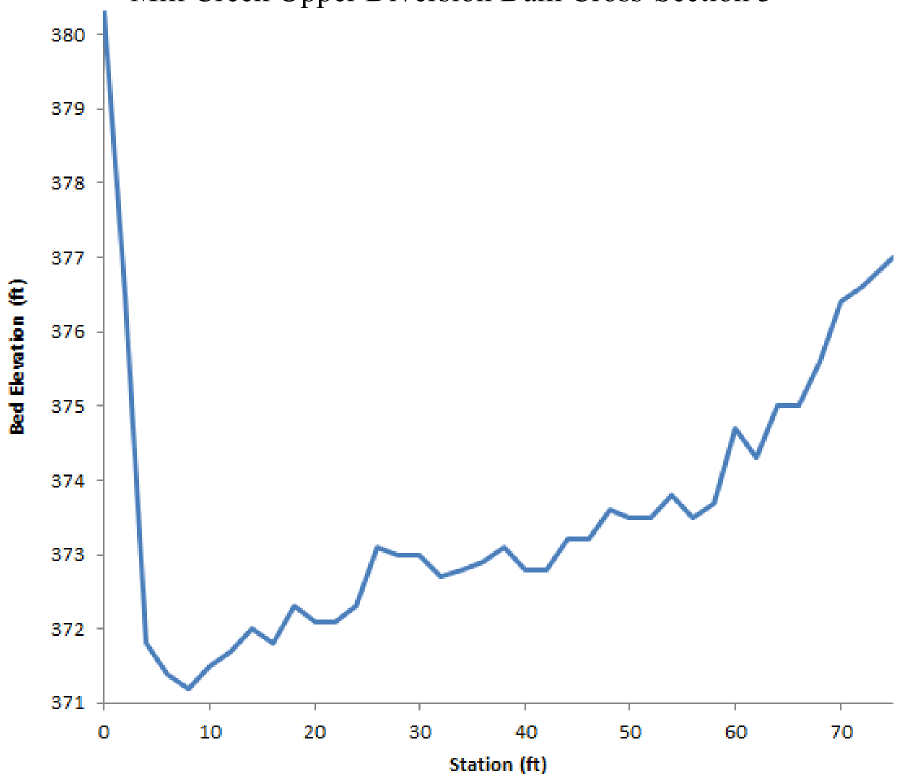
Mill Creek Upper Diversion Dam Cross-Section 1



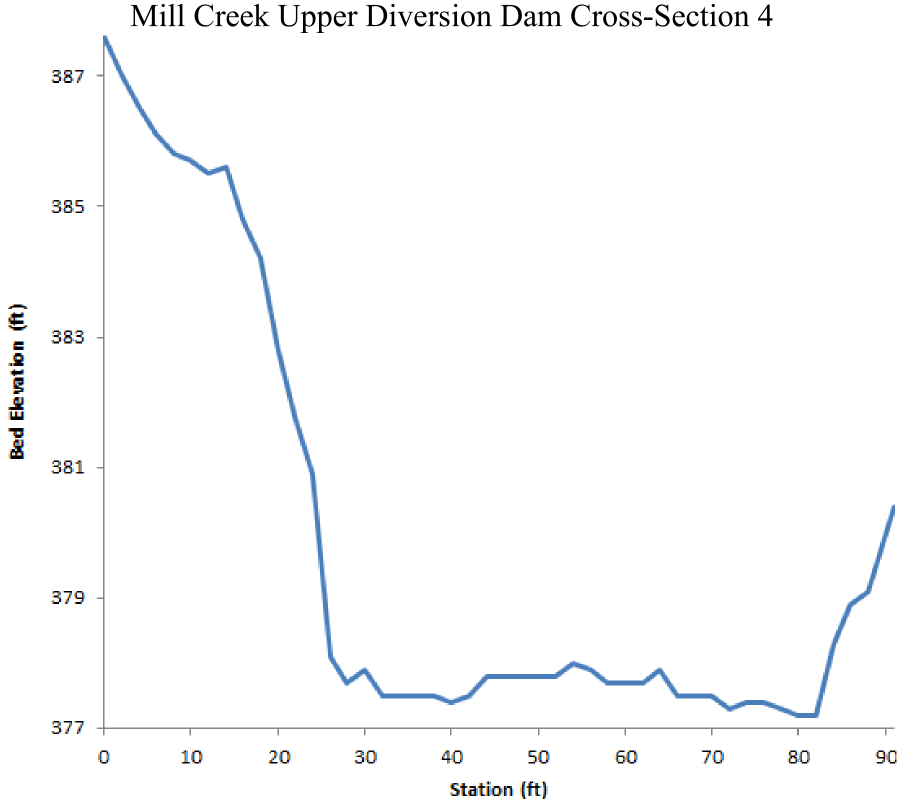
Mill Creek Upper Diversion Dam Cross-Section 2



