FISH PASSAGE ENGINEERING PROJECT

Site Analysis Final Report

JULY 2022

Page Left Blank

FISH PASSAGE ENGINEERING PROJECT

SITE ANALYSIS FINAL REPORT

Prepared for:

Caltrans Division of Research Innovation and System Information (DRISI)
Agreement Number 65A0711

Prepared by:

Humboldt State University
Michael Love & Associates, Inc.

July 2022

CONTENTS

1 INTRODUCTION

In 2019 Caltrans Division of Research Innovation and System Information (DRISI) initiated the Fish Passage Engineering Project (Agreement Number: 65A0711) with the objective of evaluating the implementation of recent fish passage road crossings for barrier remediation. Crossings that span the bankfull channel width, referred to as full span crossings, were of primary interest given their recognized benefits of maintaining geomorphic continuity, providing passage for aquatic and terrestrial species other than fish, lower maintenance costs and resilience to extreme events (Gillespie, et al., 2014; Long, 2010). Some of the study sites were partial span crossings defined here as a site with a width less than the bankfull channel width.

Seventeen sites consisting of both full and partial span crossings were identified by Caltrans and agency (CDFW, NMFS) personnel serving on the project Advisory Board for inclusion in the study (Figure 1, Table 1). As indicated in Table 1, one site was dropped from the list because Right of Way access was denied and another removed due to work restrictions imposed by the pandemic. The remaining 15 sites all had at least one site visit and assessment by the project Principal Investigators (PIs), Margaret Lang, Ph.D., P.E. of Humboldt State University and Michael Love, P.E. of Michael Love and Associates. The original project intent was to conduct detailed field surveys at all of the listed field sites but field work restrictions due to COVID19 required a modification to the project scope. The nine sites where full field surveys were completed are indicated in Table 1 and these sites were selected to maintain the greatest variety in site design and conditions. The findings for all surveyed and assessed sites were used to inform the project findings and recommendations.

This report describes the methods used to assess the study sites current performance and presents the findings from the site assessments and detailed site surveys. These findings are synthesized to identify project elements that have worked well for all sites and causes and lessons learned from elements that have underperformed. Detailed site assessments and observations are provided in Appendix A, and completed Caltrans Expert Fish Passage Site Assessment forms for each study site are included in Appendix B. Additional appendices include:

- The project monitoring plan (Appendix C) submitted and approved by the project advisory board in August 2019
- Modeling case studies comparing 1D and 2D model simulations (Appendix D), and
- A literature review summarizing relevant design documents and resources (Appendix E).

FIGURE 1. SITE MAP.

TABLE 1. STUDY SITES IDENTIFIED FOR ASSESSMENT BY THE PROJECT ADVISORY BOARD AND THEIR ASSESSMENT STATUS AND LEVEL.

Site Name & Location	District	Preliminary Site Visit	Detailed Field Survey[1]	Crossing Type (Partial or Full Channel Spanning)
Peacock Ck (DN197, PM 2.12)	1	5/9/19	8/6/20	Partial spanning corrugated metal pipe arch with baffle retrofit
Sultan Ck (DN197, PM 5.00)	1	5/9/19	1/9/20	Full spanning bridge
Little Mill Ck (DN197, PM 6.15)	1	5/9/19	11/11/19	Full spanning bridge
Hall Ck (HUM299, PM 4.20)	1	6/9/20	7/25/20	Full spanning bridge with fish ladder retrofit
Dunn Ck (MEN001, PM 92.80)	1	7/17/19	10/17/20	Full spanning bridge with rock weir grade control
Upp Ck (MEN101, PM 48.14)	1	9/12/19	2/24/21	Full spanning bridge with rock weir grade control
NF Ryan Ck (MEN101, PM 52.25)	1	9/12/19	2/25/21	Partial spanning, embedded reinforced concrete box culvert
SF Ryan Ck (MEN101, PM 52.36)	1	9/12/19	2/25/21	Partial spanning double barrel embedded circular steel pipes
Rattlesnake Ck (MEN101, PM 81.40)	1	7/17/19	Not surveyed	Partial spanning concrete arch culvert w/concrete outlet weir retrofit
Cedar Ck (MEN101, PM 89.04)	1	4/15/21	Not surveyed	Partial spanning concrete arch culvert w/baffles and fish ladder retrofit
Edwards Ck (MEN128, PM 49.66)	1	Site removed from the project due to COVID work restrictions		
Yank/Lemm Ck (SHA299, PM 32.20)	2	10/4/19	Not surveyed	Full spanning bridge
Ft Goff Ck (SIS096, PM 56.00)	2	9/19/19	3/31/21	Full spanning bridge
O’Neill Ck (SIS096, PM 65.40)	2	9/19/19	Not surveyed	Full spanning bridge
Elder Ck (TEH005, PM16.90)	2	Site removed from the project, Right of Way access denied		
Dibble Ck (TEH005, PM 28.10)	2	10/4/19	Not surveyed	Full spanning bridge w/low flow channel retrofit for fish passage
Craig Ck (TEH099, PM 21.10)	2	10/4/19	Not surveyed	Full spanning bridge

[1] For sites with multiple site visits the last date of the field survey is provided.

2 FIELD MONITORING METHODS

Prior to conducting field site visits, a monitoring plan was developed and reviewed by the project advisory board (Lang & Love, 2019). This section summarizes the methods and procedures used for the study with additional details available in the monitoring plan (Appendix C). The monitoring protocols used for the project are adopted from existing, accepted methods for stream channel measurements (Harrelson et al., 1994; Wolman, 1954) and those developed or proposed specifically for assessing fish passage crossings (FishPAC, 2019; Barnard et al., 2015; Klingel 2014).

The initial site assessment and site background data provided by Caltrans staff were used to assess the overall site conditions, plan the detailed site surveys and identify the best sites for case studies. The detailed field surveys were then conducted to collect data needed to fully assess site performance. Using these results and through consultation with the advisory board, case study sites were also selected for evaluating the use of 2D hydraulic models in design and analysis of fish passage crossings (Appendix D). Additional site survey data was collected at the case study sites to be able to develop 2D hydrodynamic models and employ additional analytical tools.

2.1 Initial Site Assessment

The initial site visit provided an overall assessment of the site's performance, identified obvious problems or maintenance conditions needing attention, and was used to develop site specific plans for the more detailed second survey. Information collected on these site visits included all data on Caltrans' Fish Passage Facility Monitoring Form, Expert Inspection (FishPAC, 2019). Completed forms are provided in Appendix B.

The initial site visits also compared current conditions to design plans or as-built drawings from available Caltrans documents. When possible, available plans were reviewed prior to each site visit and brought to the site to compare current to previous or intended conditions. For the initial site visit, these comparisons are qualitative, with the second site survey collecting detailed measurements that might quantify changed conditions. Specific site features and indicators that were documented included:

- Identifying the tailwater control
- Verifying the type, number and drop heights at grade control structures
- Measuring the active channel and bankfull channel widths upstream and downstream
- Qualitatively assessing the influences of the crossing on the channel including observed aggradation/degradation, widening/narrowing, and headcuts
- Describing the channel bed conditions and characteristics in the project area and adjacent channel – sediment size (qualitative), sediment sorting, channel forcing features

controlling plan and profile (large wood, roots, bedrock, rock), and documenting other influences

- Identifying features that may create adverse hydraulic conditions for fish passage or potentially capture debris and sediment

Site features and conditions were documented with photos, sketches and notes; and key features were flagged or marked for detailed measurement during the second, more intensive survey. The PIs also documented their initial interpretation of site conditions and functionality, and potential lessons that could be learned from the site. Of particular note for the site condition and performance assessment were documenting:

- Missing or damaged grade control elements
- Missing or compromised/under-cut bank protection
- Debris accumulation
- Structure damage from debris or other sources

2.2 Detailed Field Surveys

The nine sites where detailed field surveys were completed varied in type from full span stream simulation projects with natural channel beds to full and partial spanning crossings designed to meet fish passage criteria using hydraulic design approaches. Many of the sites that employed a hydraulic design approach have concrete weirs, rock weirs, baffles, or technical fishways for grade control and to produce favorable passage hydraulics.

For all of the sites, the detailed survey focused on confirming and evaluating that the crossing design components were intact, performing as intended and were not having adverse impacts on the stream channel, habitat, roadway, other adjacent property and infrastructure. This included the ability of the crossing to convey the stream’s flow, sediment, and debris load without adverse impacts. Important elements measured to evaluate these conditions included:

- A longitudinal thalweg profile
- Upstream, downstream and within crossing cross sections
- Sediment aggradation, degradation or preferential sediment sorting
- Stability and condition of the crossing and, if present, grade control structures
- Rock sizes used for grade control structures and bank protection
- Active and bankfull channel widths in a representative section of the adjacent natural channel
- Grain size (pebble count) and apparent mobility/embeddedness in a representative section of the adjacent natural channel and in the crossing, if present

Sites designed as full-span, stream simulation crossings, which requires the crossing channel be designed to match the natural channel slope and morphology of a reference reach, were evaluated using additional monitoring methods, similar to those described by Barnard et al. (2015) and Klingel (2014). The selected representative channel segment identified during the initial site reconnaissance served as the “reference reach” for these sites. A reference reach is a stable, natural channel section that defines the design template for a stream simulation crossing design. The reference reach is usually located upstream of the crossing and has the same geomorphic conditions and slope as the crossing site (USFS, 2008). For the project sites with reference reaches, all suitable reference reaches were identified upstream in the natural channel. Geomorphic conditions at the crossing were compared to those measured in the reference reach to evaluate the project’s success at providing channel morphology through the project similar to the reference reach. The additional data collected for this comparison were:

- Extending the thalweg profile to understand context of the site within the overall channel slope and to include the reference reach in this profile
- Noting the channel forcing features such as large boulders and bedrock outcrops in both the crossing and reference reach
- Surveying the active channel margins and bankfull indicators in both the crossing and reference reach
- Measuring the streambed material characteristics at similar channel features (i.e., riffles) in the crossing and reference reach

More detailed descriptions of the measurements and measurement protocols are included in the project monitoring plan distributed for review and approved in July 2019 and included here as Appendix C.

3 FISH PASSAGE PROJECT IMPLEMENTATION SUCCESSES

Many aspects of the sites were well designed and functioning as intended. This section highlights those designs and design elements that were highly successful across the variety of project types evaluated.

3.1 Full Span Bridge Crossings

Eight of the assessed sites were newly constructed full spanning bridges or fish passage/stream restoration projects accompanying a new bridge. Several of the smaller bridges were constructed using improved bridge construction materials and methods being developed by Caltrans to more efficiently and cost effectively replace large culverts. These new bridge types provide spans that support a fully functioning stream channel corridor, meaning the crossing allows for continuity in geomorphic processes and hydrodynamic conditions. Additionally, the bridge sites were the only project sites that met full span crossing conditions. At almost all of the full-span bridge sites, channel conditions had clearly undergone post-construction geomorphic change or adjustment. Even with notable changes to the channel shape and elevation under the crossings, the provided bridge spans were all sufficient to make them resilient to the resulting channel adjustments.

Caltrans development and adoption of an Accelerated Bridge Construction (ABC) process using the Prefabricated Bridge Element System (PBES) was observed to be highly successful. The Fort Goff Creek bridge built using this process and the stream restoration accompanying the bridge project created channel conditions through the crossing that matched well with the channel conditions in an upstream reference reach. Caltrans has developed 11 pre-designed bridges from 20-ft to 120-ft (in 10-ft increments) to the 65 percent design level, reducing the remaining design effort of 35 percent to account for site specific design needs (*Pers Comm M. Molinar*). Continued use of these bridge designs will improve fish passage, reduce maintenance costs and reduce time and cost to implement barrier remediation projects.

Another example is the O'Neil Creek bridge which also replaced an undersized culvert on State Route 96 in Siskiyou County. The provided bridge span was sufficient to accommodate natural processes in a steep, boulder dominated step-pool channel. At the time of the site assessment, it appeared that a debris flow or large bedload transport event occurred recently. The channel through the crossing was able to self-form step-pool features from the deposits similar to upstream channel conditions. None of the bridge structure was exposed or damaged, demonstrating the resilience of full spanning bridges and their ability to allow full geomorphic function.

Similar observations of significant geomorphic adjustment or change were also observed at the Sultan Creek, Little Mill Creek, and Yank Creek crossings. Of these sites, only Sultan Creek experienced conditions that compromised or altered fish passage conditions through the crossing due to the site constrained low bridge soffit elevation. This site is located in a depositional zone of the Smith River flood plain and high aggradation rates have significantly reduced the height of the opening under the bridge and its ability to convey flow, sediment and debris from upstream (see Section 4.1 for more discussion of these site conditions).

The Little Mill Creek bridge crossing had both sufficient span and height above the channel bed to accommodate dynamic channel changes associated with deposition from river backwater combined with high sediment and debris loads from upstream. The bridge height and span provided sufficient area under the bridge for a large and high gravel bar to form during backwatering and subsequently erode without causing adverse geomorphic or fish passage conditions. A narrower crossing structure would have likely experienced clogging with debris and sediment, resulting in blockage to fish passage during these Smith River backwater events.

At Yank Creek, the new bridge widened the crossing from 26 feet to a span just over 90 feet increasing the cross-sectional area by four times. This provides an opportunity for the channel to have a more gradual bend and improved alignment as it flows through the crossing.

The Dunn Creek and Upp Creek bridges span the channel flood prone width, eliminating the crossings' influence on the stream channel form or function. At these sites, fish passage conditions depend solely on the in-channel fish passage elements and how they were designed, implemented and perform.

Continued improvement in small and economical bridge construction and permitting is recommended. These structures are resilient; provide stream function continuity, aquatic and terrestrial organism passage; and reduce maintenance costs.

3.2 Fish Baffle and Fishway Retrofits

Four of the study sites incorporated baffle or fishway retrofits to improve passage and none of these sites were full spanning. Peacock Creek was retrofitted with fish baffles within the culvert barrel while the Hall, Rattlesnake and Cedar creek sites had a fishway retrofit to mitigate steep grades and/or outlet drops. At all of these sites, the design and overall implementation of the retrofits were successful and functioning as intended. The elevation differences between baffles and weirs were consistent and, for the most part, matched fish passage criteria and design drawings.

The Peacock Creek crossing consisted of a 13 ft wide, 9 ft high structural steel pipe arch retrofitted with sloping steel baffles. The baffle retrofits at Peacock Creek were intact, maintained a low flow channel and resting zones, and were not capturing debris. Skewed to the flow, the low end of the baffle was placed upstream of the high end; thus, concentrating flows along one side of the culvert to maintain slow velocities along the other side. The fishways at Cedar, Hall and Rattlesnake creeks were all well designed, had good hydraulic conditions during site visits and weir-to-weir elevation differences met all fish passage criteria.

The Hall Creek fishway is well designed and, currently, well placed in the system. Prior to the fishway, Hall Creek flowed over large rock slope protection (RSP) rocks that maintained grade control beneath the HUM 299 bridge. This RSP has now been placed along the outer edge of the fishway and vegetated so that at flows exceeding the fishway capacity the water spills over the RSP, preventing erosion, while the interplanting of willow in the RSP provides shade over the edges of the fishway.

4 SUMMARY OF SITE CONDITIONS AND PERFORMANCE ISSUES

None of the sites assessed had conditions creating a complete fish passage barrier at the time of their assessment visits. However, many sites had issues or characteristics that either spatially or temporally could present passage challenges to some fish species and life-stages. Other issues caused or perpetuated conditions that altered natural geomorphic processes. Table 2 summarizes the condition and performance issues observed at assessed sites.

In our evaluation of Caltrans' fish passage projects, unexpected or unaccounted for channel profile adjustments and rock weir failure, instability or inaccurate constructed elevations were the most common site issues. This section summarizes observations across the sites, describes the factors likely to be responsible, and suggests approaches or analysis that may have prevented the issue. More detailed analysis for each of the sites, including field data and photo documentation, is provided in Appendix A. Recommendations for modifications to current design practices and analytical approaches to address these findings are included in Section 5.

4.1 Post-Project Channel Profile adjustments

At several sites the stream channel profile experienced vertical adjustments since project construction. These adjustments, which include downstream channel incision and channel aggradation within the project reach, were not anticipated as part of the project design, resulting in adverse fish passage and/or crossing stability conditions. It is likely that conducting a thorough evaluation of the channel morphology and vertical adjacent potential (VAP) of the stream, as recommended by CDFG (2009) and others (USFS, 2008), would have identified these resulting issues during the early design phase, allowing for projects to address them accordingly.

4.1.1 CHANNEL INCISION/LOWERING

At Dunn Creek, and to a lesser extent Peacock Creek, the channel downstream of the project reach incised (lowered) following construction. Both of these designs appeared to lack a geomorphic evaluation of the overall channel stability and estimation of the potential vertical adjustments that may occur. At Peacock Creek the channel at the downstream end of the project downcut up to 0.5 feet since construction in 2013, causing an excessive drop over the culvert outlet weir.

At Dunn Creek, the design relied on a tree that had recently fallen across the channel downstream of the project reach to control the stream grade at the downstream-most rock weir. This in-channel wood should have been noted as a transitory control of the streambed elevation and not relied on for the long-term stability of the rock weirs. After construction this wood shifted, causing the streambed to incise through deposited sediments. The resulting downcutting of the streambed caused an excessive drop over the downstream rock weir. The excessive drop likely increased the exposure and instability of the footer rocks eventually leading to the rock weir’s failure. Loss of the most downstream weir has created a larger drop over the next upstream weir, placing additional upstream weirs in jeopardy.

At Craig Creek the stream had incised to the extent that the previous crossing was replaced with a full-span bridge. However, there is evidence that the channel may have experienced additional downcutting at the crossing since replacement. As a result, the channel under the bridge has exposed the toe of the RSP along the bridge abutments. Under current conditions, the RSP toe constricts the channel through the crossing compared to the adjacent natural channel. Better predicting the potential range in streambed elevations at the crossing would have supported the design of the RSP, making sure that the RSP toe was set below the future bed elevation and that the RSP would be placed to not constrict the bed at this lower elevation.

TABLE 2. SUMMARY OF OBSERVED SITE ISSUES

Issue	Sites with Noted Issue
Channel Incision/Lowering	Peacock Creek, Dunn Creek[1], Craig Creek[1]
Channel Influenced by Adjacent River	Sultan Creek, Little Mill Creek[1], Hall Creek
Local Aggradation from Pre-Project Crossing	SF Ryan Creek NF Ryan Creek, Little Mill Creek[1], Sultan Creek
Channel Constriction	SF Ryan Creek, Peacock Creek, Craig Creek[1], NF Ryan Creek
Overwidened Channel	Little Mill Creek[1], Yank Creek[1], Upp Creek[1]
Lack of Channel Slope and Bedform Inside Crossings	NF Ryan Creek, SF Ryan Creek
Rock Weir Failure/Instability	Little Mill Creek[1], Dunn Creek[1], Cedar Creek, Rattlesnake Creek, North Fork Ryan Creek, South Fork Ryan Creek, Upp Creek[1], Dibble Creek[1]
Rock Weir – Inconsistent Drop Heights and Widths	SF Ryan Creek, Dunn Creek[1], NF Ryan Creek
Streambed Sealing	NF Ryan Creek
Localized Scour of RSP at Structure	Ft Goff Creek[1], Craig Creek[1], Little Mill Creek[1]
Other Construction Oversights	SF Ryan Creek, Cedar Creek

[1] Indicates sites that meet full span crossing criteria with crossing widths greater than the bankfull channel width.

4.1.2 CHANNEL INFLUENCED BY ADJACENT RIVER

In contrast to incision and degradation, other sites experienced aggradation that impairs crossing performance. This is most apparent at the Sultan Creek crossing, where aggradation has reduced the height of the bridge opening to only 2.5 feet. The field assessment found that a downstream debris jam associated with backwatering by the Smith River had caused the channel bed to aggrade at the crossing since construction. The crossing no longer has capacity to convey typical high flows and associated sediment and debris, causing additional aggradation and formation of upstream debris jams. Aggradation at the Little Mill Creek site due to backwatering by the Smith River is also extensive. The channel profile at both of these sites is influenced by backwatering from the downstream river, causing the streambed to aggrade and degrade cyclically in response to high river events.

The Hall Creek bridge crossing is located immediately adjacent to the lower Mad River. In this area the river laterally migrates across the valley, frequently shifting. The bridge crossing had a RSP apron that was retrofitted with a pool-and-chute fishway. The fishway appears to have been designed based on the downstream channel bed associated with a period when the main river channel was on the opposite side of the valley. By the time of construction, the main flow of the river had moved towards the crossing, resulting in a lower bed elevation at the downstream end of the fishway than had originally been designed for. This required returning to the site the following year and adding two more pool and weir sequences to the project.

An evaluation and interpretation of the overall channel profile, including the geomorphic setting of the stream channel relative to the downstream river, would have highlighted the vertical adjustments that should be incorporated into all three of these crossing designs.

4.1.3 RECOGNIZING LOCAL AGGRADATION FROM PRE-PROJECT CROSSINGS

Some of the sites had undersized pre-project crossings that caused frequent backwatering, resulting in upstream local sediment aggradation. The crossing-induced aggradation at each of these sites did not appear to be identified or addressed as part of design development.

At the SF Ryan Creek crossing, the upstream channel had experienced substantial aggradation from culvert backwatering prior to the project. As a result, the channel bed was artificially high and at a lower slope than the overall stable channel profile. Instead of restoring the upstream channel profile, the project held this sediment in place by constructing rock weirs upstream of the replacement culvert inlet, thus maintaining this artificial discontinuity in the overall stream channel profile. The resulting partial failure of the rock weirs has led to compromised low-flow passage over the weirs due to large drop heights.

At the NF Ryan Creek crossing, the upstream aggradation from the undersized crossing was retained as part of the design by constructing two upstream rock weirs spaced closely together with drop heights exceeding 1-foot. The result is a failure of the lower rock weir, an excessive drop over the remaining rock weir, and a distinct discontinuity in the channel profile that makes fish passage conditions challenging, especially over the remaining upstream rock weir.

The pre-project Little Mill Creek crossing also included substantial upstream aggradation due to backwatering from the undersized culvert. The project design attempted to control the profile associated with this crossing-induced aggradation by installing four rock weirs. With the subsequent failure of all four weirs, the channel mobilized this stored sediment and restored its overall profile with no notable adverse effects. However, this resulted in the RSP along the left bridge abutment being undermined, in part due to the RSP toe elevation being set based on the rock weir elevations rather than placing the toe below the overall stable profile that would, and did, develop without the weirs.

4.2 Channel Constrictions

Several of the assessed sites were noted as constricting the natural channel width. The SF Ryan Creek crossing replacement used a culvert crossing that was substantially narrower than the channel width, relying on an overflow culvert to provide additional high-flow capacity. Based on observations at high flow, the constriction associated with this crossing (combined with limited height) causes substantial backwatering that would make it difficult for any larger debris floating down the stream to pass through the culvert. A similar issue was seen at the Peacock Creek crossing, a retrofitted pipe-arch culvert. It is substantially narrower than the upstream approaching channel, and during the site visits there was clear evidence of recent high flows causing debris racking at and around the culvert inlet.

The RSP under the full-span bridge crossing at Craig Creek constricts the natural channel width when compared to upstream and downstream channel dimensions. This has resulted in local scour of the channel bed through the crossing. The constriction may have arisen from downstream incision moving through the project reach, thus lowering the streambed under the bridge and exposing the toe of the RSP. This constriction appears to cause higher velocities under the crossing than in the adjacent channel and creates upstream backwater conditions that have resulted in local aggradation of the upstream channel bed.

The NF Ryan Creek crossing was reportedly designed based on sizing the box culvert width to exceed the natural channel width. However, measurements of the active and bankfull channel widths upstream of the project found them to be substantially wider than the culvert. The channel width measurements made during our site visits matched those reported in site assessments completed by Prunuske Chatham, Inc. (Prunuske Chatham, Inc., 2007). The relatively narrow channel through the culvert may be a factor causing the channel bed within the culvert to develop a plane bed with almost zero slope. There is also insufficient width to consider constructing stream banks within the culvert to simulate the natural channel margins that provide increased hydraulic diversity.

4.3 Overwidened Channel Dimensions

An issue observed at several crossings built with spans exceeding the stream’s bankfull channel width was overwidening of the channel bed and lack of streambanks through the crossing. All of these sites consisted of bridges with spans that exceeded the channel’s measured bankfull width. At three of the sites (Little Mill Creek, Yank Creek and Upp Creek), the only confinement through the crossing was the RSP placed against the concrete bridge abutments, resulting in an overwidened channel that produces noticeably shallower flow depths than those occurring in the adjacent natural stream reaches. This likely causes a low-flow barrier to fish at certain flows relative to passage conditions in the adjacent channel. At Little Mill Creek, the formation of a depositional bar under the bridge due to backwatering from the downstream river helped confine the channel post-project compared to its constructed condition. However, at the other two sites no such depositional features have formed, and the overwidened channel condition persists.

At Yank Creek, the replacement bridge crossing design exceeded the channel width to improve the stream's poor alignment with the road which previously had ninety-degree bends in the channel at the crossing inlet and outlet. The lack of streambanks and channel definition through the new bridge crossing creates a relatively wide and flat gravel streambed. It appears that depths through the crossing are likely shallower than the adjacent natural channel, potentially creating a low-flow barrier to fish. At this site, the channel through the crossing is attempting to develop a thalweg and new channel alignment so there may be an opportunity to develop banks or encourage bank development at this site.

A related issue is design of channels with excessive width. Streambanks were constructed outside of the bridge crossing at Upp Creek. However, the active (bottom) and bankfull (top of bank) widths created by the constructed banks far exceed those measured in the adjacent natural channel reaches. At Upp Creek it appeared that the constructed channel was sized based on conveying a large flood event (i.e., 100-year flow) rather than the basing the design on the size and morphology of the adjacent channel. As a result, the overwidening of the channel downstream of the Upp Creek bridge causes aggradation due in part to shallower flow depths and lower sediment transport capacity.

As a standard practice, projects should construct streambanks through the project reach that create channel dimensions similar to the adjacent natural channel. Recognizing that vegetated streambanks are unattainable through crossings, these banks should be constructed of a blend of RSP and smaller material to fill voids. Rather than overwidening the channel, incorporate overbank areas to provide additional flow capacity as needed.

4.4 Lack of Channel Slope and Bedform inside Crossings

The NF and SF Ryan Creek crossings were the only assessed sites with embedded culvert crossings. Both were characterized as gravel bedded channels through the crossings. Noteworthy was the nearly flat channel slope in both and lack of bedforms in the NF Ryan Creek culvert. Although the natural channel slope at both sites is greater than 1 percent, the streambed in the culverts had close to no slope. In the natural channel, tree roots, small and large wood, and bends in the channel served as the primary bed controls that formed steps, riffles, and pools. The stream simulation design approach includes noting the locations and sizes of different types of bed controls within a nearby reference reach and then building those into the crossing – often in the form of rock bands. Without these features the gravel bedded channel slope appears to flatten and can become more uniform. Given the substantial length of these crossings ($\geq$ 100 feet), future stream simulation culvert crossing should consider adding bed controls using large rock to simulate the controls mapped in the reference reach. Spacing and arrangement of these features should be guided by their distribution in the reference reach.

Besides the bed within the culvert being flat in profile, the NF Ryan Creek crossing also had almost no channel definition in cross section. Instead, the bed was nearly completely flat. In contrast, much of the length of the SF Ryan Creek culvert had “disrupter” boulders placed within the streambed gravel. These produced local scour around the boulders and caused changes in the direction of the thalweg, making for a more topographically diverse channel bed with areas of deeper water. Adding large rocks along the edges of the culvert and in the center should be considered in future embedded culvert projects to help roughen the margins of the channel and diversify velocity patterns.

4.5 Grade Control

Grade control was incorporated into almost all of the site designs and rock weirs were the most common type of grade control, followed by concrete weirs. As noted in Section 4.1, the need for grade control was sometimes not adequately evaluated or documented. The cause of a discontinuity in the channel profile from downstream to upstream, the need to maintain the grade at the upstream end of the project, and the risk associated with allowing upstream channel adjustments to occur should be better documented in project plans and reports.

4.5.1 ROCK WEIR FAILURE/INSTABILITY

At assessed sites the primary means of controlling channel grade was the use of rock weirs. However, at numerous sites these rock weirs had either completely failed or were no longer stable. Below is the list of assessed sites where one or more rock weirs had failed:

- The four rock weirs constructed at the Little Mill Creek crossing appeared short-lived, potentially due to the relatively small rock used and the amount of upstream stored sediment that was mobilized after bridge construction.
- The Dunn Creek crossing was constructed with 11 rock weirs. The downstream-most weir failed in response to downstream channel degradation, placing the next upstream weir in jeopardy of failing. If this weir is undermined and fails, it could create a domino effect for the remaining upstream weirs.
- Rock weirs were constructed downstream of the Cedar Creek concrete pool and weir fishway. However, when visiting the site these weirs had failed. The large rock they were constructed with remained just downstream of their original location creating a reasonably stable channel control that was helping to define the fishway tailwater

control. The current channel conditions were observed to provide good water elevation control for the fishway entrance and passage was not compromised.

- A rock weir comprised of 1- to 2-ton boulders was constructed downstream of the concrete weirs at the Rattlesnake Creek crossing. At the time of the site visit the weir was no longer present and only remnant boulders were observable. Similar to Cedar Creek, a stable tailwater control has formed and passage into the fishway is not compromised.
- NF and SF Ryan Creek had rock weirs upstream and downstream of the replacement culverts. At both sites, the weir placed immediately upstream of the culvert inlet had failed, causing a larger drop and poor fish passage conditions over the next upstream weir.

Based on these numerous observations, rock weirs may not be an appropriate means of providing grade control. Other approaches, including roughed channels and concrete weirs are likely more reliable. If the use of rock weirs is to continue, additional design guidance should be developed and focused in-part on the limited geomorphic setting for which they are applicable, appropriate hydraulic analysis and considerations, and that proper construction oversight is essential.

4.5.2 ROCK WEIR – INCONSISTENT DROP HEIGHTS AND WIDTHS

At several of the assessed sites with rock weirs, the weirs varied in both drop height and weir width. Some of the designs included drops across weirs in excess of the 1-foot criterion. For example, the SF Ryan Creek crossing design included weirs with 1.3-foot and 2.0-foot drops. These drop heights result in increased scour to the downstream channel that can undermine weirs and compromise the weir integrity.

Additionally, construction of rock weirs needs to include an acceptable vertical tolerance given the challenges with placing and stacking large boulders to meet design grade. The 11 weirs at Dunn Creek were designed with 1.0-foot drops. However, even with close construction oversight, the drops over the constructed weirs varied from 0.5 feet to 1.5 feet. Because of this, the weir drop heights should generally be designed to be less than the typical maximum 1.0-foot to account for the variability associated with construction.

Another issue observed with rock weirs is variation in the width of the weirs from one to another. Variation in weir width and cross-sectional shape through a project also causes the flow depths over each weir to vary, thus causing variability in the water surface drops. This can also lead to some weirs being vulnerable to additional scour of the downstream channel bed, potentially undermining their footing.

4.6 Sealing the Streambed

Adequate sealing of the placed streambed material is essential to ensure flows remain on the surface through the project reach. At the NF Ryan Creek site, the flow upstream of the project was on the surface during site visits. However, on more than one occasion, the flow was observed going subsurface at the culvert inlet and remaining subsurface through the culvert and much of the downstream re-constructed stream channel. The flow remained subsurface through the culvert and resurfaced at select locations to form isolated pools in the downstream project reach. Downstream of the project the surface flow reemerged. Although the project was constructed two years prior to this observation and had experienced several large flow events that transported bed material, the streambed in the project remained more porous than in the natural channel, creating a low-flow fish passage barrier. This site illustrates that even in streams with high fine sediment loads, such as the NF Ryan Creek site, the placed streambed material can remain too porous for years after construction if fines are not used to sufficiently reduced the porosity of the engineered streambed during construction.

The exact cause of the inadequately sealed streambed is unknown at the NF Ryan Creek site but is likely due to a lack of sufficient fine material in the lower layers of the placed streambed. The design should specify a sufficient proportion of the streambed material be comprised of sands and finer (typically 8 to 10 percent). During construction the streambed material should be compacted during each lift using water to wash those fines into the voids between the gravels until water remains on the surface.

4.7 Localized Scour of RSP at Structure

Several of the assessment sites experienced scour, shifting, and loss of RSP. At Fort Goff Creek there was loss of RSP at the upstream face of the bridge along the left abutment. This area is located on the outside of an approaching channel bend and it appeared that impinging flow concentrated here caused the large-sized RSP to become dislodged. Potentially contributing to this was the placement of large boulders in the channel bed near this location that may have increased local scour. Use of two-dimensional hydraulic analysis may have identified the issue during the design phase.

At Craig Creek the exposure of the RSP toe associated with the bridge abutments was apparently due to not properly estimating the potential bed elevation adjustment through the crossing following replacement. The RSP not being placed at a low enough elevation, and also constricting the channel once the bed degraded, resulted in movement of the RSP.

At Little Mill Creek, the RSP toe was undermined causing displacement of some rock. The scour along the toe of the RSP appears to have been a result of the failure of the rock weirs and subsequent incision of the constructed streambed elevation.

4.8 Other Construction Oversights

Several sites had notable construction issues not covered by the site conditions described above. The two culverts at SF Ryan Creek were installed using trenchless ramming due to the fill height and large traffic volumes at the crossing. The main culvert was designed to be installed flat and backfilled with streambed material, but installation did not go as planned and the culvert was installed at an adverse slope of 2.1%. It is unclear why the installation was allowed to continue once the culvert slope deviated so far from the design. Also, the rest of the channel work appears to have been constructed following the original design plans rather than redesigning to best accommodate the changed culvert layout.

The Cedar Creek crossing retrofit involved a substantial amount of detailed concrete form work associated with the fishway weirs. The weir shape was based specifically on providing passage for juvenile salmonids and Pacific lamprey. Providing favorable passage conditions for both species required the right-side and notch of the weir to have a square-edge top to form good nappe flow to support passage for leaping salmonids and the left side of the weir to have a rounded top to create a continuously wetted surface for lamprey to climb up. However, the concrete work did not receive the level of attention warranted creating several seams and joints that disrupt flow over the continuous wetted surface and fail to form a clear nappe through the weir notch (see Appendix A for details). Clearly communicating the importance of good nappe separation and flow for juvenile salmonid passage, and a continuous wetted surface for lamprey passage might encourage site engineers and contractors to pay more attention to these details.

5 OVERALL RECOMMENDATIONS

5.1 Institute Geomorphic Site Assessments as a Standard Study for Project Development

Most of the project design and performance issues noted in Section 4 could have been identified early in the project development phase by conducting a geomorphic site assessment of channel conditions. Detailed project studies that include the characterization of channel morphology and a geomorphic assessment of the stream should be mandatory for all streams and especially for stream crossing projects on fish-bearing streams. These studies should be conducted in conjunction with the project hydraulic studies. In many instances, an initial geomorphic study should be conducted during project initiation to identify the appropriate project type and extents. Project development teams should include members with an understanding of fluvial geomorphology and experience with understanding and interpreting geomorphic channel responses as related to road-stream crossing projects.

Both CDFG (2009) and USFS (2008) provide guidance on conducting geomorphic assessments as part of planning a stream crossing replacement project. The California Fish Passage Advisory Committee has also developed guidance on collecting longitudinal profiles that fully capture the site geomorphic context (*https://www.cafishpac.org/fishpac-fact-sheets*). They recommend conducting the geomorphic characterization in the initial phase of the project. The assessment is essential in performing the following tasks:

- Identifying geomorphic risk factors and potential channel changes over the structure lifetime (e.g., channel incision, aggradation, lateral migration)

- Determining acceptability of risk factors and need for mitigation measures (e.g., grade control, raising the road profile)
- Establishing detailed project geomorphic and fisheries objectives, and defining project extents
- Providing a template for design of the channel profile and shape along with minimum crossing dimensions to support continuity of geomorphic processes through the crossing
- Determining the project footprint, stream reach length and Right of Way required to restore geomorphic function.
- Establishing the long-term potential variability and range in channel bed elevations the crossing should accommodate
- Selecting the appropriate crossing type and size

A geomorphic site assessment ultimately predicts how the channel will react to the removal of the existing crossing and how the proposed crossing structure will interact with the stream. Such an assessment should include, at a minimum, the following elements with proper interpretation of the geomorphic site assessment information being essential.

5.1.1 THALWEG PROFILE ASSESSMENTS

The geomorphic assessment is highly reliant on having a well-defined profile of the channel thalweg extending sufficiently upstream and downstream of the project reach. The project hydrologist/geomorphologist should lead this effort, including identifying early in the planning phase the needed survey extents. The thalweg survey should include notes regarding features controlling the profile and their anticipated long-term stability, sizes and changes in substrate composition, and other geomorphic field observations and interpretations. This includes noting the apparent extent of the existing crossing influence on upstream and downstream channel conditions and influences from downstream water bodies among others.

Surveyors are not generally trained to collect this information. One approach is for the project hydrologist/geomorphologist to accompany or precede the survey crew and mark these features with pin flags so that the survey crew captures all important channel features. A profile that does not include geomorphic features is inadequate and may possibly lead to design deficiencies. The thalweg profile can also be extended using an available high-resolution LiDAR DEM. Although it lacks field interpretation and can include a lot of noise associated with vegetation, extending the profile using a LiDAR DEM can help interpret the project site within the larger geomorphic context, such as if the project is in a naturally aggrading reach.

The evaluation of the profile as part of the geomorphic site assessment should identify the existing overall channel profile through the project reach along with the potential for channel incision or aggradation. The potential vertical changes in the streambed through the project should be estimated following the approach outlined in USFS (2008). This analysis of vertical adjustment potential (VAP) is important for selecting and sizing the crossing structure, and ensuring appropriate design depth for bridge footings so that they are placed below the low VAP. These vertical ranges will likely be updated and refined as the project design progresses.

5.1.2 Evaluating Risk of Channel Adjustment

If the upstream channel is anticipated to incise in response to the crossing replacement, the assessment should evaluate the likely extents and magnitude of the incision and the associated risks. Results from this risk assessment will help determine if grade control is needed as part of the project. These findings ultimately guide the approach for design of the stream channel through the crossing and whether approaches such as stream simulation verses profile control are the appropriate basis for a crossing design.

The Hall Creek crossing performance was influenced by lateral migration of the Mad River away from the confluence of Hall Creek since the project was constructed. The lateral migration of the Mad River at this site, and subsequent development of bars/islands that block access to Hall Creek, demonstrates the importance of evaluating the risk of lateral channel migration for stream crossing projects, especially those at or near the confluence with a larger river.

5.1.3 Characterizing a Reference or Representative Reach for Design Development

Full span crossings are generally designed based on channel dimensions measured in a reference reach outside of the existing crossing influence. A project geomorphic site assessment should include characterizing a reference or representative reach. If the project will require grade control to prevent upstream channel incision, a selected reach that is generally representative of the overall stream geometry should provide guidance on the project channel width and depth, and the minimum crossing span based on CDFG (2002) and NMFS (2019) design criteria. A reference reach is used when the channel design will rely on mimicking the natural channel form, including channel dimensions and features that control the profile. In both cases, the project hydrologist/geomorphologist should identify a suitable reach, collecting channel dimensions and preparing a detailed sketch of the reach noting the various channel controlling features. Ultimately, characteristics of the reference or representative reach guide the channel design and selection of the crossing type.

5.1.4 Establishing Geomorphic Design Objectives for Each Project

The characterizations and understanding gained through the geomorphic site assessment should guide selection of a design approach and establishment of clear design objectives. These could include:

- Simulation of a reference reach for aquatic organism passage
- Removal of upstream deposition caused by the pre-project crossing
- Restoration of the channel shape through an existing scour pool

- Use of grade control to prevent channel incision from migrating upstream
- Adjustment of the crossing elevation, opening, or hydraulic capacity to accommodate long-term channel aggradation, passage of large wood, transport and deposition of large boulders, or backwater influences from downstream
- Determination of the appropriate low elevation for structure footings and RSP toes
- Incorporation of streambanks through the crossing for hydraulic diversity along channel margins and potential pathway for terrestrial organisms.
- Adjustment/improvement of the channel alignment through implementing a wider crossing or other means

These geomorphic-based design objectives for the crossing can then be moved forward as part of the project phases.

5.2 Additional Guidance for Design and Construction of Grade Control

Additional guidance on the application, design, and construction of grade control appears needed based on the frequent use and observed poor performance of rock weirs as channel grade control features. If the use of rock weirs is to continue, additional design guidance should be developed and focus in-part on the limited geomorphic setting in which they are applicable, appropriate hydraulic analysis and considerations, and emphasize that diligent construction oversight is essential to verify rock placement that achieves design specifications. The guidance should also include other accepted approaches to providing grade control, including the use of roughened channels such as rock ramps, roughened riffles, and chutes and pools.

5.3 Develop Standard Special Provisions for Channel Construction

Most of the assessed projects included channel restoration and construction elements that are not part of the Caltrans standard specifications or standard special provisions (SSPs). Instead, each project appears to have needed and prepared their own non-standard special provisions (NSSPs). An example of this is specifications for engineered streambed material; both the composition of the material and its placement. Developing unique NSSPs across similar project types can result in wide variations between projects in methods and materials used to achieve the design intent. Collating previously prepared NSSPs associated with full-span crossing and stream restoration projects and preparing SSPs that can be used Statewide would:

- Help standardize crossing designs to those beyond the recently developed Accelerated Bridge Construction designs,
- Better ensure the desired outcomes, and
- Provide clear guidance for design of future projects.

5.4 Adjust and Implement Design Changes when Field Conditions Change

Field conditions for fish passage projects often change unexpectedly during construction requiring field changes to the original design. These changes can include unanticipated subsurface conditions requiring modification of the crossing structure alignment or elevation, a lack of suitable material available for channel, weir or bank construction, or environmental regulatory constraints not originally incorporated into the design. To address unexpected conditions and meet project objectives, field and design engineers need to communicate and be available for consultation as projects are being constructed. The designers often have a more complete understating of the detailed design objectives and fish passage requirements, allowing them to readily determine the acceptability of different field modifications. Additionally, procedures should be implemented and adhered to that fully document field changes to the design, the reasons for these changes, and provide an analysis and description of how changes may affect the project performance.

REFERENCES

Barnard, R., Johnson, J., Brooks, P., Bates, K., Heiner, B., Klavas, J., . . . Powers, P. (2013). *Water Crossings Design Guidelines.* Olympia, WA: Washington Department of Fish and Wildlife. Retrieved from http://wdfw.wa.gov/hab/ahg/culverts.htm

Barnard, R., Yokers, S., Nagygyor, A., & Quinn, T. (2015). An Evaluation of the Stream Simulation Culvert Design Method in Washington State. *River Research and Applications* , 1376–1387.

CDFG. (2002). *Culvert criteria for fish passage.* California Department of Fish and Game.

CDFG. (2009). *California Salmonid Stream Habitat Restoration Manual. Part XII - Fish Passage Design and Implementation.* California Department of Fish and Wildlife.

FishPAC. (2019). *California Fish Passage Advisory Committee (FishPAC) Expert Inspection Form.* Retrieved from https://www.cafishpac.org/science-data

Gillespie, N., Unthank, A., Campbell, L., Anderson, P., Gubernick, R., Weinhold, M., . . . Kirn, R. (2014). Flood effects on road-stream crossing infrastructure: economic and ecological benefits of stream simulation designs. *Fisheries*, 62-76.

Harrelson, C. C., Rawlins, C. L., & Potyondy, J. P. (1994). *Stream Channel Reference Sites: An Illustrated Guide to Field Technique.* United States Department of Agriculture - Forest Service.

Klingel, H. (2014). *Developing a Physical Effectiveness Monitoring Program for Aquatic Organism Passage Restoration at Road-Stream Crossings.* Fort Collins, Colorado: Department of Geosciences, Colorado State University.

Lai, Y. G. (2008). *SRH-2D version 2: Theory and User's Manual.* Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation.

Lang, M., & Love, M. (2019). *Study Site Monitoring Plan for Project 65A0711: Design Guidance for Full-Span Crossings.*

Long, J. (2010). *The economics of culvert replacement: fish passage in eastern Maine.* Retrieved 6 6, 2018, from Natural Resources Conservation Service, Maine: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcs143_009452&text=pdf

NMFS. (2019). *Guidelines for Salmonid Passage at Stream Crossings: For applications in California at Engineered Stream Crossings to Facilitate Passage of Anadromous Salmonids.* NOAA National Marine Fisheries Service.

Prunuske Chatham, Inc. (2007). *NORTH AND SOUTH FORK RYAN CREEK FISH PASSAGE IMPROVEMENT PROJECTS, Draft Scoping Report.* Occidental, CA: Prunuske Chatham, Inc.