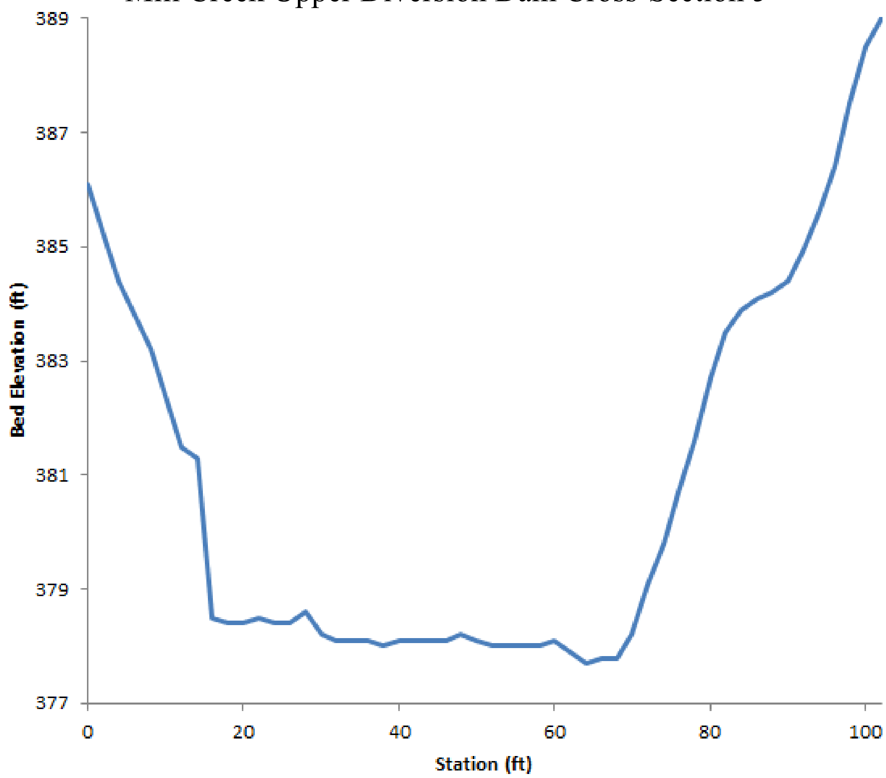
Mill Creek Upper Diversion Dam Cross-Section 3