USFS. (2008). *Stream Simulation: An Ecological Approach To Providing Passage for Aquatic Organisms at Road-Stream Crossings.* Forest Service Stream-Simulation Working Group. San Dimas, CA: USFS National Technology and Development Program. Retrieved from https://www.fs.fed.us/eng/pubs/pdf/StreamSimulation/hi_res/%20FullDoc.pdf

Wolman, M. (1954). A Method of Sampling Coarse River-bed Material. *Transactions, American Geophysical Union, 35*(6), 951-956.

APPENDIX A – SITE ANALYSIS SUMMARIES

APPENDIX A – SITE ANALYSIS SUMMARIES

MAP OF SITE LOCATIONS

Map of field sites indicating site type and level of analysis conducted. Surveyed sites received an initial assessment and a full field survey. Assessment sites received only the initial assessment site visit.

1 PEACOCK CREEK (DN197 – PM2.12)

1.1 Project Description

Peacock Creek crosses under State Route 197 (North Bank Road) approximately 4,600 feet upstream of its confluence with the lower Smith River. The stream drainage area is approximately 2.1 square miles. Constructed in 1972, the crossing is a structural steel plate pipe arch culvert, 13 feet wide by 8.67 feet tall, at a slope of 2.3%, and with inlet and outlet wingwalls and apron. The crossing was designed to provide fish passage. It included a concrete weir across the outlet apron (Figure 1-1b and c) and seven 16-inch tall wooden baffles spaced 10 feet apart with alternating notches set approximately 8 inches above the culvert invert. The baffles were failing due to age and were replaced in 2013.

1.1.1 DESIGN AND AS-BUILT CONDITIONS

The project replaced the seven failing wooden baffles with nine steel baffles spaced 8 feet apart. Based on the culvert slope and baffle spacing, the drop from one baffle to the next was designed at 0.18 feet. The baffles were designed with a 20-degree skew and a sloping crest, with the low and high ends of the baffle being 12 inches (right side) and 20 inches (left side) tall, respectively. The low end of the baffle was upstream of the high end, thus concentrating flows along the right side of the culvert to maintain slow velocities along the left side.

The baffles were connected to the culvert using welded gussets. The bottoms of the baffles were bedded in grout to provide a watertight seal and prevent underflow.

The notch in the existing outlet apron weir was cut and lowered 0.2 feet to reduce the outlet drop. A steel cap was also placed over the notch to protect it from bedload impact.

1.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the site during low-flow conditions on May 9, 2019 and August 6, 2020. Visually, the baffles appeared to provide suitable passage conditions and had retained gravel substrate throughout most of the culvert (Figure 1-1e). During the second visit a small piece of wood was lodged across the weir notch at the outlet and appeared to make the weir impassable by juvenile salmonids at this low flow (Figure 1-1c). Recent debris racking was noted on top of the inlet wingwalls, indicating that recent high flows resulted in a headwater level that was only a couple feet below the culvert soffit.

1.1.3 SITE OBSERVATIONS OF CHANNEL REACHES

Approximately 350 feet downstream of the SR197 crossing is a county-maintained crossing that was constructed in 2003 and includes a concrete pool and weir type fishway through an arch culvert. Downstream of the fishway the channel is more entrenched and has coarser substrate. This fishway has maintained a stable channel between the two crossings.

FIGURE 1-1. PEACOCK CREEK AT (A)CHANNEL DOWNSTREAM OF SR197, THE CULVERT OUTLET APRON (B) AT HIGH FLOWS AND (C) WITH WOOD PLUGGING NOTCH, (D) REPLACEMENT BAFFLES IN CULVERT IMMEDIATELY AFTER CONSTRUCTION AND AFTER SEDIMENT ACCUMULATION, AND (F) THE WOOD JAM ACROSS THE CHANNEL IMMEDIATELY UPSTREAM OF THE CULVERT INLET.

1.1.4 SITE OBSERVATIONS OF CHANNEL REACHES

Approximately 350 feet downstream of the SR197 crossing is a county-maintained crossing that was constructed in 2003 and includes a concrete pool and weir type fishway through an arch culvert. Downstream of the fishway the channel is more entrenched and has coarser substrate. This fishway has maintained a stable channel between the two crossings.

Approximately 75 feet upstream of the crossing is a channel spanning wood jam initiated by a large tree that was undermined along the bank and recently fell across the channel (Figure 1-1f). Key wood pieces in the jam look sufficient in size that they are unlikely to be transported downstream to the culvert inlet and form a long-term structure. The cause of the bank undermining that led to the tree falling is not known but it might be due to the backwater from the SR197 culvert inlet and resulting eddying along the channel banks. There was additional evidence of backwatering on the upstream banks and deposits at the headwall edges.

1.2 Channel Morphology and Profile

A detailed channel profile was surveyed by HSU extending approximately 350 feet downstream and 225 feet upstream of the State Route 197 crossing. Additional survey data was obtained from a 2007 monitoring survey of the downstream fishway at the county crossing. Green Diamond Resource Company provided a LiDAR DEM of the channel corridor from the river to near the top of the watershed (Figure 1-2) to generate additional channel profile information. Figure 1-2 also shows the project area and the locations of cross sections and pebble counts completed during the site surveys. An earlier channel survey of this stream reach from January 1999 by HSU was also reviewed.

1.2.1 CHANNEL SLOPES

A combined survey and LiDAR DEM generated profile is provided in Figure 1-3 along with defined channel slope segments. The profile reveals that the profile of the stream is generally between 1.6% and 1.8%, but the slope segments are offset at each of the two crossings. It appears that the downstream fishway, at a 6.2% slope, is controlling the upstream channel grade and preventing incision from migrating upstream.

Figure 1-4 shows a 1-foot drop from the culvert outlet weir to the downstream channel. This drop was reportedly 0.5 feet when designed in 2013. Additionally, the 1999 HSU survey showed this drop being 0.5 feet as well. These findings suggest that the channel bed immediately downstream of the crossing has lowered by 0.5 feet in recent years. This drop and the culvert being steeper than the channel, suggests that the SR197 crossing is also protecting the upstream channel from incising.

1.2.2 CHANNEL WIDTH AND DEPTH

Channel cross sections were surveyed upstream and downstream of the crossing (Figure 1-5) and measured channel geometry is listed in Table 1-1 along with the width provided by the culvert. In general, bankfull widths are between 18 feet and 20 feet while the crossing is only

13 feet wide. The downstream county crossing and fishway are 20 feet wide, which was selected to match the bankfull channel width.

1.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

The stream channel immediately upstream and downstream of the culvert is gravel bedded, with riffles and pools. In general, it appears geomorphically stable. Three surface pebble counts were conducted to characterize the streambed materials upstream and downstream of the crossing (Figure 1-6). The median grain size ranged from coarse to very coarse gravel. Material deposited between the baffles in the culvert appears similar in size.

TABLE 1-1. CHANNEL DIMENSIONS AND SLOPE BY REACH.

Location	Slope	Active Channel Width (ft)	Bankfull Width (ft)	Bankfull Depth from Thalweg (ft)
Downstream Channel	1.7%	16.7	18.6	2.4
SR197 Baffled Culvert	2.5%	13.0	13.0	-
Upstream Channel in Culvert Influence	2.5%	15.6	20.1	2.0
75 ft Upstream of Culvert	1.6%	20.3	-	-

1.3 Discussion

Culvert width is much narrower than the upstream channel and high debris rack lines at the inlet wingwalls suggests the culvert is undersized and more prone to clogging with debris due to its constriction of the bankfull channel. This may have led to the scour and undermining of the large tree 75 feet upstream of the inlet, which has recently fallen across the channel and started a debris jam.

The baffles appear to provide good passage hydraulics. Keeping the low side of the baffles on the same side throughout the culvert compared to the previous baffles with alternating notches is an improvement, as it ensures a continuous passage corridor (slow water) along the opposite side through the entire culvert. The design drop of 0.18 feet between baffle crests appears to provide suitable hydraulics while also allowing some coarse sediment to deposit between the baffles. This deposited sediment does not appear to be decreasing the effectiveness of the baffles and may offer better passage conditions for smaller fish moving along the bottom.

The drop over the outlet weir appears to have increased by 0.5 feet since 2013. Without continuous monitoring, the cause of this change is difficult to identify. The stream section between the outlet weir and the fishway at the Tan Oak Road crossing approximately 400 feet downstream appears stable and elevations are controlled by these two structures. The observed adjustment is most likely due to local wood or bedload repositioning. The increased drop may influence overall fish passage performance so periodic monitoring of fish passage flow conditions is recommended.

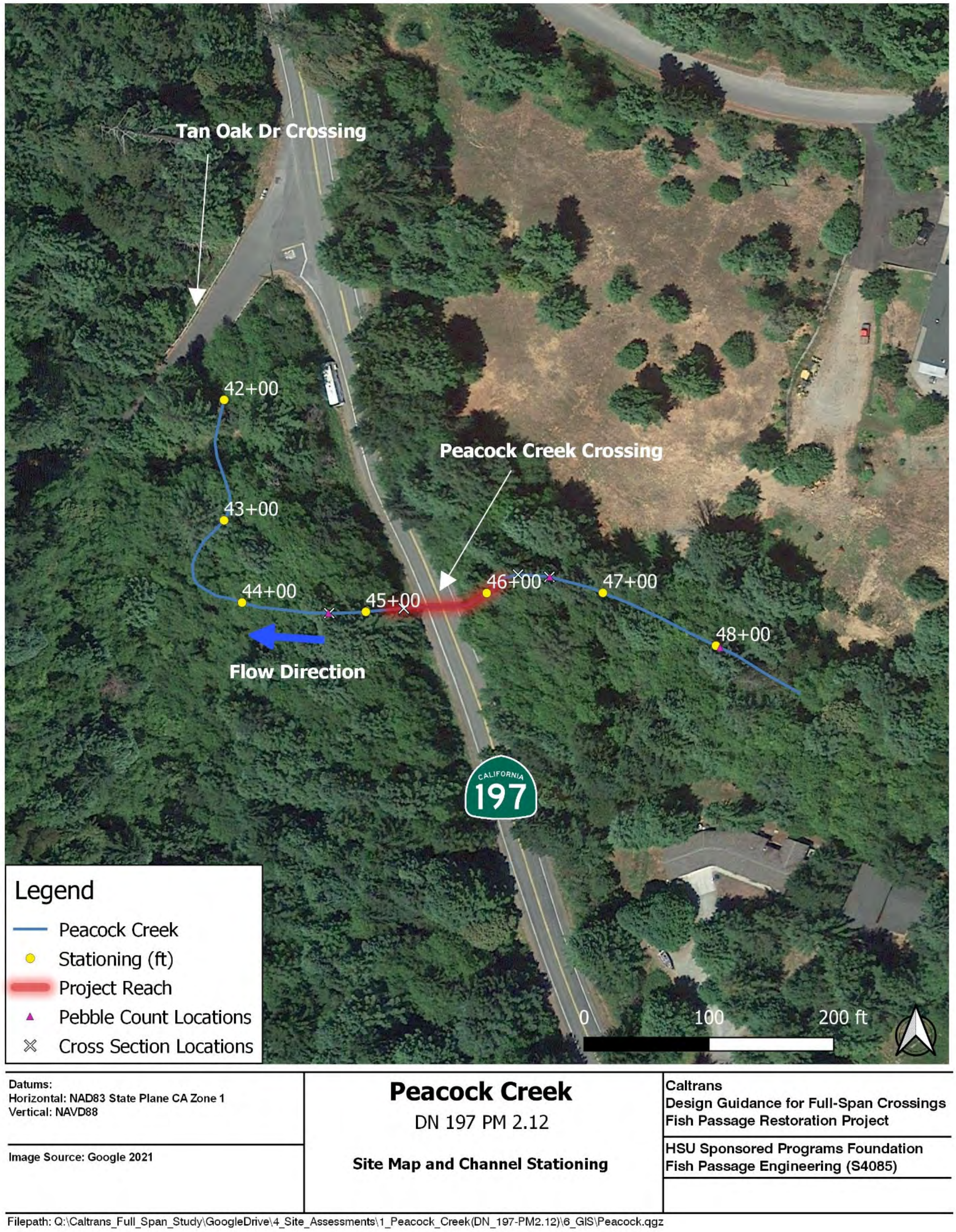


FIGURE 1-2. OVERVIEW SITE MAP FOR PEACOCK CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING STARTING AT THE SMITH RIVER CONFLUENCE.

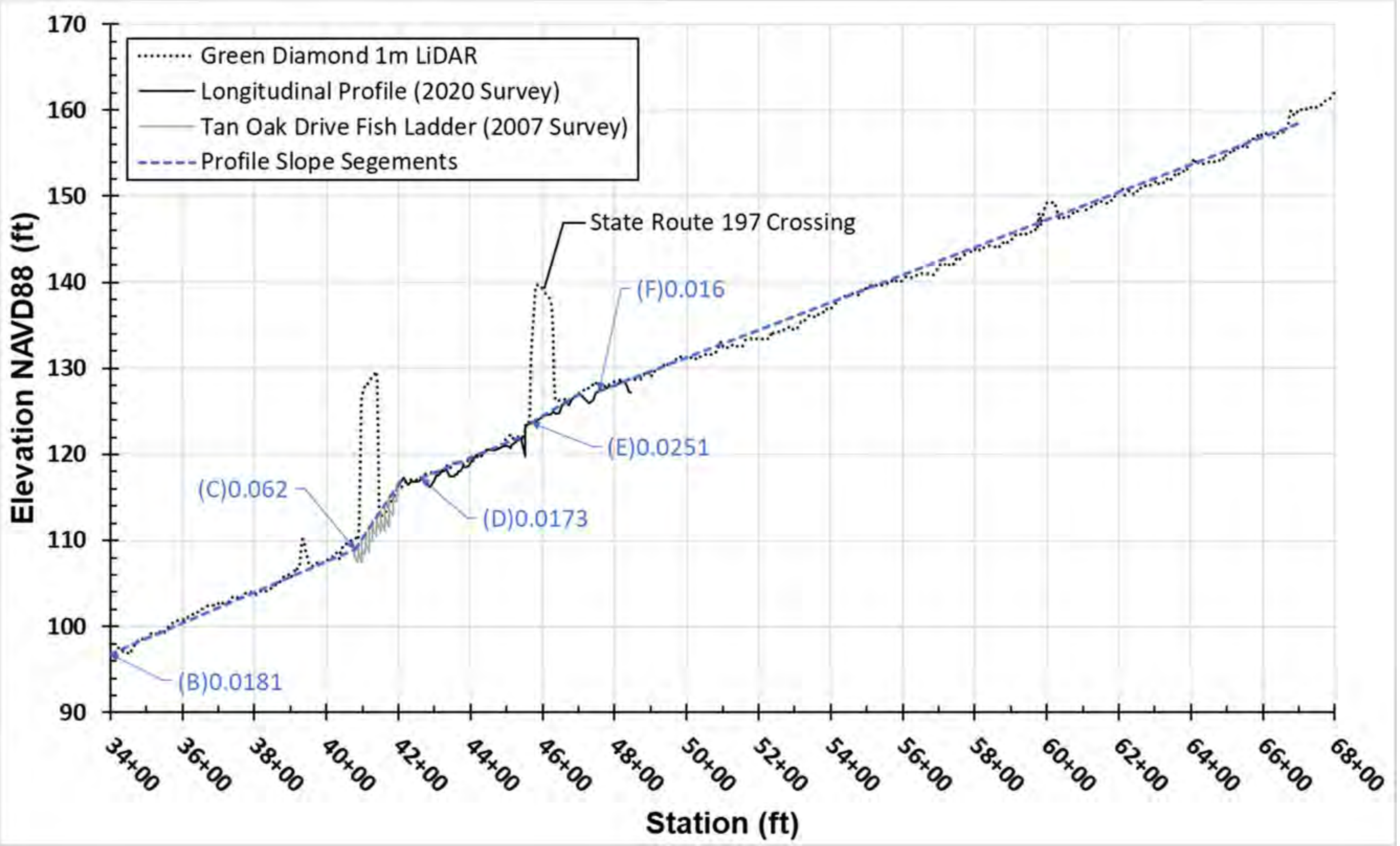


FIGURE 1-3. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED.

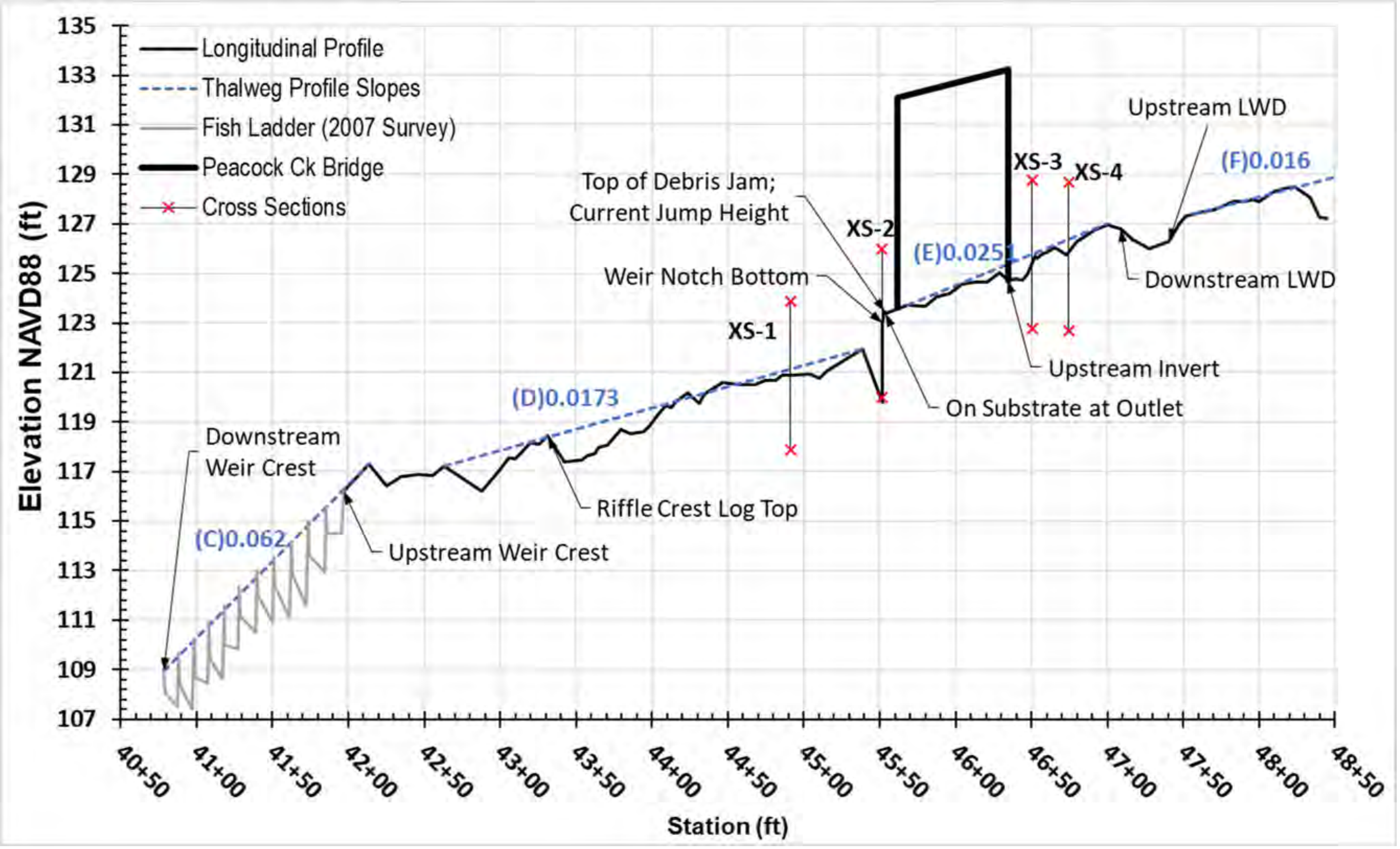


FIGURE 1-4. 2019 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

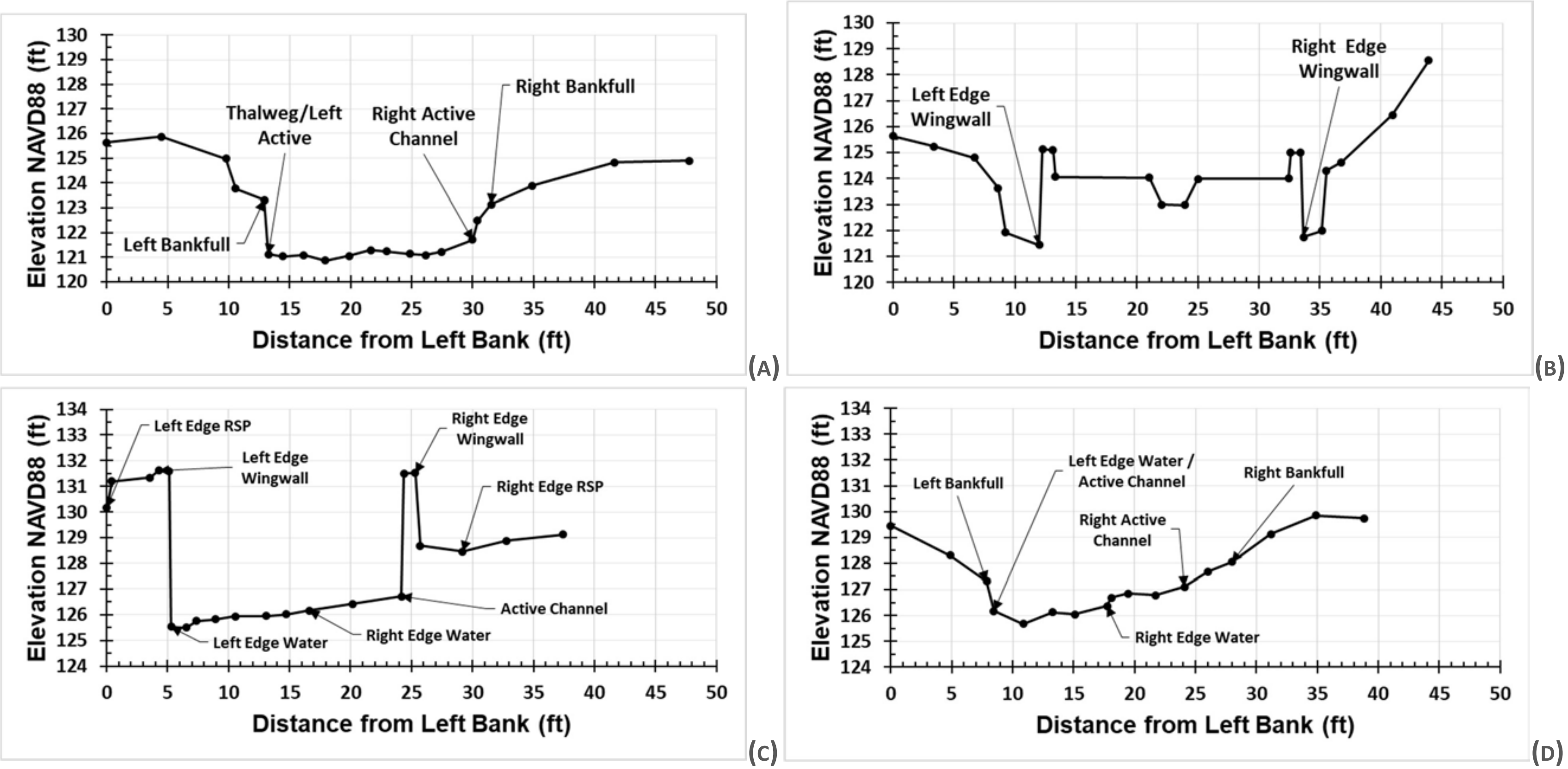


Figure 1-5. Cross-sectional surveys of the channel at cross sections (XS) 1 through 4. XS 1 (A) is in the downstream channel. XS2 and 3 are at the face of the culvert outlet and inlet apron, respectively. XS4 is taken immediately upstream of the culvert inlet.