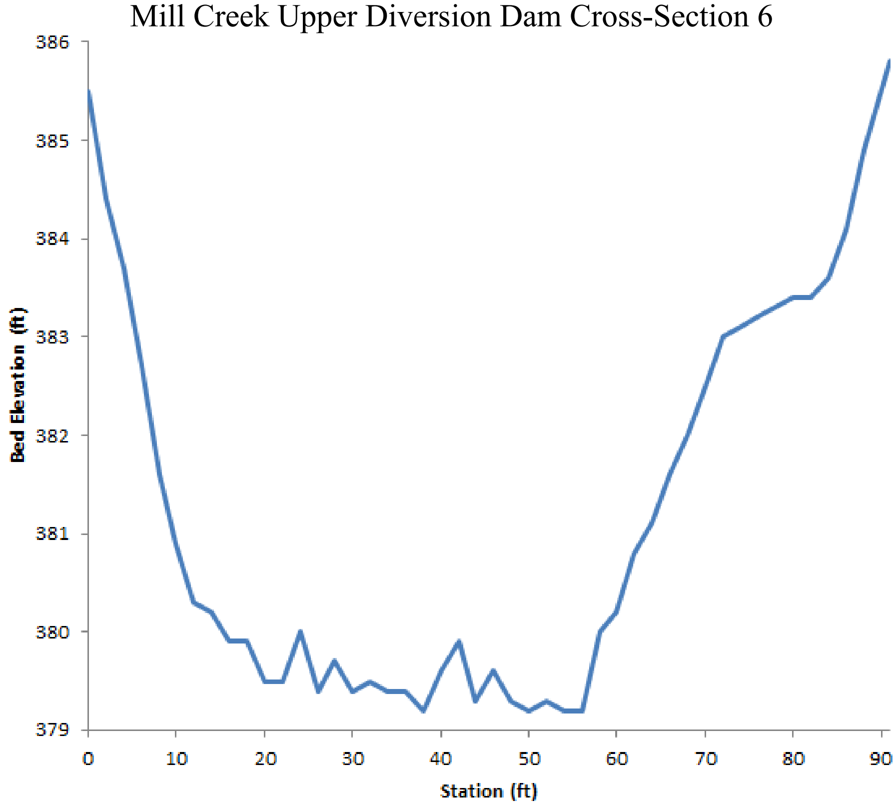
Mill Creek Upper Diversion Dam Cross-Section 4



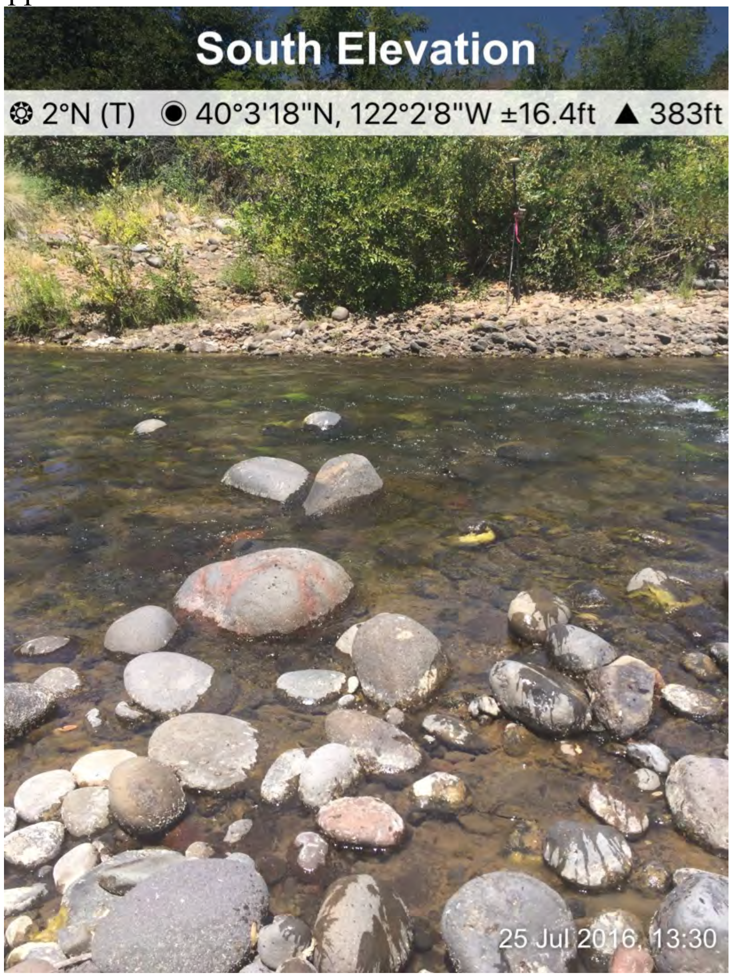
Mill Creek Upper Diversion Dam Cross-Section 5