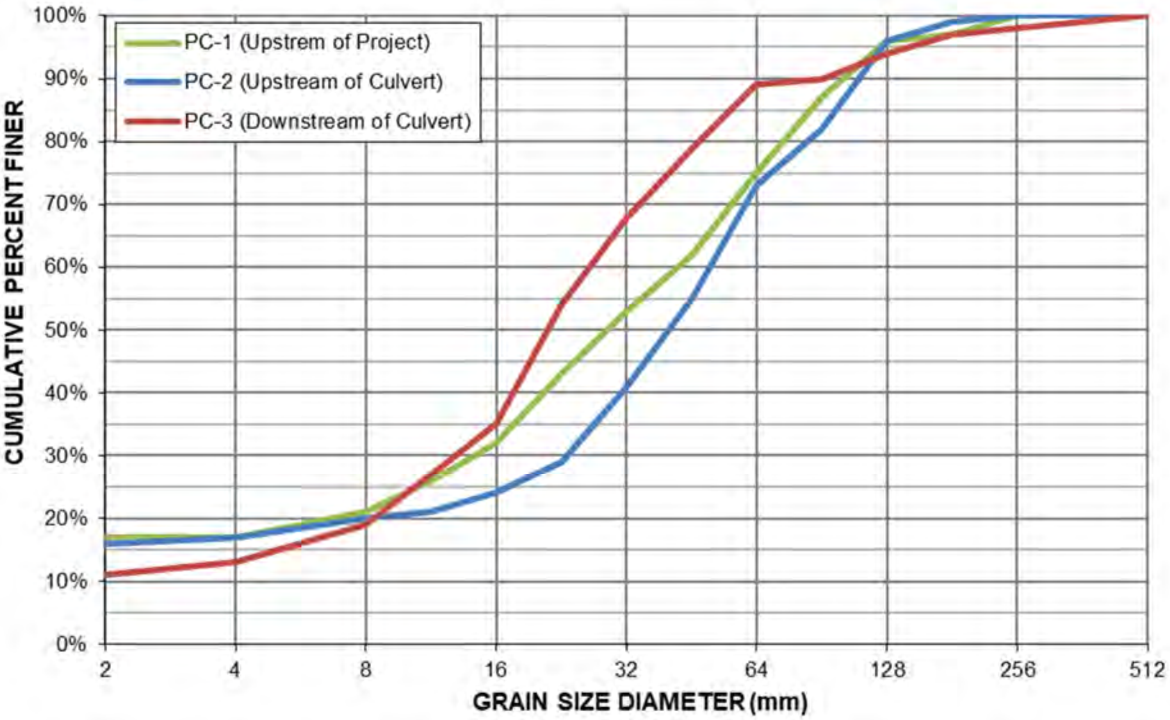


FIGURE 1-6. STREAMBED GRADATION BASED ON SURFACE PEBBLE COUNTS TAKEN DOWNSTREAM AND UPSTREAM OF THE CROSSING AND UPSTREAM OF THE LARGE WOOD JAM.

2 SULTAN CREEK (DN197 – PM5.00)

2.1 Project Description

Sultan Creek crosses under State Route 197 (North Bank Road) approximately 800 feet upstream from its confluence with the Smith River. The stream drainage area is approximately 2.2 square miles. Prior to replacement, the SR197 Sultan Creek crossing consisted of two elliptical culverts with 6-foot spans and 6-foot rises, and minimal cover over the culverts. (Figure 2-1a). The crossing had less than a 2-year flow capacity before water began inundating the roadway.

2.1.1 DESIGN AND AS-BUILT CONDITIONS

The replacement crossing consists of a 35-foot clear span bridge set on spread footings, with the top of the footings approximately 5 feet below the design channel bed elevation. The road profile was maintained and the bridge deck thickness is shown in the design drawings as 1.9 feet. The channel under the bridge was designed as trapezoidal with a 15-foot bottom width and 1.5H:1V side slopes. The design plans show the opening under the bridge, from the thalweg to the bridge soffit, was designed as 4.8 feet. Caltrans Structure Hydraulics report for the project indicates that the crossing as designed would convey a 10-year flow, with higher flows anticipated to overtop the channel and spread out. The return period associated with overtopping the roadway was not identified due to insufficient survey data.

2.1.2 SITE OBSERVATIONS OF PROJECT REACH

During site visits by HSU on May 9, 2019, October 28,2019 and January 9, 2020, existing channel and crossing conditions were evaluated and the channel was surveyed. During the first two site visits the project reach was dry, but the identified upstream reference reach was still flowing.

The crossing site appeared to have experienced substantial aggradation since construction, leaving a minimal opening height under the bridge for conveyance of streamflows (Figure 2-1). Additionally, the thickness of the bridge deck and the low-profile of the roadway appeared to place the soffit of the bridge below the channel's bankfull height.

Downstream of the crossing the stream flows through a dense riparian forest before entering the Smith River. Approximately 350 feet downstream of the crossing a large and complex debris jam was identified that formed an approximately 4-foot drop in the channel profile (Figure 2-1d). The jam appeared to be associated in part with backwatering from the nearby Smith River. Downstream of the jam the channel split into multiple branches as it flowed towards the river located approximately 600 feet downstream. Upstream of the jam the channel appeared highly aggraded, with the base of riparian trees buried in recently deposited gravels.

Figure 2-1. Sultan Creek (A) original crossing inlet at high flow and current (B) upstream and (C) downstream bridge face, (D) downstream and (E) upstream channel aggradation and debris jams, and (F) the selected reference reach, which is also aggrading.

A large flow event had occurred prior to the first site visit in 2019. Walking upstream of the channel revealed a large debris jam near station 12+50 (Figure 2-1e) which had pushed flow overbank onto an adjacent roadway owned by Green Diamond Resource Company. Debris lines showed that the floodwaters were conveyed down this road and onto State Route 197. Other locations of overbank flows leaving the channel were observed. The channel upstream of this debris jam appeared aggraded.

SITE OBSERVATIONS OF REFERENCE REACH

A potential reference reach was identified approximately 850 feet upstream of the SR197 bridge crossing and just upstream of the Green Diamond (GD) bridge crossing (Figure 2-2). The reference reach has a well-defined channel shape and characteristics and maintained year-round surface flow (Figure 2-1e and f). However, even the reference reach had indicators of recent aggradation, including the base of riparian redwood trees being buried in recent gravel deposition and the partial burial of constructed log and rock fish habitat structures.

2.2 Channel Morphology and Profile

The project reach is an unconfined alluvial channel draining out of steep mountains. The crossing is located on the upper floodplain of the Smith River and within the depositional section of Sultan Creek.

2.2.1 CHANNEL SLOPES

A detailed channel profile was surveyed by HSU extending approximately 250 feet downstream and 1,000 feet upstream of the State Route 197 crossing. Green Diamond Resource Company provided a LiDAR DEM of the channel corridor from the river to near the top of the watershed to generate additional channel profile information (Figure 2-3).

A combined survey and LiDAR DEM generated profile is provided in Figure 2-4 along with defined channel slope segments. The observed debris jam downstream of the crossing near Station 6+50 and resulting nearly 5-foot step in the profile is clearly visible in the LiDAR DEM. The top of the jam is about 15 feet above the low-flow elevation of the river, which places it within the river backwater influenced during high flows. The profile suggests aggradation extends more than 1,500 feet upstream of this jam. Ignoring the aggraded channel segments, the overall slope of the channel appears to be 1.5% extending from near the river confluence to approximately 2,800 feet upstream. However, the aggradation has reduced the channel slope through the crossing to approximately 0.9%.

The surveyed profile (Figure 2-5) reveals that aggradation at the bridge crossing resulting from the downstream debris jam may be as much as 2 feet. Based on the project design plans, it appears the constructed channel under the bridge was built close to the elevation of the overall profile, and the downstream debris jam formed subsequent to the design and installation of the new bridge.

Upstream of the crossing the profile shows the channel spanning jam described above near Station 12+50 that also appears to be causing local channel aggradation that extends into the upstream reference reach.

2.2.2 Channel Width and Depth

The channel shape and dimensions were recorded at select cross sections (Figure 2-6). The active (scoured bottom) channel widths and bankfull width and depth above thalweg were noted and are summarized in Table 2-1. The elevation of the active and bankfull channel indicators were also collected as part of the channel survey and shown on the profile in Figure 2-5.

The active channel widths were similar upstream of the bridge and in the reference reach. Downstream of the bridge the width was substantially wider due to the degree of sediment aggradation. The bankfull widths upstream of the bridge and in the reference reach were similar and slightly narrower than the available bridge opening.

The bankfull elevation of the channel upstream of the bridge opening, as seen in the cross sections and surveyed profile, are at least 0.5 feet higher than the bridge soffit. As such, the bridge opening constricts the bankfull channel, and results in pressure flow through the bridge at flows below bankfull.

Table 2-1. Channel dimensions and slope by reach.

Location		Slope	Active Channel Width (ft)	Bankfull Width (ft)	Bankfull Depth from Thalweg (ft)
Project	Downstream of Bridge	0.9%	30.4	39.7	2.9
	Upstream Bridge Opening	0.9%	31.9	31.0*	2.5*
	Upstream of Bridge	0.9%	21.3	26.0	3.2
Upstream Reference Reach		1.2%	21.7	29.9	3.2

** Width and height above thalweg of bridge opening.*

2.2.3 Streambed Morphology and Substrate

The stream channel is gravel bedded and unconfined. It contains long riffles and shallow pools forced generally by wood within the channel. Wood jams also control grade and form steps in the profile.

Pebble counts of the streambed material (Figure 2-7) revealed the bed material downstream of the bridge is much finer than immediately upstream and within the upstream reference reach. This may be in part due to decreasing stream power associated with the decreasing channel slope and loss of flow confinement, causing the bed material to become finer downstream of the bridge.

2.3 Discussion

The crossing is in a depositional reach of Sultan Creek, and within the influence of the Smith River during elevated river flows. Additionally, the forested watershed delivers a substantial amount of woody debris. Given the shallow depth and unconfined nature of the channel, the site is subject to variable streambed elevations and prone to debris jams and channel avulsions. As designed, the crossing only had 4.8-feet of clearance from the thalweg to the bridge soffit. Aggradation, caused in part from the downstream debris jam, has reduced this opening to only 2.5 feet high at the thalweg. It appears that the constricted opening causes the bridge to enter into pressure flow during frequently occurring high flows in Sultan Creek, resulting in upstream backwatering. This may be causing sediment and debris to deposit further upstream, exacerbating upstream out of bank flooding. Additionally, the small opening is highly susceptible to debris plugging, which could compromise fish passage.

The project's Final Hydraulics Report (FHR) highlighted that the crossing as designed could convey up to the 10-year flow at the design channel bed elevation and raised concerns about passage of woody debris. However, a review of the provided project documents did not reveal any assessment of the channel geomorphic state as it relates to the design of the crossing. A detailed analysis of the channel profile as it relates to debris, sediment, and river backwater influences would have highlighted the likelihood that the streambed elevation at the crossing is highly susceptible to aggradation. Developing an estimate of the vertical adjustment potential (VAP) of the channel bed may have influenced the overall project design to make it more resilient to channel bed fluctuations.

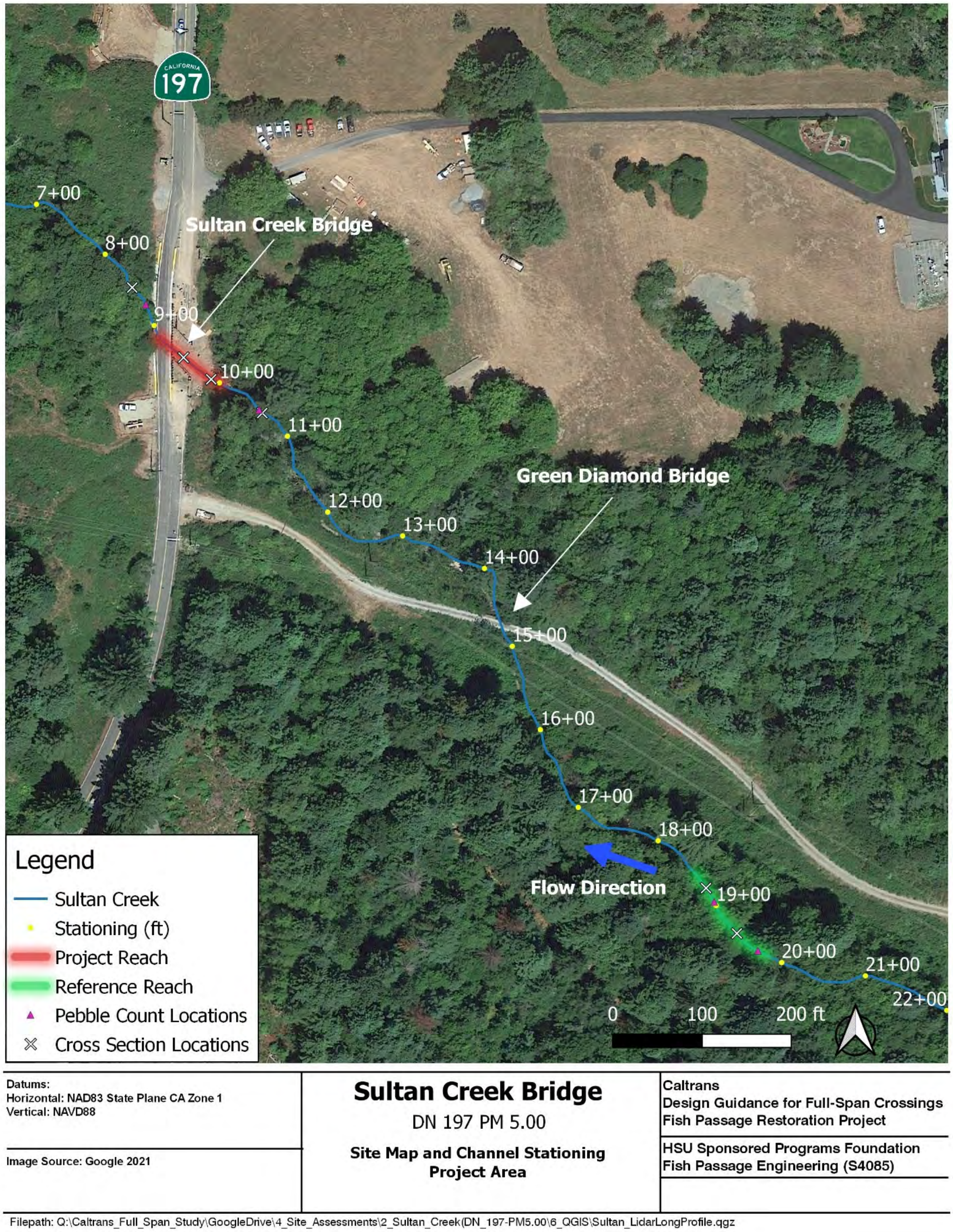


FIGURE 2-2. PROJECT AREA MAP FOR SULTAN CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION AND PEBBLE COUNT LOCATIONS.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

Sultan Creek Bridge

DN 197 PM 5.00

Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\2_Sultan_Creek(DN_197-

Figure 2-3. Overview site map for Sultan Creek showing channel alignment and stationing starting at the Smith River confluence.

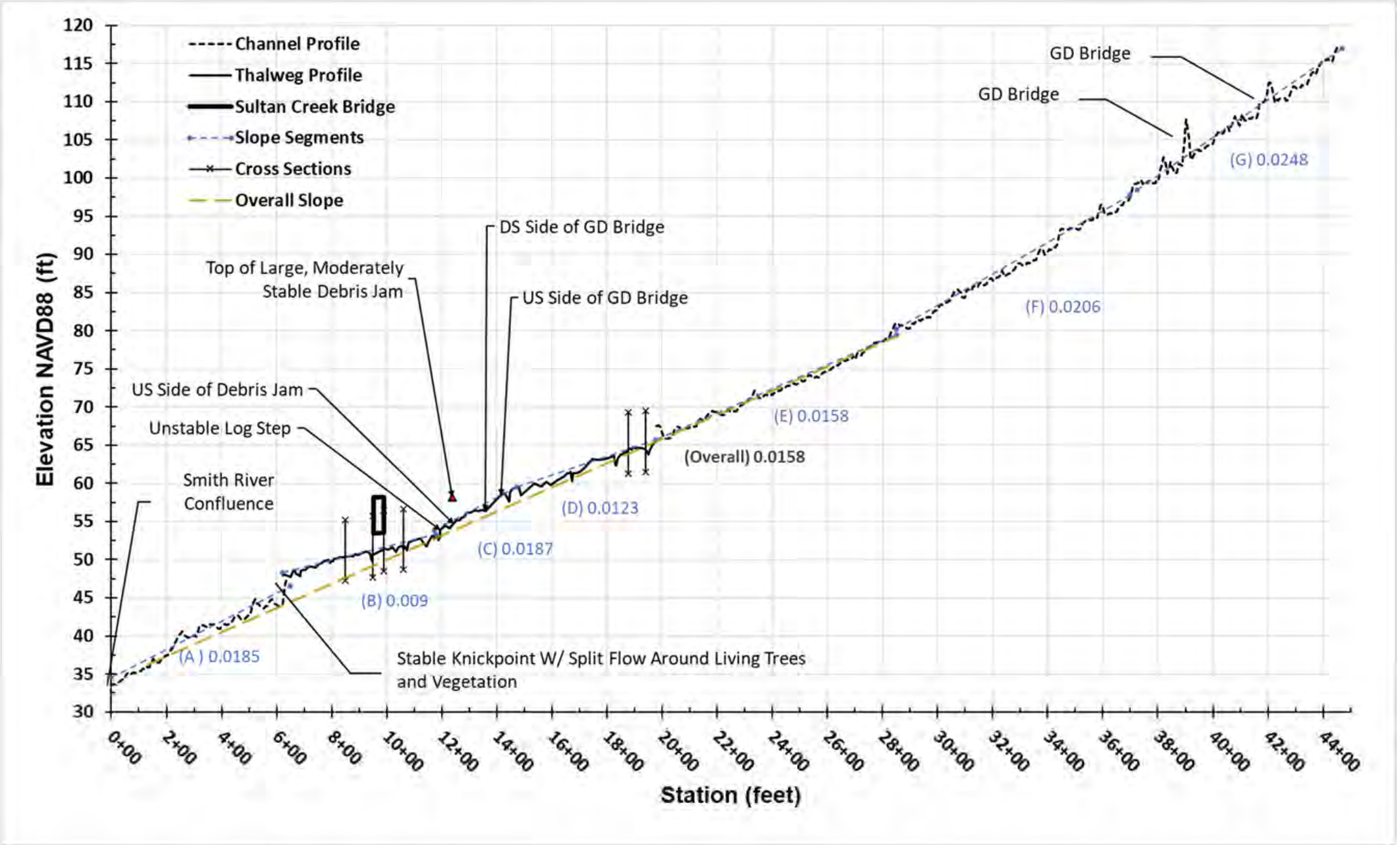


FIGURE 2-4. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED.

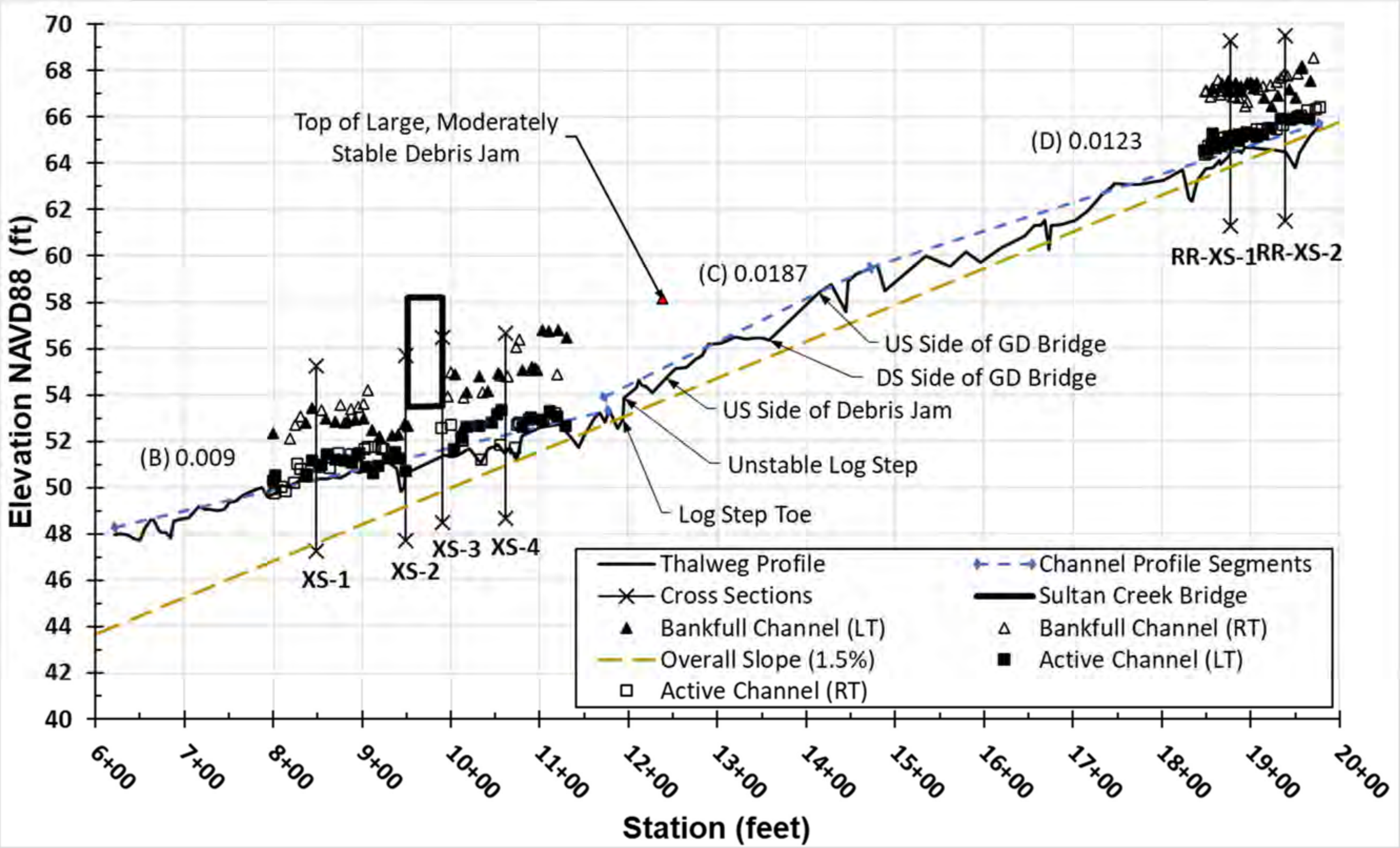


FIGURE 2-5. 2019 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

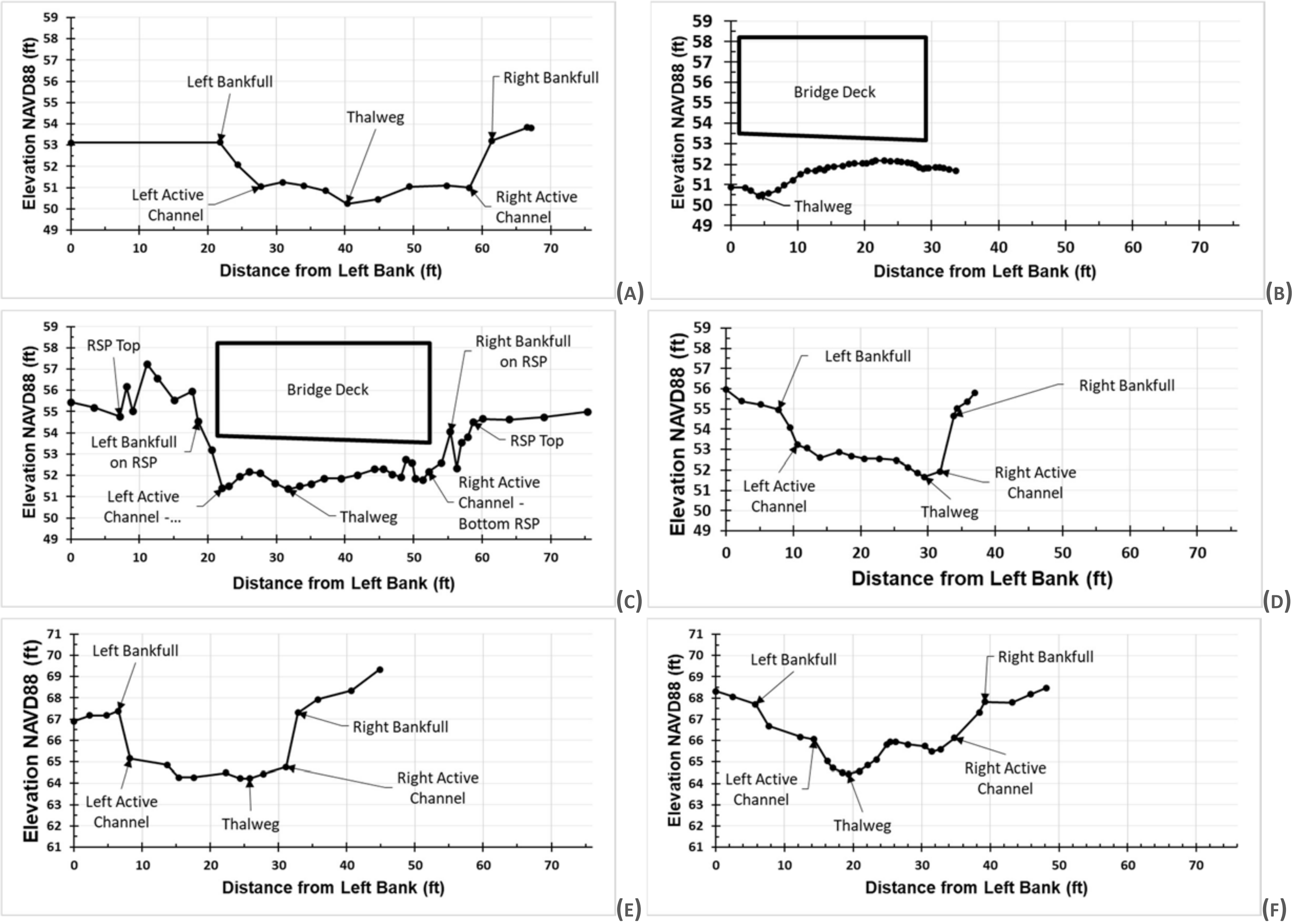


FIGURE 2-6. CROSS-SECTIONAL SURVEYS OF THE CHANNEL AT CROSS SECTION XS 1 (A) DOWNSTREAM OF THE BRIDGE, AT THE (B) DOWNSTREAM AND (C) UPSTREAM BRIDGE FACES, (D) UPSTREAM OF THE BRIDGE IN THE PROJECT REACH, AND (E AND F) IN THE UPSTREAM REFERENCE REACH.

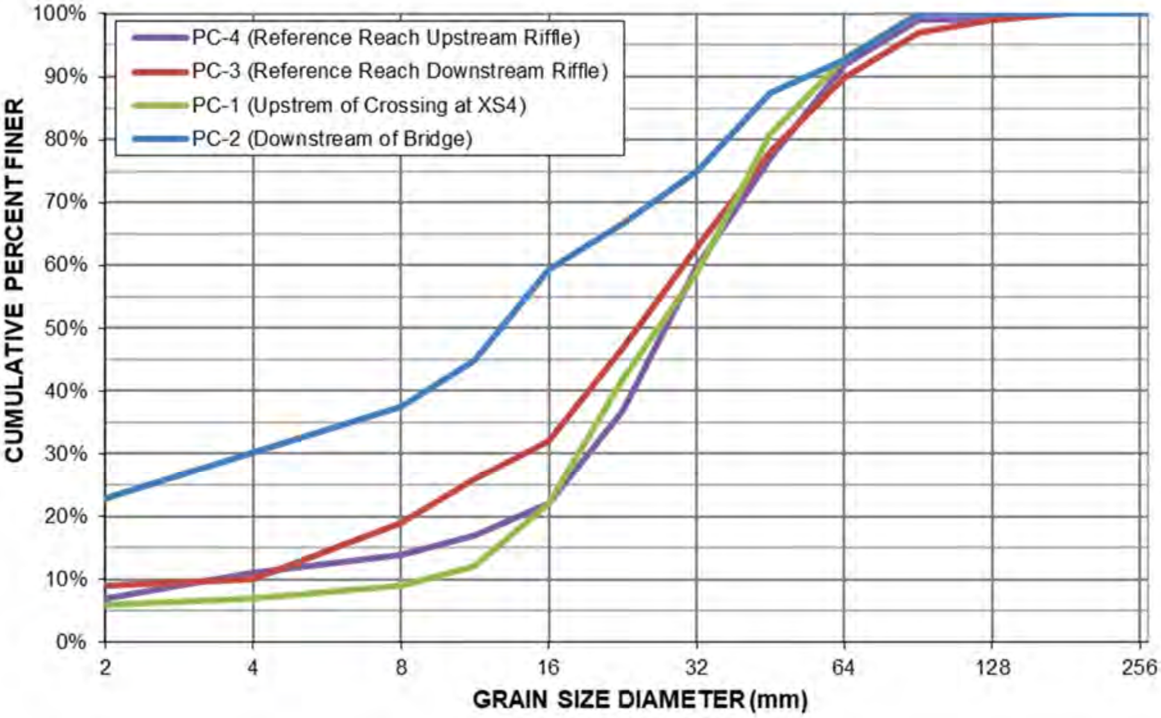


FIGURE 2-7. SURFACE STREAMBED GRADATION MEASURED USING PEBBLE COUNTS.

3 LITTLE MILL CREEK (DN197 – PM6.15)

3.1 Project Description

Little Mill Creek crosses under State Route 197 (North Bank Road) immediately upstream of its confluence with the lower Smith River. The stream drainage area is approximately 3.7 square miles. Prior to replacement, the SR197 Little Mill Creek crossing consisted of a 14-foot diameter structural steelplate pipe (SSP) culvert with a culvert inlet relief riser to provide emergency overflow protection in case the main inlet became plugged with debris. Prior to the SSP culvert (Figure 3-1a, b), the crossing consisted of a three-span bridge built in 1931 with piers located along the left and right sides of the active channel (Figure 3-1c).

3.1.1 DESIGN AND AS-BUILT CONDITIONS

The replacement crossing consists of a 90-foot clear span bridge set on shallow spread footings. Both footings are protected from scour with RSP placed at 1.5H:1V side slopes. The plans show the RSP extending to the elevation of the design thalweg. Constructed between the RSP slopes was a 3-feet deep by 29 feet wide “bankfull” channel with a small floodplain bench along both banks. The overall channel slope was designed to be 2.9%. A series of four boulder weirs were constructed within the project reach, each spaced 35 feet apart. Drops over the weirs were designed to range from 1.0 to 1.5 feet.

3.1.2 SITE OBSERVATIONS OF PROJECT REACH

During site visits by HSU on May 9, 2019 and November 11, 2019, existing channel and crossing conditions were evaluated and the channel was surveyed. The site visit followed several large flow events in Little Mill Creek and the adjacent Smith River. A large gravel bar had formed under the bridge along the right side of the channel (looking downstream) (Figure 3-2c-d). The surface of the bar was approximately 7 feet above the streambed and had a nearly vertical face. There were also large amounts of woody debris from Little Mill Creek racked in the trees downstream of the project. It was apparent that elevated river stages had backwatered the project reach, causing dynamic flow patterns and deposition of debris and sediment delivered from Little Mill Creek.

The constructed rock weirs were no longer present, and the channel bed appeared to have down-cut approximately 1 foot below its constructed grade. The streambed material in the project reach was native coarse cobble and gravel transported from upstream. Immediately upstream of the project reach, the channel bends to the right which causes flow to concentrate along the left bank under the bridge. The RSP along the left bridge abutment had been scoured and undermined, with the lower layers of rock missing (Figure 3-2e). With a portion of the RSP toe removed, the RSP slope appeared potentially unstable.

FIGURE 3-1. LITTLE MILL CREEK (A) ORIGINAL BRIDGE CROSSING PRIOR TO 1988, (B) 14-FT DIAMETER SSP CULVERT CROSSING INLET PRIOR TO CURRENT BRIDGE (1988 – 2016), (C) CULVERT CROSSING OUTLET PRIOR TO CURRENT BRIDGE (1988 – 2016).

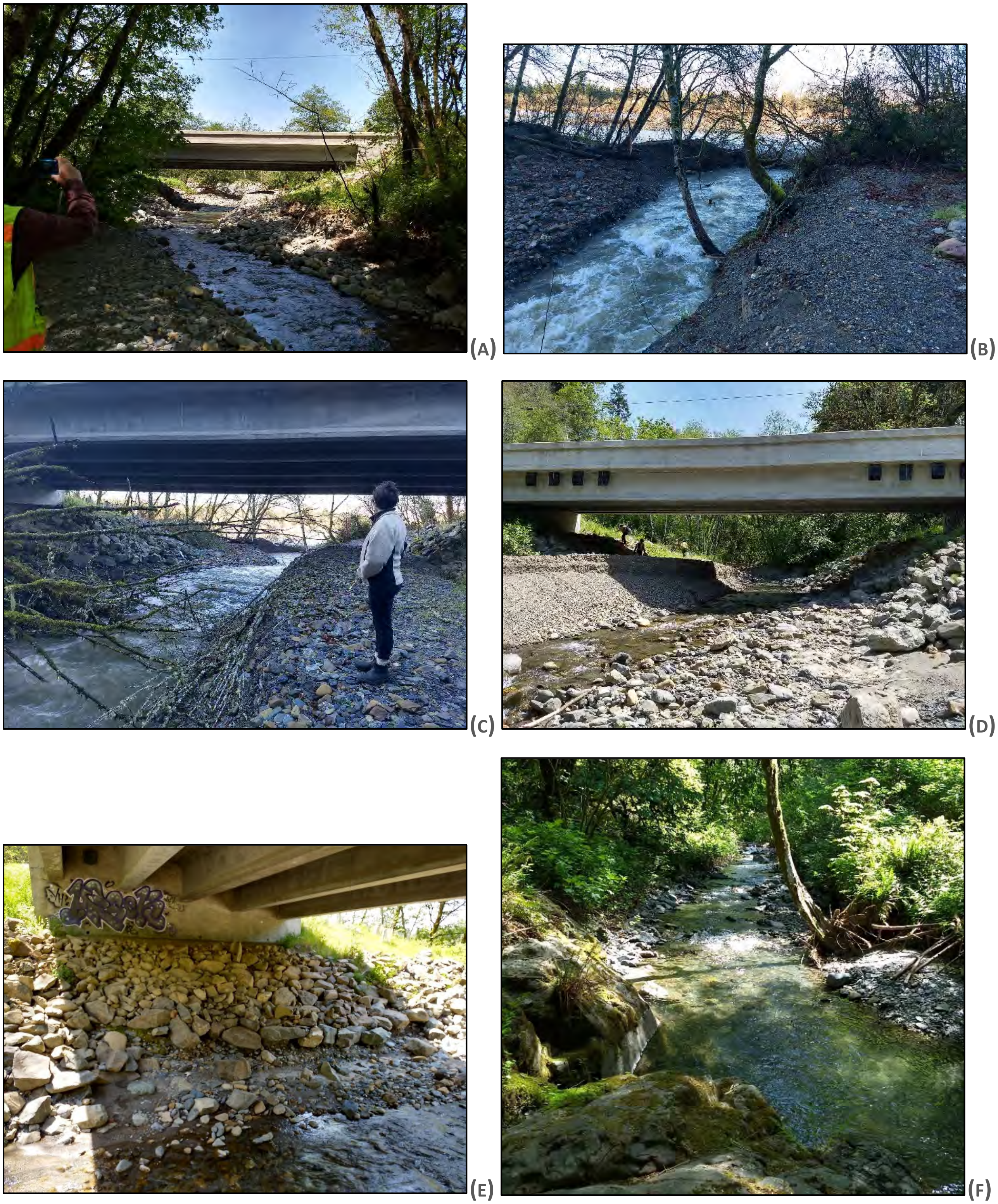


Figure 3-2. Little Mill Creek (a) bridge looking downstream, (b) steep channel section flowing into Smith River downstream of bridge, (c) bridge looking downstream (d) looking upstream at channel and depositional bar under bridge, (e) close up of scoured RSP toe under bridge, and (f) looking upstream at the reference reach.

3.1.3 SITE OBSERVATIONS OF REFERENCE REACH

Upstream of the project a tall and wide depositional terrace was noted that extended over three hundred feet upstream. This deposition was potentially caused by inlet plugging of the previous culvert crossing, or alternatively a result of a backwatering from a large river flood event. Several wood jams were noted and a natural channel reference reach was identified upstream of this depositional terrace.

The reference reach was approximately 150 feet in length and consisted of a relatively straight and predominately alluvial channel with some bedrock controls (Figure 3-2f). The reach was free of wood controls and had a well-defined actively scoured channel width dominated by coarse cobble.

3.2 Channel Morphology and Profile

The channel surveys extended from the river confluence to 650 feet upstream of the bridge, to Station 8+33 (Figure 3-3). A LiDAR DEM of the channel corridor was provided by Green Diamond Resource Company for use in extending the channel profile upstream beyond the limits of the site survey. Figure 3-4 shows a more detailed view of the project area, location of the reference reach, cross sections and pebble counts.

3.2.1 CHANNEL SLOPES

The combined survey and DEM channel profiles in Figure 3-5 shows an overall channel slope of approximately 2.2% beginning at the bridge crossing and extending upstream for 2,000 feet. Local slope segments are generally lower sloped, with steeper controls between them.

The crossing is located in the backwater of the downstream river during frequent high flows, resulting in a dynamic channel. Beginning at the bridge, the channel has a steep transition slope as it cascades into the river when not backwatered (Figure 3-2b and Figure 3-6). It appears that the slope of this transition reach fluctuates in response to the timing of high flows in Little Mill Creek relative to Smith River backwater conditions.

From the bridge, extending upstream, the channel slope is relatively uniform at an average slope of 2.7%. The reference reach, upstream of a log jam that is controlling the channel profile, has a much lower slope of 1.3%. Although the reference reach slope is approximately half of the project reach slope, this section of channel has similar morphology and dimensions.

3.2.2 CHANNEL WIDTH AND DEPTH

A total of four cross sections were surveyed in the project reach and two in the upstream reference reach, with their locations shown in Figure 3-6. The actively scoured bottom widths (active channel width) and bankfull channel widths were measured, and are noted on the cross sections (Figure 3-7) and summarized in Table 3-1.

TABLE 3-1. CHANNEL DIMENSIONS AND SLOPE BY REACH.

Location		Slope	Active Channel Width (ft)	Bankfull Width (ft)	Bankfull Depth from Thalweg (ft)
Project	Downstream of Bridge	3.6%	26.9	46.1	8.9
	Upstream of Bridge	2.7%	23.4	33.9	7.1
Upstream Reference Reach		1.3%	24.4	37.5	6.7

The right and left sides of the cross sections in the project reach were defined by the tall gravel depositional bar and the RSP slope, respectively. Comparing the channel cross sectional shape and dimensions of cross sections XS2 through XS4 from the project reach to those from the reference reach shows that the cross sections have relatively similar shape and dimensions. In general, the active channel (bottom) and bankfull widths in the project and reference reaches were approximately 25 feet and 35 feet, respectively.

3.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

The channel is highly entrenched, as seen in the surveyed cross-sections (Figure 3-7). The channel substrate throughout the surveyed reach is dominated by very coarse gravel and cobble, with boulders. The bed material generally appears mobile. The pebble count analysis shows that the deposit on the left bank beneath the bridge is smaller substrate than in the active channel and likely to mobilize and reform in response to high flow events (Figure 3-8). The channel contains long riffles between controlling large wood features. In some areas, small boulders have deposited to create small steps in the channel profile. Bedrock outcrops controlled the planform of the channel further upstream of the crossing.

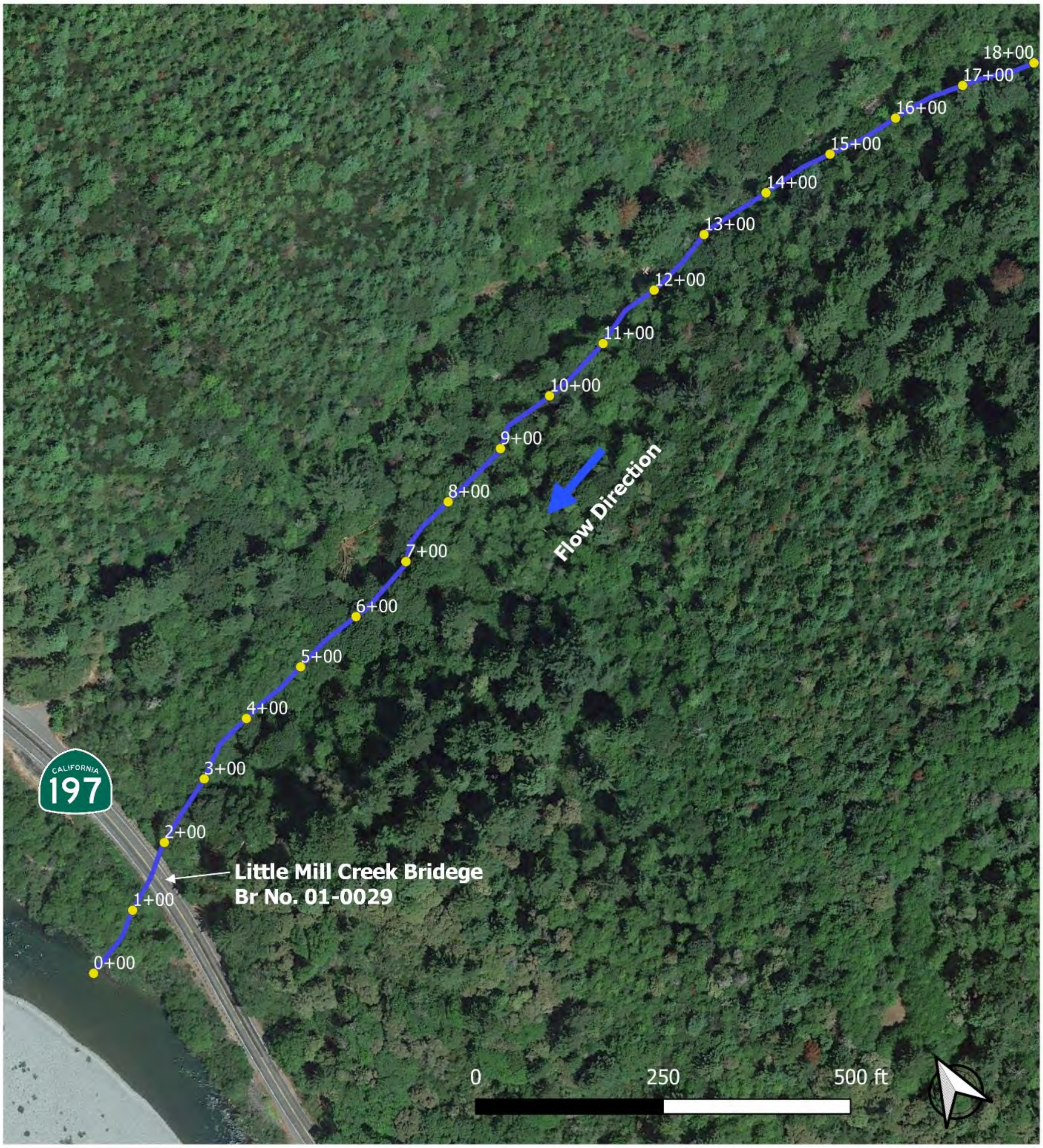
3.3 Discussion

The stream channel at the crossing location is in the Smith River’s backwater influence, and therefore is highly variable in terms of hydraulics and sediment transport/depositional patterns. The streambed at this location likely fluctuates vertically and laterally in response to high-flow interactions between Little Mill Creek and the river. The 90-foot clear-span bridge appears to provide the stream corridor sufficient width and open area to allow for these dynamic stream processes to occur.