Mill Creek Upper Diversion Dam Cross-Section 6



Mill Creek Upper Diversion Dam Section 1 – View of Left Bank from Right Bank



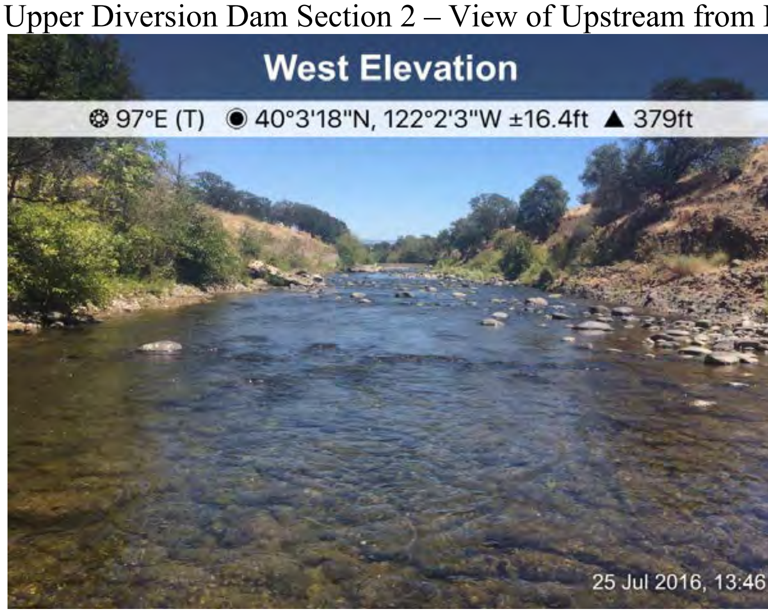
Mill Creek Upper Diversion Dam Section 1 – View of Upstream from Mid-channel

Mill Creek Upper Diversion Dam Section 1 – View of Downstream from Mid-channel

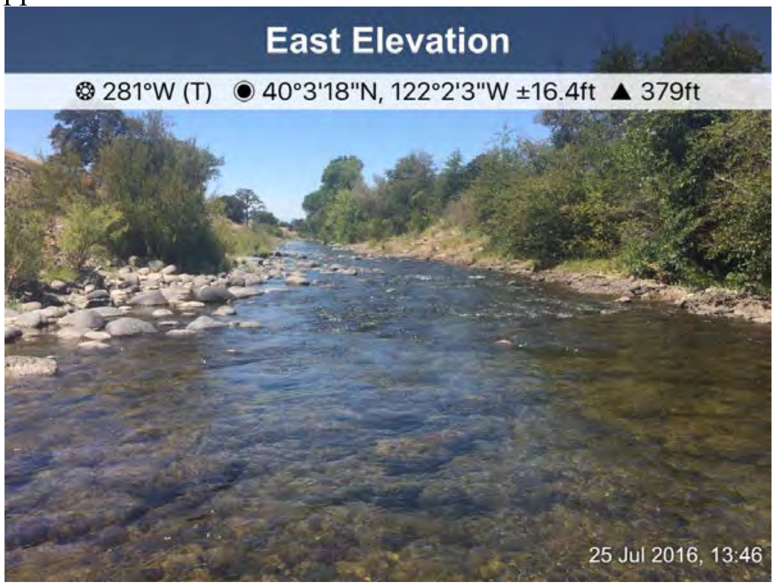
Mill Creek Upper Diversion Dam Section 1 – View of Right Bank from Left Bank