The project included grade control in the form of four rock weirs. The reasons for including these weirs were not apparent in the design documents. The natural channel profile upstream of the project is at a similar grade as the project reach and is not controlled by “forcing features,” such as wood jams or boulder or bedrock steps. As such, the geomorphic or stream simulation channel design approach for this site would generally not include grade control, but rather allow the channel bed to adjust vertically. Loss of the four rock weirs also does not appear to have compromised fish passage through the crossing.

The overall channel design slope through the bridge opening was relatively close to the current slope of 2.7%. However, the channel design cross section was narrower than the channel widths measured in the reference reach and other locations upstream of the project. High flow events reshaped the constructed channel, widening the channel and eliminating all of the rock weirs. With this, the channel also adjusted vertically downward, undermining the shallow RSP toe along the left side of the channel.

Given the dynamic nature of the channel, allowing the stream to be vertically and laterally unconstrained between the two RSP embankments will allow for natural stream processes. An analysis of the channel’s longitudinal profile and natural vertical adjustment potential (VAP) through the project reach as part of the design process would have assisted in identifying the range of channel elevations that may occur over the service life of the bridge crossing and could have ensured that the RSP toe was placed below the low VAP elevation to avoid undermining and loss of RSP protection along these banks.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

Little Mill Creek

DN 197 PM 6.15

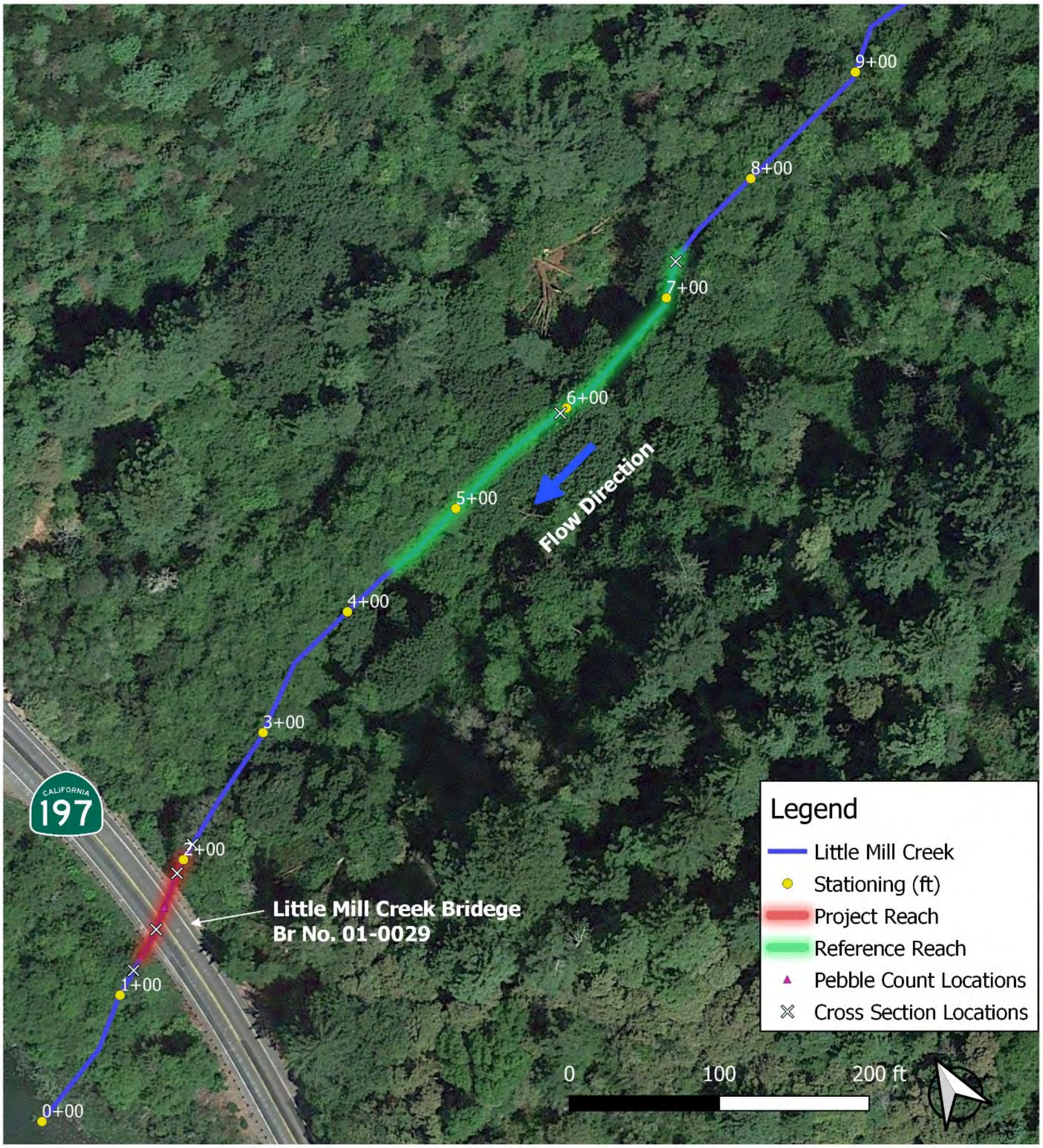
Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\3_Little_Mill_Creek(DN_197-PM6.15)\6_GIS\L_mill.qgz

FIGURE 3-3. OVERVIEW SITE MAP FOR LITTLE MILL CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING STARTING AT THE SMITH RIVER CONFLUENCE.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

Little Mill Creek

DN 197 PM 6.15

Site Map and Channel Stationing
Project Area

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\3_Little_Mill_Creek(DN_197-PM6.15)\6_GIS\L_mill.qgz

FIGURE 3-4. PROJECT AREA MAP FOR LITTLE MILL CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION AND PEBBLE COUNT LOCATIONS.

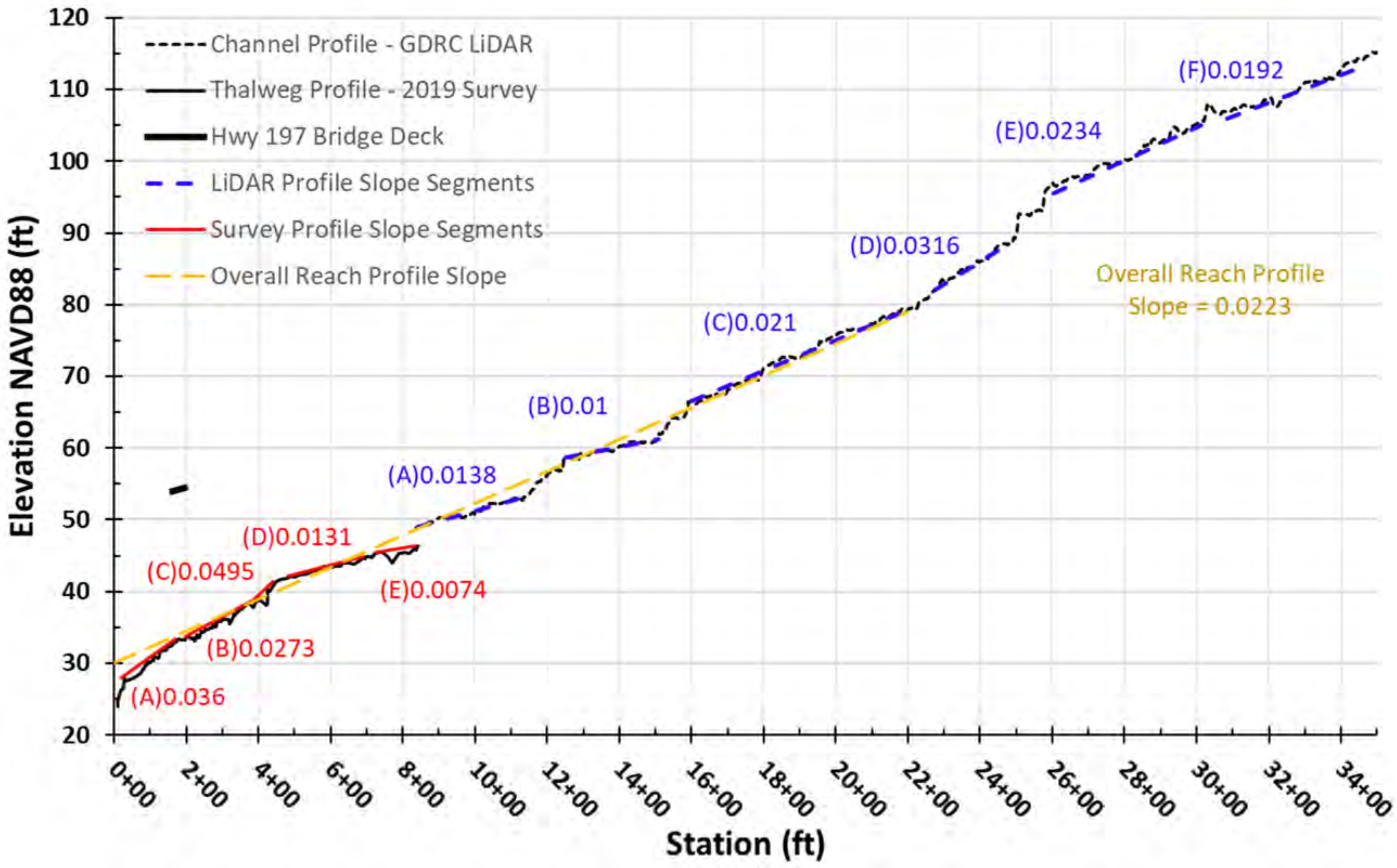


FIGURE 3-5. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED.

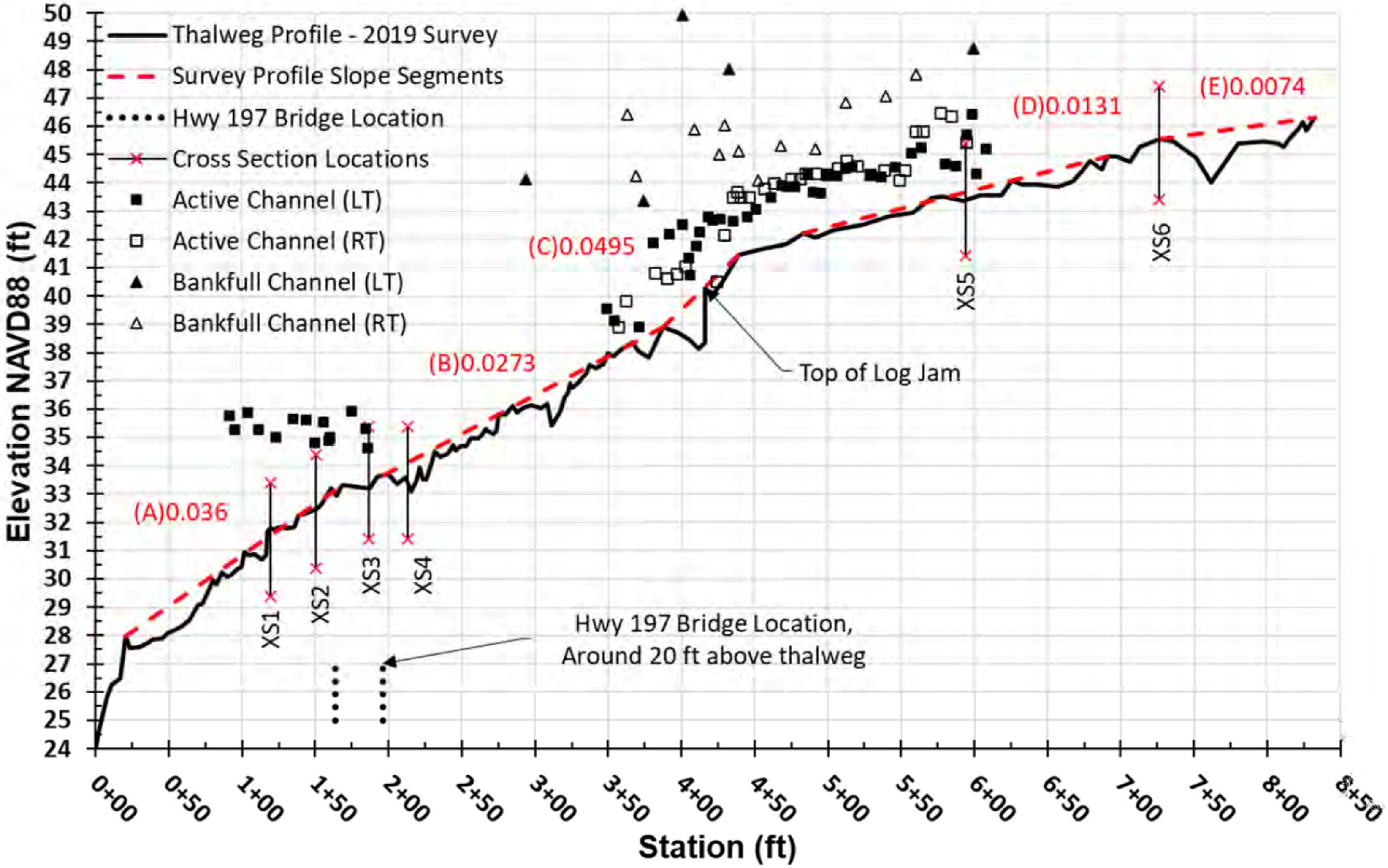
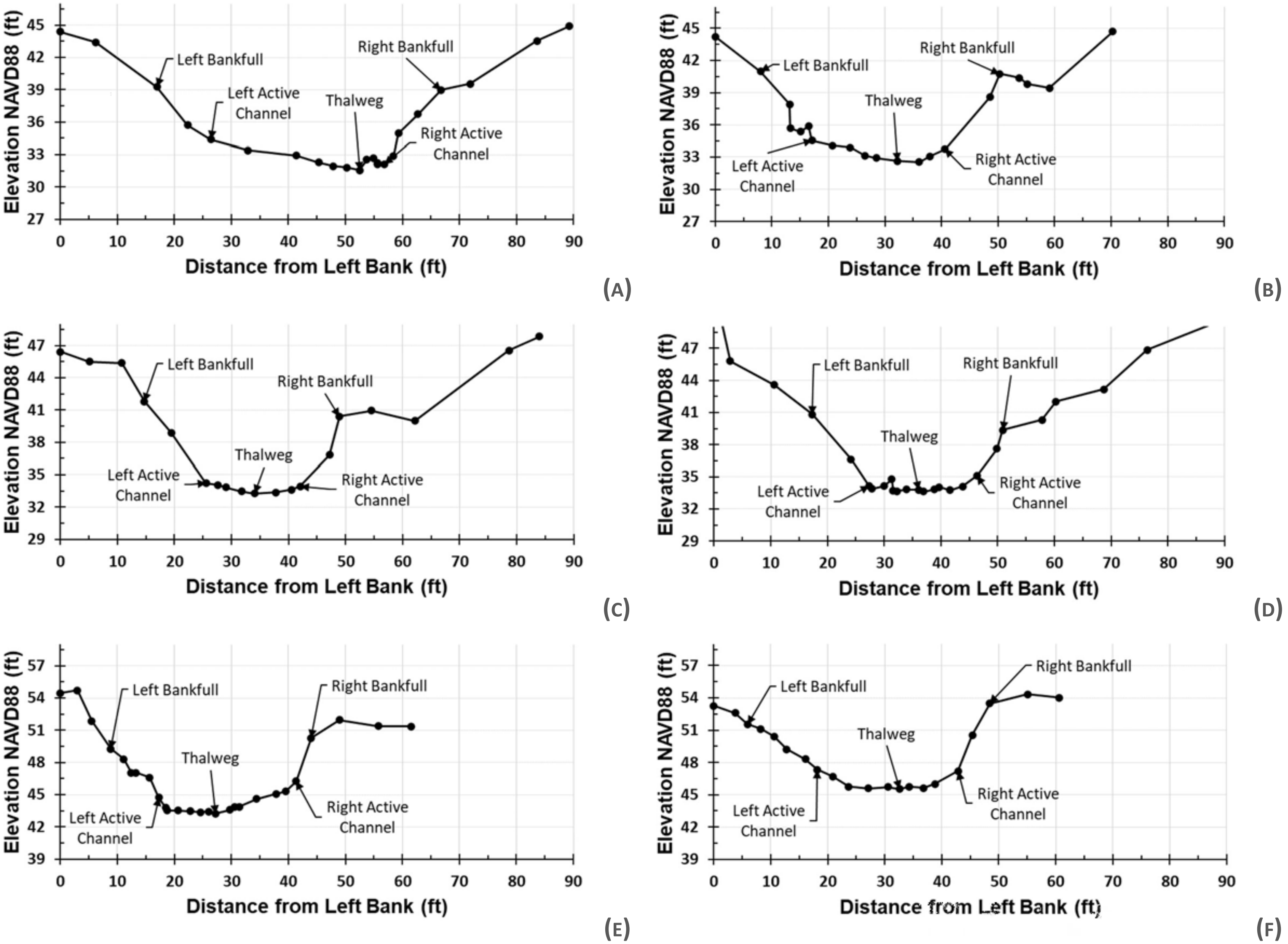


FIGURE 3-6. 2019 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.



(A) (B) (C) (D) (E) (F)

FIGURE 3-7. CROSS-SECTIONAL SURVEYS OF THE CHANNEL AT CROSS SECTIONS (XS) 1 (A) THROUGH 6 (F). XS 1 THROUGH XS 4 (A-D) ARE WITHIN THE PROJECT REACH AND XS 5 (E) AND XS 6 (F) ARE FROM THE UPSTREAM REFERENCE REACH.

FIGURE 3-8. SURFACE STREAMBED GRADATION MEASURED BY PEBBLE COUNT AT LITTLE MILL CREEK.

4 HALL CREEK (HUM 299 – PM 4.20)

4.1 Project Description

Hall Creek crosses under the State Route 299 bridge at post mile 4.20 in Humboldt County near Blue Lake, California. The crossing is just upstream of the confluence of Hall Creek with the Mad River; thus, the entire drainage area of Hall Creek and its tributaries, approximately 4 square miles, is upstream of this crossing. Built in 1965, the bridge crossing fully spans the stream channel but had an RSP apron between the abutments for scour countermeasures under the bridge (Figure 4-1 top). The RSP apron created an elevation difference of approximately 7 feet over 1-ton RSP, and steep drop from Hall Creek to the Mad River confluence. Removal of this fish passage barrier and construction of a channel-spanning pool and weir style fishway was completed in 2013 as mitigation for the Mad River bridge replacement on US 101 (Figure 4-1 bottom).

4.1.1 DESIGN AND AS-BUILT CONDITIONS

The Hall Creek as-built plans describe the concrete fishway as 108-foot long with a 15-foot interior width and 12 weirs. The two downstream-most weirs were added the year after initial construction due to an excessive drop at the fishway entrance (downstream end) (Figure 4-2). The weir crests were designed to have an 8-inch drop between adjacent weirs and the overall elevation drop from the most upstream to downstream weir crest is 7.4 feet. The weirs are skewed 45 degrees to the flow, creating a V-shape. The resulting crest length is approximately 29 ft and slope down at a 4H:1V slope from the fishway wall to their center apex. The top elevation of the fishway wall and the weir crests are coincident at the weirs' outer edges; thus, there is no freeboard available at flows that fully submerge the weirs. HEC-RAS 1D analysis summarized in Appendix E of the Hall Creek Mad River Fish Passage Mitigation Report (Hurlburt, 2013) shows that for simulated flows of 55 cfs and greater the flow width exceeds the 15-foot fishway width. Fifty-five cfs is the resident salmonid high fish passage flow and $Q_{2\text{-year}}$ is reported as 374 cfs. Along both sides of the fishway, the banks are constructed primarily of 1-ton RSP reused from the previous outlet conditions. Live willow and cottonwood cuttings were installed into the RSP.

As surveyed, the fishway geometry conforms to the as-built plans with an overall slope of 7.4 percent slope. The average drop height between the 12 weirs is 8.0 inches (range 6.7 – 8.8 inches) and spacing between the weir apexes is 9 feet. The pools between the weirs have a residual depth of 4 feet and there was little accumulated sediment in the fishway pools.

4.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in June 2020 for preliminary assessment and completed a site survey on July 12, 2020. Photos taken during the field site visits are provided in Figure 4-3. During the preliminary assessment visit, Hall Creek was well connected to a side channel of the Mad River (Figure 4-3e) but this pool's outlet riffle was close to drying up and disconnecting from the Mad

River. The Mad River confluence pool was stagnant and completely disconnected during the July 2020 field survey. Hall Creek and the fishway had continuous low flows during the July survey that terminated in the confluence pool.

4.1.3 SITE OBSERVATIONS OF CHANNEL

Upstream of the fishway Hall Creek and its tributaries, Noisy and Mill creeks, flow through agricultural and forested lands with habitat quality varying from good to severely degraded by livestock. Stream gradients are low across the Mad River valley and Caltrans estimated the upstream habitat at approximately four channel miles. A county road crossing 0.5 miles upstream at Glendale Road is passable.

The Hall Creek confluence with a side channel of the Mad River is approximately 100 feet downstream of the fishway. The confluence does not remain connected through the dry season because the side channel dries out and becomes discontinuous shallow pools.

4.2 Channel Morphology and Profile

4.2.1 CHANNEL SLOPES

Upstream of the site, the channel is low gradient extending across the Mad River valley to the first road crossing at Glendale Road (Figure 4-4). Figure 4-5 shows a more detailed plan map with the surveyed longitudinal profile extent and cross section locations. The surveyed fishway slope matches the as-built plans at 7.4 percent (Figure 4-6). A LiDAR coverage was not available to develop an extended channel profile upstream of the fishway and SR 299 bridge.

4.2.2 CHANNEL WIDTH AND DEPTH

Channel and fishway cross sections were surveyed (Figure 4-7) and measurements of channel width were made upstream of the fishway (Table 4-1). The channel upstream of the bridge and fishway is slightly narrower than the more exposed, armored channel under the bridge (Figure 4-3a).

4.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

The surface substrate sizes were not measured at this site because the channel beneath the bridge upstream of the fishway is armored with non-native rock, much of which has been grouted in place. The natural channel substrate upstream of the bridge is a mix of fine sediment deposited over medium gravel.

TABLE 4-1. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Under SR299 bridge just upstream of fishway	15	22
In channel upstream of bridge	12.5	19.5

4.3 Discussion

The fishway conditions match the design and appears to be functioning as intended to provide passage. The fishway interior width matches the active channel width. Thus, the active channel filling flow likely corresponds to the flow that just fully submerge the weirs which is consistent with the HEC-RAS analysis of the fishway summarized above (Section 4.1.1). As noted, the fishway side wall elevations are coincident with the weir heights so higher flows are not contained within the fishway. The adult high fish passage flow was reported as 133 cfs and the top width of flow in the fishway was predicted by HEC-RAS as 20 to 23 feet. Under these conditions, the fishway could act as a passage corridor through a wider flow channel but fish passage under these conditions should be confirmed. Additionally, there is some concern of stranding of fish on the RSP outside of the fishway at these flows. Typical fishway design criteria include containing the fish passage flows within the fishway and providing a minimum of 2 feet of freeboard to prevent fish from leaping out of the fishway.

During the design process for fishways and other types of grade control it is important to evaluate the stability of the downstream tie-in elevation. The Mad River main channel in this reach is unconfined and experiences frequent lateral migration as revealed when reviewing historical photos. For example, in 2003 the main river channel was directly adjacent to the SR 299 Hall Creek bridge, and the next year it was more than 400 feet away from the bridge. These shifts in the main channel will change the tie-in elevation at the downstream end of the fishway. This must be considered during the design process through review of historical aerial photographs and geomorphic interpretation to establish the lowest fishway tie-in elevation that may occur. This may have been the reasons additional weirs had to be added to the downstream end of this fishway a year after initial construction.

Before: Photo of downstream end of the RSP barrier looking upstream (top left) and photo of downstream end of the project near the mouth of Hall Creek, looking upstream (top right). Photos courtesy of the California Department of Transportation.

After: Photo of resident engineer Glenn Hurlburt and JoAnn Dunn, CDFW, observing juveniles migrating up the fishway, October 2012 (top left) and photo looking upstream towards left bank from downstream of fishway. Photos courtesy of the California Department of Transportation.

FIGURE 4-1. HALL CREEK PRE- AND POST-CONSTRUCTION OF THE FISH LADDER. PHOTOS PROVIDED BY M. MOLINAR, CALTRANS.

FIGURE 4-2. DOWNSTREAM FISHWAY EXTENSION UNDER CONSTRUCTION IN AUGUST, 2013.

Figure 4-3. Hall Creek (A) upstream channel looking upstream at the transition from the armored to natural channel, (B) looking downstream at the fishway (C) looking upstream at the fishway entrance (D) looking upstream from weir 11, (E) confluence of Hall Ck and the Mad River side channel on June 9, 2020, and (F) looking downstream along fishway and armored banks. Photos taken June 2020 by M. Love and M. Lang.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

Hall Creek Bridge

HUM 299 PM 4.20

Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\4_Hall_Creek(HUM_299-PM4.20\6_GIS\hall.qgz

FIGURE 4-4. OVERVIEW SITE MAP FOR HALL CREEK SHOWING CHANNEL ALIGNMENT AND TRIBUTARIES.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

Hall Creek Bridge
HUM 299 PM 4.20

Site Map and Channel Stationing
Project Area

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\4_Hall_Creek(HUM_299-PM4.20\6_GIS\hall.qgz

FIGURE 4-5. PROJECT AREA MAP FOR HALL CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION LOCATIONS.

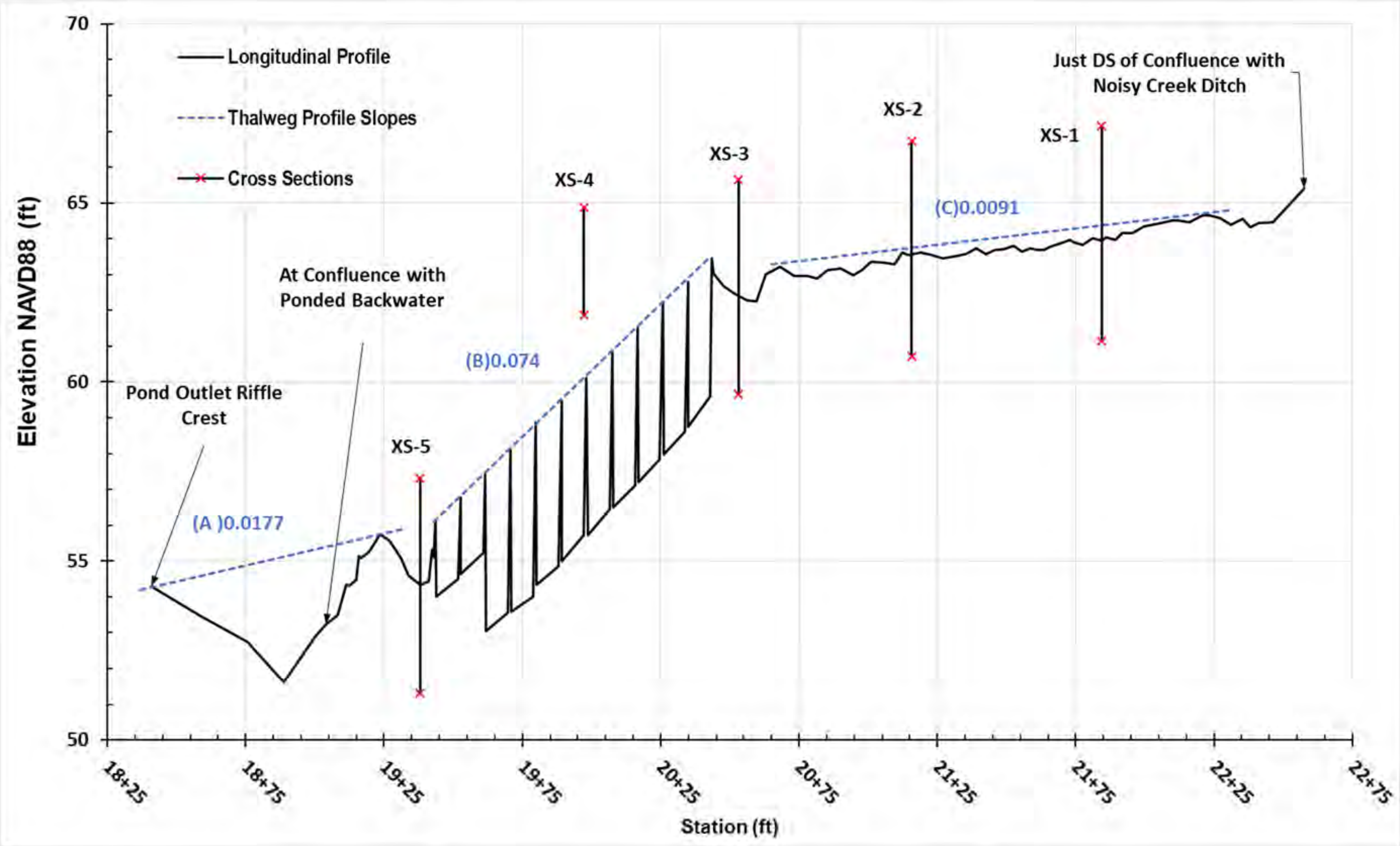


FIGURE 4-6. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED. DOTTED LINES ARE EXTRAPOLATION OF THE CHANNEL PROFILE SEGMENT.

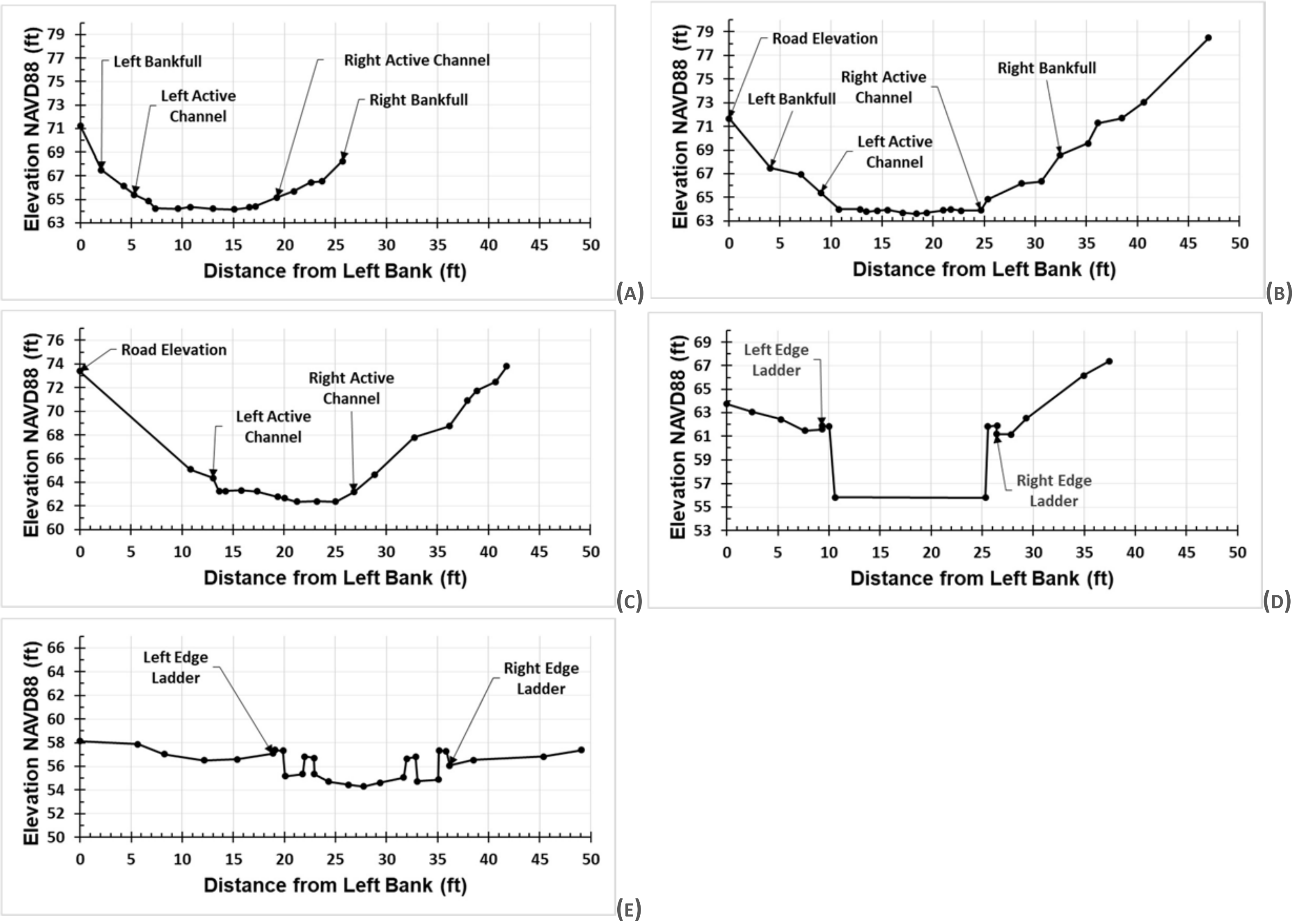


FIGURE 4-7. CROSS-SECTIONAL SURVEYS OF THE CHANNEL (A) UPSTREAM OF THE BRIDGE, (B) UNDER THE BRIDGE, (C) JUST UPSTREAM OF THE FISHWAY UNDER THE BRIDGE, (D) WITHIN A FISHWAY POOL, AND (E) AT THE DOWNSTREAM END OF THE FISHWAY.

5 DUNN CREEK (MEN 1 – PM92.8)

5.1 Project Description

5.1.1 DESIGN AND AS-BUILT CONDITIONS

The Dunn Creek crossing on State Route 1 in Mendocino County was replaced in 2013. Prior to the replacement, the crossing consisted of a 9-foot diameter, 87-foot long culvert with baffles and a series of downstream weirs formed with gabion baskets that had partially failed. Likely due to channel incision downstream of the original culvert, there was approximately 12 feet of drop from the culvert inlet to the downstream channel bed. The crossing was considered a migration barrier to salmon and steelhead.

The culvert was replaced with a full-span bridge crossing and a series of 11 boulder weirs were installed to control grade through the project reach (Figure 5-1c). The bridge was placed downstream of the original culvert crossing and the channel was realigned to the right of the culvert crossing. In some locations the new channel alignment was placed through existing road fill. The weirs started immediately downstream of the bridge and extended upstream for 211 feet, tying into the channel upstream of the original culvert.

The weirs were designed with drops from weir to weir of 0.97 feet. The weir cross-slope was designed at 5H:1V to concentrate flow towards the center of the channel. During construction changes to the channel design included increasing the number of 1-ton and 2-ton rocks used to build the weirs and adding rock along the banks of the channel to reduce potential for bank scour and flanking of the weirs.

There was concern regarding the elevation of the downstream most weir not meeting the existing channel bed elevation, thus creating an excessive drop over the downstream weir. Additionally, the elevation of the downstream-most weir was based on a log that had fallen into the channel during the project design phase (Figure 5-2). During construction, recommendations were made to add at least one more weir, and up to three, to the downstream end of the project to avoid an excess drop if the downstream log shifted. Due to right-of-way constraints and because the project was already in construction, no additional weirs were constructed. However, the elevation over the downstream most weir was lowered by 0.3 feet by increasing the drop across all the weirs to 1.0 feet.

5.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in July 2019 and surveyed the site in October 2020. Alder trees had revegetated much of the project reach, except under the bridge (Figure 5-1d). The channel spanning log that controlled the channel bed elevation at the downstream end of the project (Figure 5-2) had shifted and the channel bed appeared to have incised immediately upstream of its location as a result. The downstream most boulder weir had failed, likely due to the increased drop following shifting of the downstream log control, thus creating a drop of greater than 2.5 feet over the second weir at low flows (Figure 5-1f). Boulders from the failed weir were pushed downstream. Remanent roots/wood buried in the channel near the failed weir location appeared to help maintain the local channel bed elevation and prevent a larger drop from forming over the second weir. However, the footer rocks of the second weir were undermined and this weir looked at risk of failing.

The channel and weir widths under the bridge appeared much wider than the weirs further upstream, and over-widened compare to channel reaches outside the project area. Weirs upstream of the bridge looked stable and provided a diversity of flow paths over their crests at low flow. However, some of the pools between weirs were scoured deep enough to expose the bottom of the upstream weir's footer rocks, raising concerns regarding long-term stability of these weirs (Figure 5-1e). Based on field notes during construction, these locations of excess scour appear to correspond to locations where the channel had been realigned and the parent material in the constructed channel was road fill.

The upstream most weir appears to be maintaining the upstream channel elevation and preventing any headcutting/incisions from the project (Figure 5-1a and b).

5.1.3 SITE OBSERVATIONS OF REFERENCE REACH

Immediately upstream of the project the stream flows through a mature second-growth redwood forest with a low floodplain (Figure 5-1a). There are decaying simple wood structures with cable anchoring from previous restoration efforts within this reach. Further upstream the valley gets confined and there are numerous debris jams and small landslides/bank failures that are inputting a substantial amount of angular bed material to the channel. This reach looks relatively unstable. Upstream of this location, the channel slope decreases and the channel appears geomorphically stable.

Downstream of the crossing, the channel is highly entrenched. There is some slash in the channel and a slide further downstream that has caused local aggradation. It is not clear if this channel reach is still actively incising.

Figure 5-1. Dunn Creek (A) upstream reference reach, (B) two upstream-most weirs, (C) overall project shortly after construction, (D) Typical weir upstream of bridge, (E) excess pool scour below U-shaped weir, and (F) excessive drop over weir 2 after downstream-most weir failure.

FIGURE 5-2. THE DESIGN ELEVATION AND DROP OVER THE DOWNSTREAM WEIR WAS BASED ON THE DOWNSTREAM CHANNEL BED ELEVATION CONTROLLED BY RECENTLY FALLEN LOG WITHIN THE CHANNEL BED, WHICH SUBSEQUENTLY SHIFTED, CAUSING THE BED TO DROP AND THE BOULDER WEIR TO FAIL.

5.2 Channel Morphology and Profile

5.2.1 CHANNEL SLOPES

Figure 5-3 and Figure 5-4 show the channel alignment and more detailed plan map of the project extent and locations of cross sections and pebble count, respectively. The DEM from the 2018 USGS LiDAR was used to generate a profile extending beyond the length of the HSU 2020 survey (Figure 5-5). The project reach appears to be at a slope transition, with the channel downstream of the project at a slope of 2.68% and upstream at 4.84%. This steep upstream reach was noted as geomorphically unstable. Further upstream, the channel slope relaxes to 2.34%, and appeared geomorphically stable. A projection of the upstream and downstream slopes has them intersecting approximately 50 feet upstream of the project.

Within the project reach, the constructed channel slope is controlled by the rock weirs (Figure 5-6. The overall slope formed by the weir crests varies from 4.18% to 4.76%, with drops over the weirs varying from 0.47 feet to 1.53 feet (excluding the 2.5-foot drop over the downstream-most weir). Spacing between weirs averaged 20.1 feet, ranging between 12.3 feet and 29.7 feet. The weirs with the largest drops had the longest receiving pool lengths.

5.2.2 CHANNEL WIDTH AND DEPTH

Channel cross sections were surveyed (Figure 5-7) and measurements of channel width were taken with a tape. The overall width of the constructed channel was wider than the measured channel dimensions upstream and downstream of the project (Table 5-1). Constructed channel widths were substantially wider under and near the bridge crossing than further upstream.

Table 5-1. Channel dimensions and slope by reach.

Location		Slope	Active Channel Width (ft)	Bankfull Width (ft)
Project	Downstream of Weir 2	0.0172	9.1-16.6	29.5-32.7
	Weir 9	0.0418	18.9	32.7
Upstream of Project		**0.0186**	**9.9 – 12.0**	**11.0 – 13.2**
Downstream of Project		**0.0144**	**10.4 – 11.4**	**12.5 -19.9**

5.2.3 Streambed Morphology and Substrate

A pebble count of the surface substrate was taken in the reference reach channel and the gradation plotted in Figure 5-8. The median particle size is classified as a coarse gravel, and the 84 percentile (D84) is very coarse gravel. Deposition in the tailouts upstream of each weir appeared to be similarly sized gravel material.

5.3 Discussion

5.3.1 Project Design and Constructed Profile and Grade Control

The project has successfully prevented upstream channel incision. However, there are a number of lessons learned from the project concerning both design and construction.

The project design was constrained in length to minimize environmental impacts and due to Right of Way. As a result, the design did not account for some influences on downstream channel adjustments, including (1) the elevation controls for the channel bed downstream of the anticipated scour pool below Weir 1 and its impact on the drop over this weir, (2) the overall long-term stability of the downstream log within the channel that was controlling the grade downstream of Weir 1, and (3) the potential for the channel downstream of the log to continue to incise. Accounting for all three of these types of channel adjustments would have likely led to installing an additional 3 weirs (1 foot drop each) to the downstream end of the project or to design solutions other than rock weirs.

The project relied on 11 boulder weirs to maintain the upstream channel grade for the service life of the bridge crossing, which is likely 70+ years. However, boulder weirs are highly susceptible to cascade failures; if one weir fails all of the upstream weirs are at a high risk of failure. Design of in-channel incision control structures could better match the bridge lifespan.

The means of failure for Weir 1 was scour and undermining of the footer rocks that serve as the foundation for the weir. Deep scour pools that exposed the bottom of the footer rocks were observed at two other upstream weirs, currently placing them at risk of failure. Some of these deep scour pools appear to coincide with where the channel was realigned into exposed fine-grain fill material rather than native streambed material. The best means for reducing risk of undermining from scour involves armoring the pool bottoms with larger rock, similar to a natural step-pool type channel. This follows the roughened channel design approach Additionally, the scour potential can be reduced by (1) reducing the drop heights over the weirs to less than 1 foot, (2) changing the shape of the weirs in plan and section to reduce concentration of flow towards to channel center, or (3) increasing the spacing of the weirs to ensure the flow's energy is dissipated in the pool before spilling over the next downstream weir.

The design drop height over the weirs was 1.0 foot. Although there was considerable oversight during building of the 11 weirs, they were still constructed with highly variable drop heights ranging from 0.47 feet to 1.53 ft. This attests to the challenges associated with constructing boulder weirs to match design grade when using large rock. This variability can be mitigated by designing drop heights to be less than the maximum allowed (1-foot) for fish passage, and including a vertical tolerance that ensures drop heights stay within criteria.

A repair is needed to prevent Weir 2 from failing and to restore the intended fish passage conditions. However, the project did not leave any practical means for accessing the channel with heavy equipment to make such repairs. When building projects that involve channel grade control, maintenance access should be included, as the service life of the grade control should match that of the crossing structure.

5.3.2 CHANNEL WIDTHS AND STRUCTURE WIDTH

The width of the channel, and especially the weirs under and adjacent to the bridge, were substantially wider than the reference reach channel. This channel widening may help reduce the flow's energy given the increased slope of the project channel compared to the natural channel. However, at low flows these wide channels, and especially the weir crests, can cause water depths shallower than found in the adjacent natural channel, thus potentially restricting fish movement.