Mill Creek Upper Diversion Dam Section 2 – View of Left Bank from Right Bank

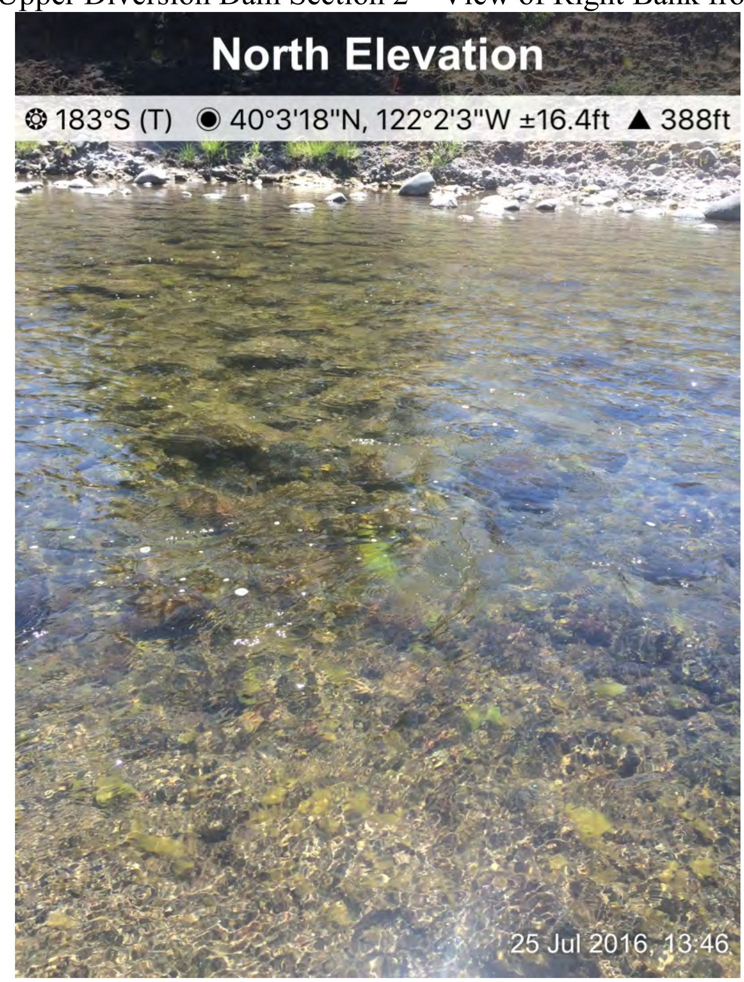
Mill Creek Upper Diversion Dam Section 2 – View of Upstream from Mid-channel



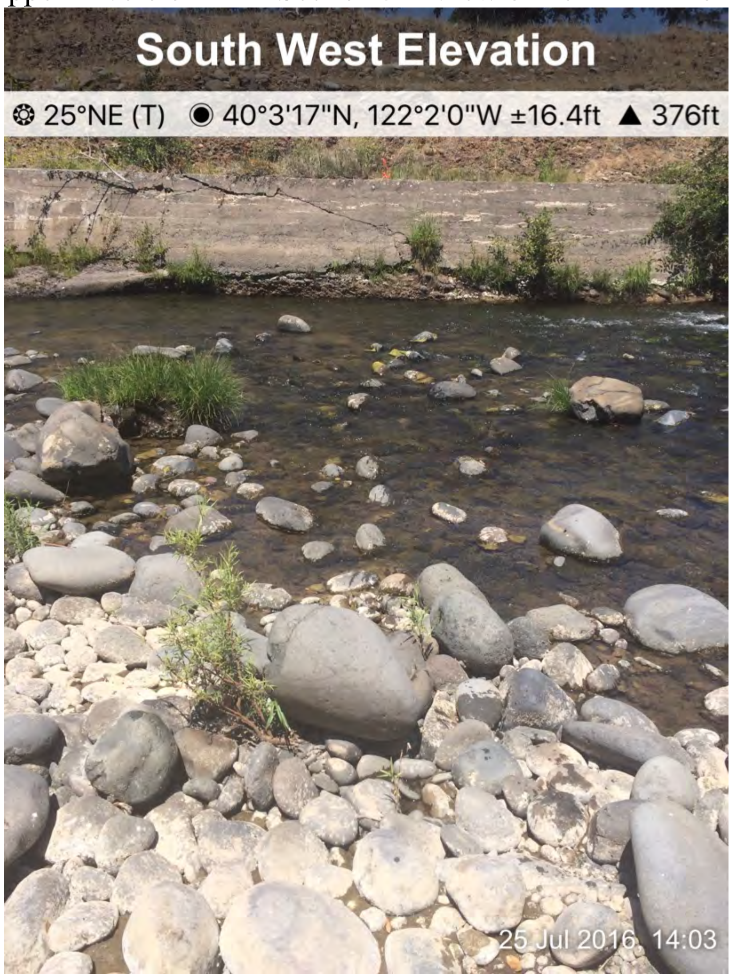
Mill Creek Upper Diversion Dam Section 2 – View of Downstream from Mid-channel



Mill Creek Upper Diversion Dam Section 2 – View of Right Bank from Left Bank



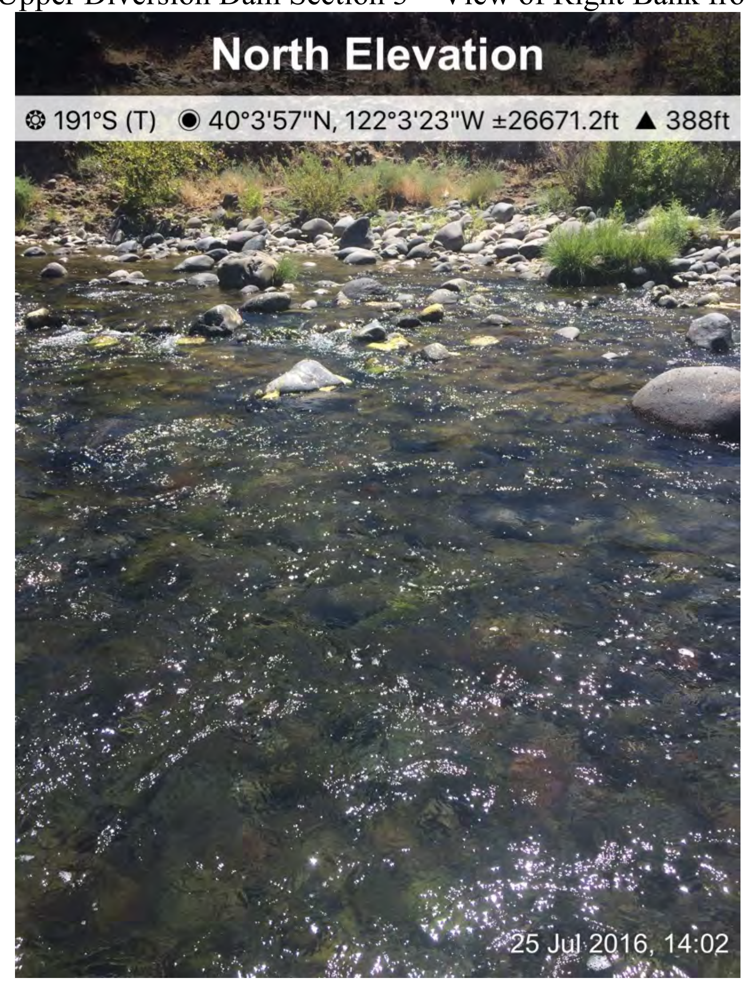
Mill Creek Upper Diversion Dam Section 3 – View of Left Bank from Right Bank



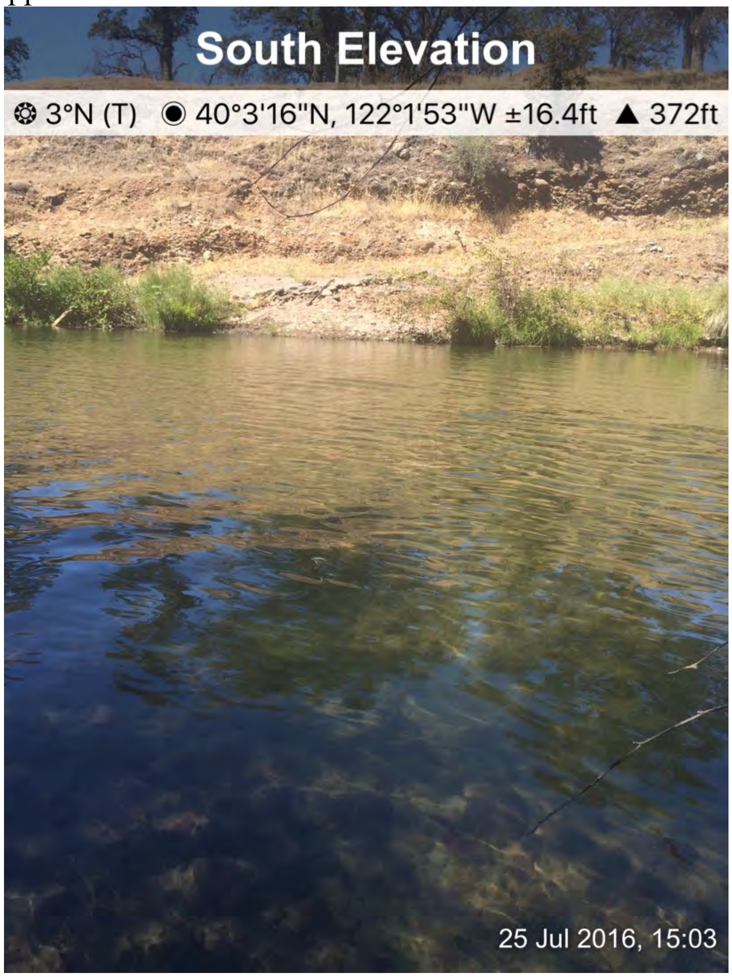
Mill Creek Upper Diversion Dam Section 3 – View of Upstream from Mid-channel

Mill Creek Upper Diversion Dam Section 3 – View of Downstream from Mid-channel

Mill Creek Upper Diversion Dam Section 3 – View of Right Bank from Left Bank



Mill Creek Upper Diversion Dam Section 4 – View of Left Bank from Right Bank



Mill Creek Upper Diversion Dam Section 4 – View of Upstream from Mid-channel

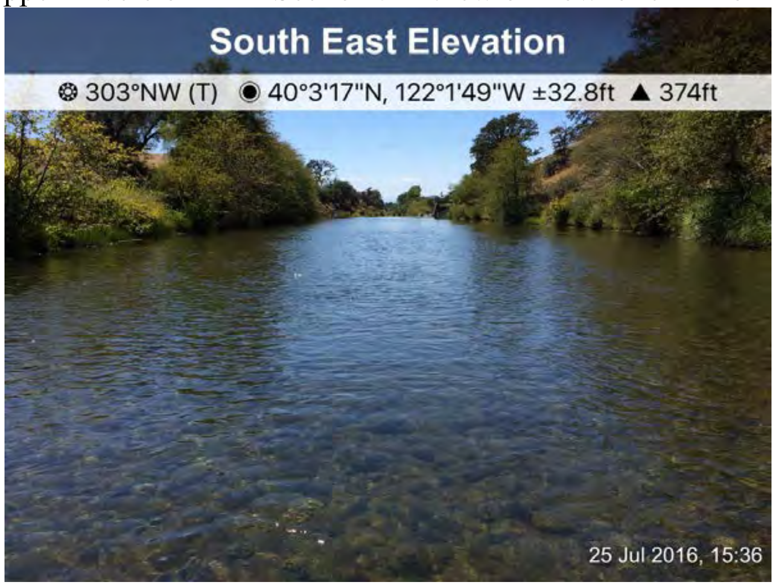
Mill Creek Upper Diversion Dam Section 4 – View of Downstream from Mid-channel

Mill Creek Upper Diversion Dam Section 4 – View of Right Bank from Left Bank

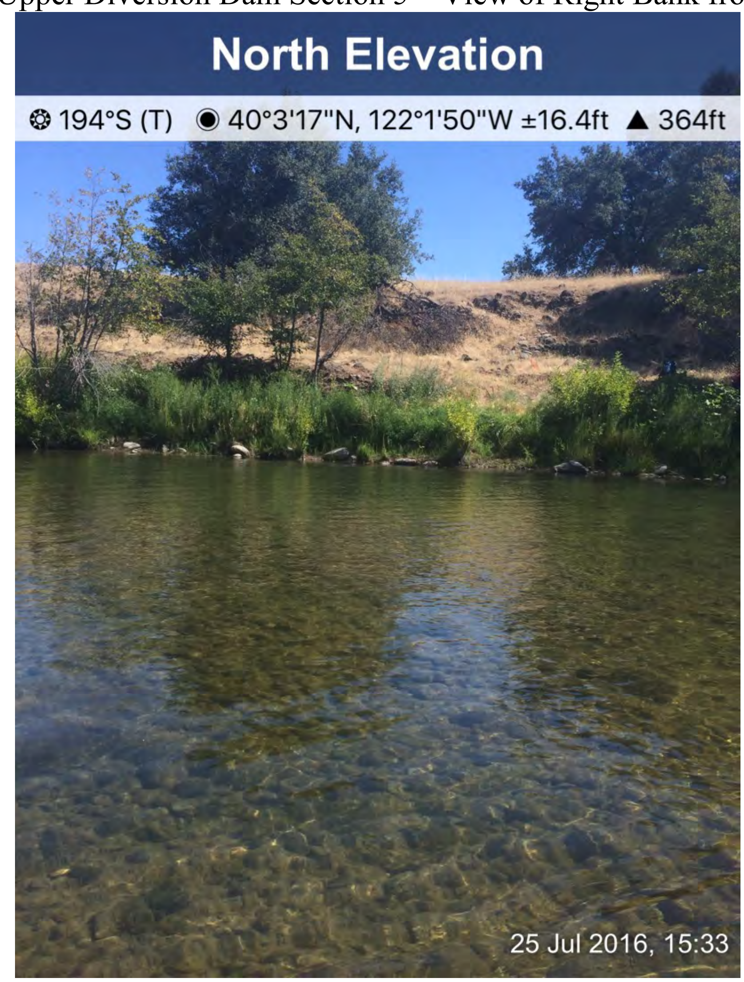
Mill Creek Upper Diversion Dam Section 5 – View of Left Bank from Right Bank

Mill Creek Upper Diversion Dam Section 5 – View of Upstream from Mid-channel

Mill Creek Upper Diversion Dam Section 5 – View of Downstream from Mid-channel

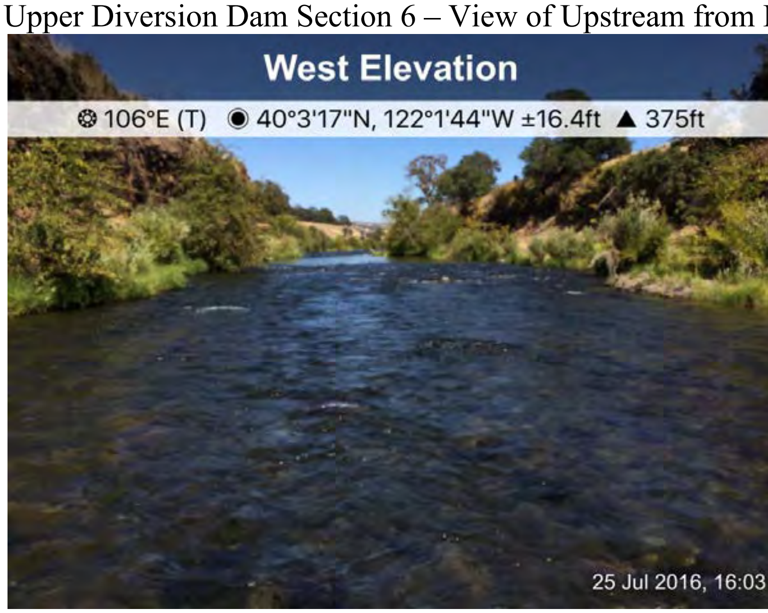


Mill Creek Upper Diversion Dam Section 5 – View of Right Bank from Left Bank



Mill Creek Upper Diversion Dam Section 6 – View of Left Bank from Right Bank

Mill Creek Upper Diversion Dam Section 6 – View of Upstream from Mid-channel



Mill Creek Upper Diversion Dam Section 6 – View of Downstream from Mid-channel

Mill Creek Upper Diversion Dam Section 6 – View of Right Bank from Left Bank