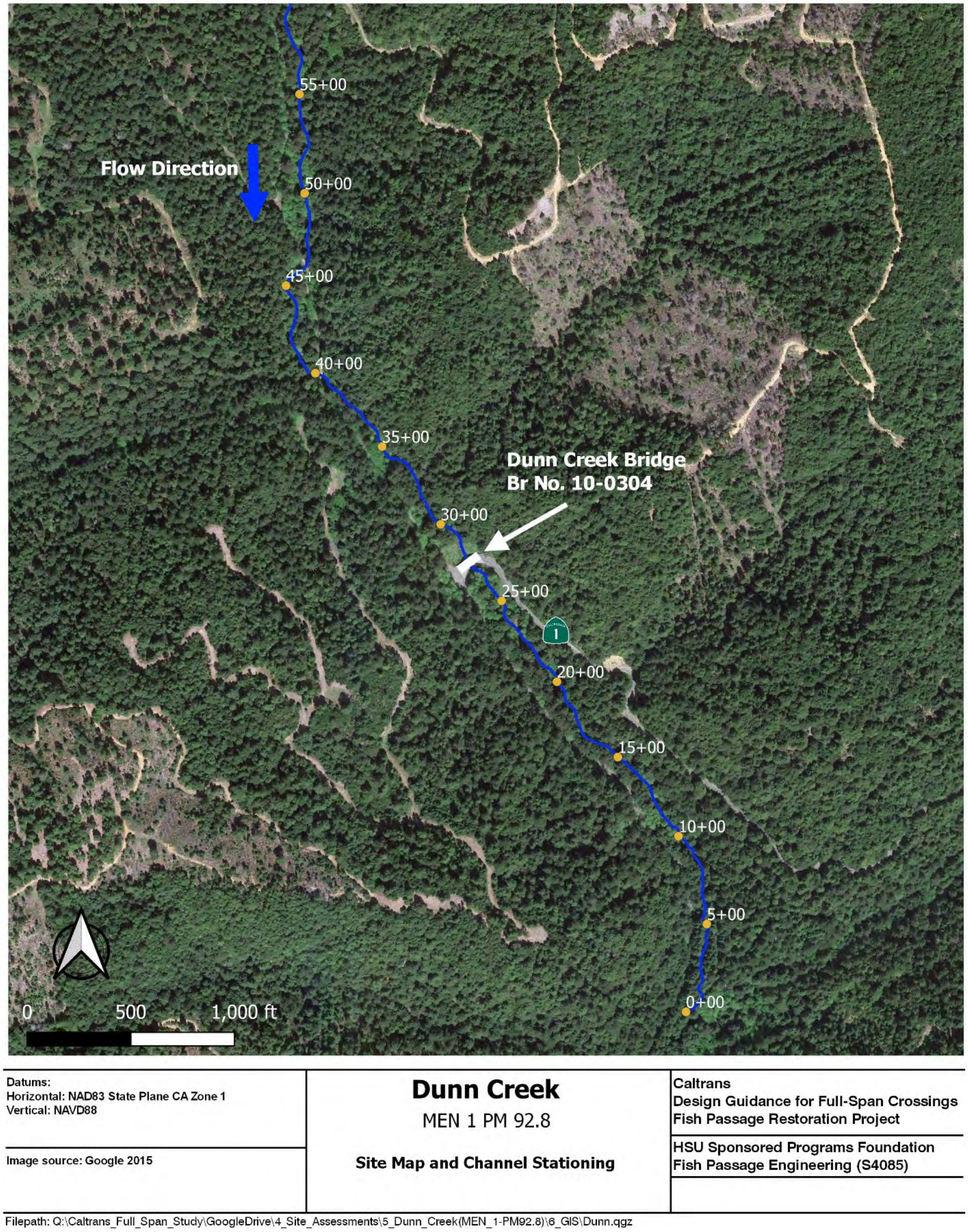
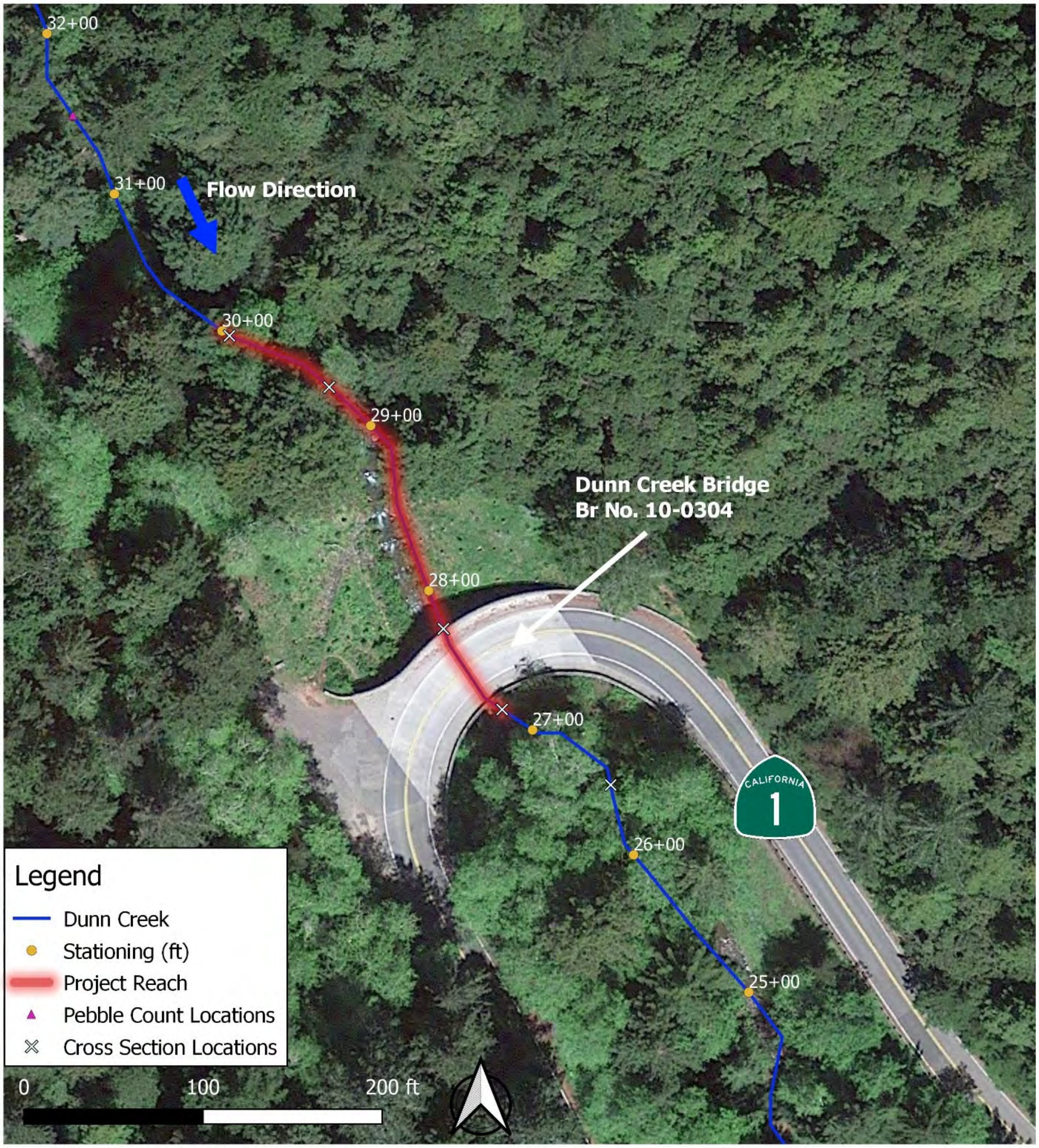


FIGURE 5-3. OVERVIEW SITE MAP FOR DUNN CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image source: Google 2015

Dunn Creek

MEN 1 PM 92.8

Site Map and Channel Stationing
Project Area

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\5_Dunn_Creek(MEN_1-PM92.8)\6_GIS\Dunn.qgz

FIGURE 5-4. PROJECT AREA MAP FOR DUNN CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION AND PEBBLE COUNT LOCATION.

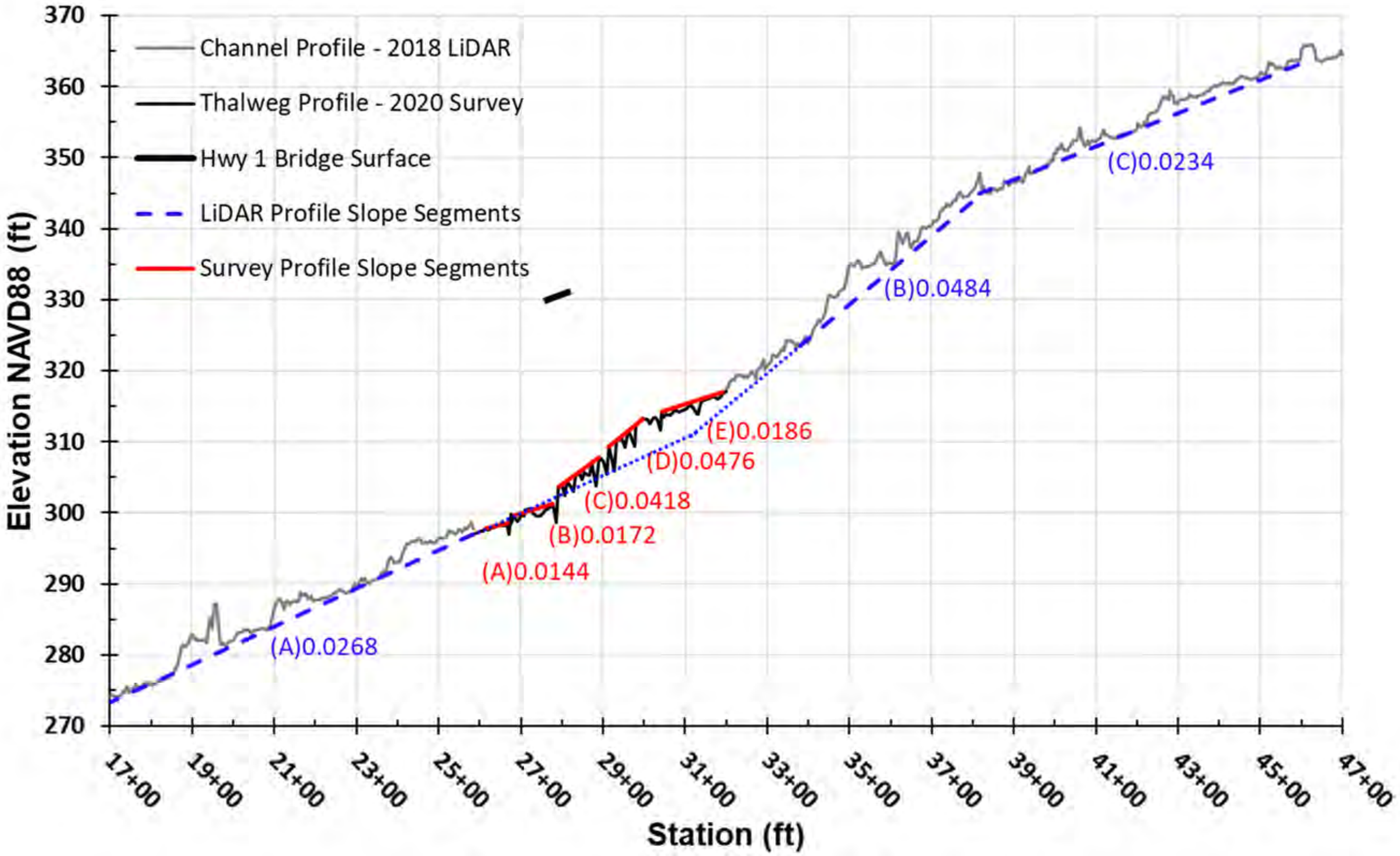


FIGURE 5-5. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED. DOTTED LINES ARE EXTRAPOLATION OF THE CHANNEL PROFILE SEGMENT.

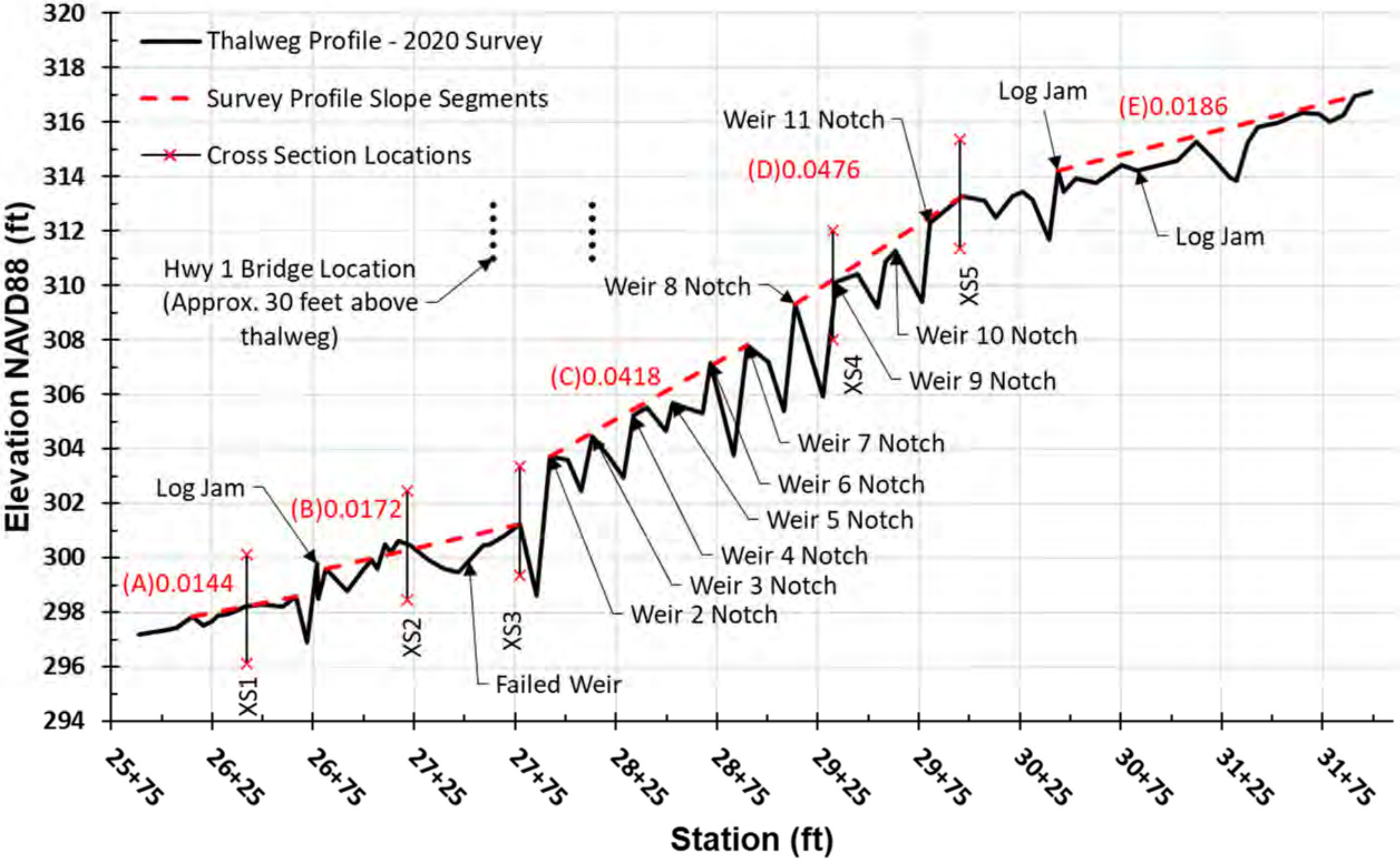


FIGURE 5-6. 2020 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS AND THE OVERALL PROFILE (AS DEFINED BY THE LIDAR DEM) PLOTTED. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

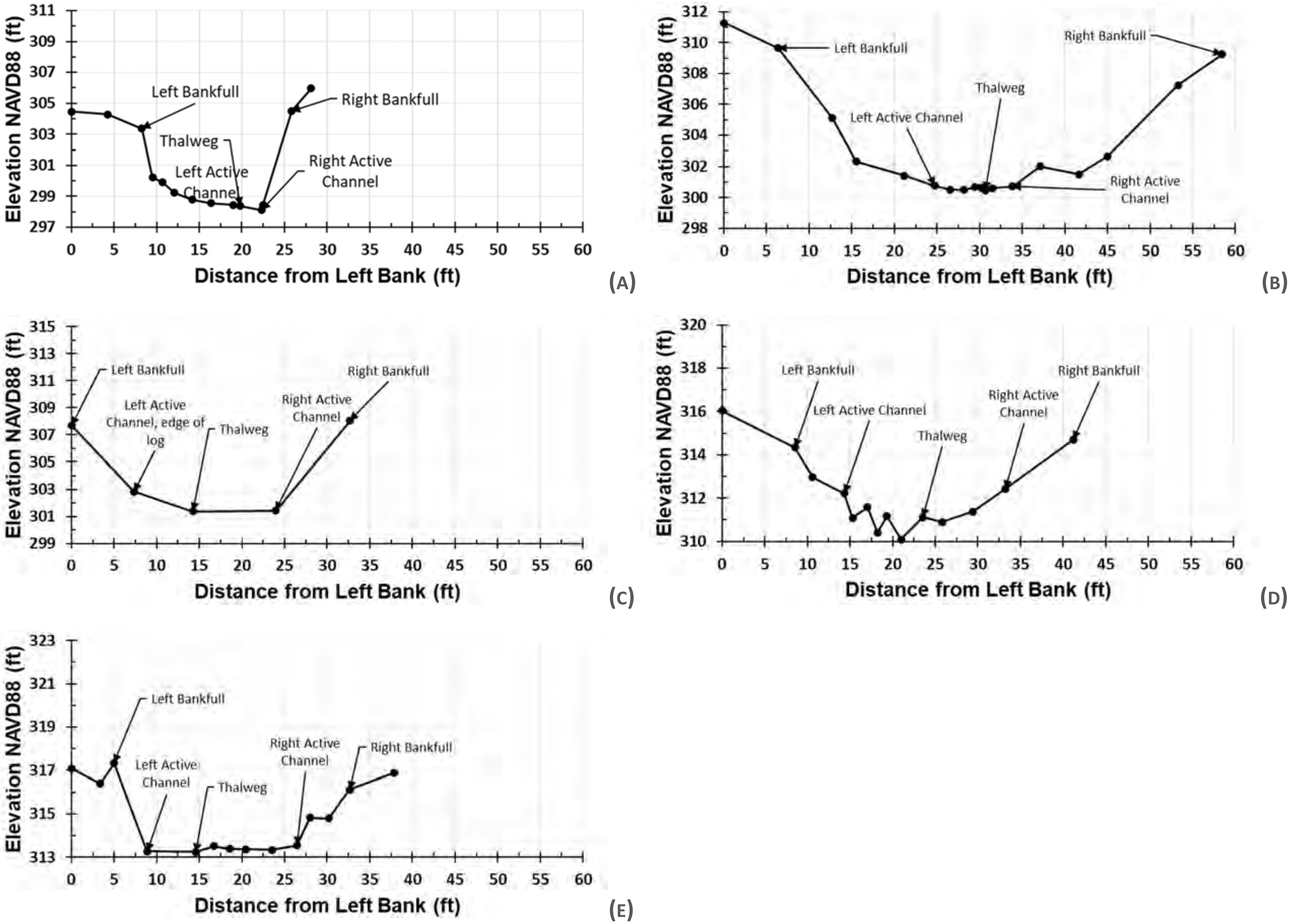


FIGURE 5-7. CROSS-SECTIONAL SURVEYS OF THE CHANNEL AT CROSS SECTIONS (XS) 1 (A) THROUGH 5 (E).

FIGURE 5-8. GRADATION OF STREAMBED MATERIAL OBTAINED FROM A SURFACE PEBBLE COUNT IN THE UPSTREAM REFERENCE REACH.

6 UPP CREEK (MEN 101 – PM48.18)

6.1 Project Description

6.1.1 Design and As-Built Conditions

The Upp Creek crossing on the original section of US 101 (now a frontage road), immediately north of Willits, California in Mendocino County was replaced in 2017 (Figure 6-1). Prior to replacement, the crossing consisted of a 71-foot long double bay box culvert (Figure 6-1), with each bay being 10-feet wide by 5-feet tall. The culvert had a slope of 4.4% and a water surface drop at the outlet of 1.0 feet.

The culvert was replaced with a 75.5-foot full-span bridge and a series of 13 boulder weirs. RSP was designed to extend to above the design flood event. The design channel bed under the bridge was approximately 3.3 feet lower than the pre-project culvert outlet invert.

Culvert Outlet Pre-Remediation. Photo taken on 07/29/2002 and taken by HSU.

Post-Remediation. Photo taken on 01/11/2018 and and courtesy of CDFW.

Figure 6-1. Pre and post project looking upstream at crossing.

6.1.2 Site Observations of Project Reach

HSU visited the site in September 2019 and conducted the channel survey in February 2021. The primary observation was that the width of the constructed channel was substantially wider than the channel upstream and downstream of the project (Figure 6-2a verses b). In portions of the project reach sediment had deposited on the inside of the bend in the channel, forming a bar that was helping to confine lower flows and maintain water depth (Figure 6-2d).

The upstream-most boulder weir had failed. It was originally constructed as a straight weir, and the mobilized rock from the weir that was deposited in the downstream channel appeared relatively small in size. Also of note was the large amount of rock used to form the streambanks downstream of the bridge crossing and the lack of successful revegetation within this bank rock (Figure 6-2d).

Figure 6-2. Upp Creek (A) upstream reference reach, (B and C) constructed channel and weirs under bridge, (D) downstream of bridge, and (E) and (F)

6.1.3 SITE OBSERVATIONS OF REFERENCE REACH

The channel downstream of the project appeared highly disturbed (Figure 6-2e and f). Further downstream the channel had been routed to flow under bridges associated with the new US 101 Willits Bypass and on- and off-ramps. Upstream of the project the channel was also relatively disturbed and geomorphically unstable, but had a floodplain and limited riparian vegetation present (Figure 6-2a).

6.2 Channel Morphology and Profile

6.2.1 CHANNEL SLOPES

Figure 6-3 and Figure 6-4 show the channel alignment and a detailed plan map of the project survey extent with locations of cross sections and pebble count, respectively. The DEM from the 2018 USGS LiDAR was used to generate a profile extending beyond the length of the HSU 2020 survey (Figure 6-5). The project appears to be at the transition location flowing from a steep confined channel within the hills to the valley bottom. The channel slope steepens upstream of the project and becomes effectively flat downstream of the project (Figure 6-6).

The HSU 2020 survey extended for approximately 1,000 feet; 300 feet upstream and 700 feet downstream of the new bridge. The upstream natural channel slope was 1.8%, with drops occurring at channel spanning roots and through steep rifles.

The constructed project channel slope ranged between 1.5% and 1.7%. Most of the project channel grade was associated with drops over the boulder weirs, although some areas also had elevation drops over recently formed gravel riffles upstream of weirs. Drops from weir to weir were generally less than 0.5 feet, with the exception of the weir under the bridge. This weir had a drop of 1.05 feet.

6.2.2 CHANNEL WIDTH

Cross sections and the active channel edges were surveyed and widths calculated for the constructed channel and upstream and downstream reaches beyond the project (Figure 6-7 and Table 6-1). The bankfull width was also measured for the constructed and downstream channel reaches. The measurements confirm that the constructed channel widths are substantially greater than the widths measured in the adjacent channel reaches. The upstream channel reach had a slope similar to the project reach, but had an active channel width less than two-thirds the constructed width. Deposition was evident in portions of the constructed channel that was beginning to confine the channel.

TABLE 6-1. CHANNEL DIMENSIONS AND SLOPE BY REACH.

Location		Slope	Active Channel Width (ft)	Bankfull Width (ft)
Project	Under Bridge	1.5%	33.7 (29.8-40.0)	NA
	Downstream of Bridge	1.7%	36.7 (30.2-42.1)	46.5 (43.1-48.4)
Upstream of Project		**1.8%**	**22.5 (19.1–26.8)**	**NA**
Downstream of Project		**0**	**8.8 (6.0–12.2)**	**16.3 (14.2-18.9)**

6.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

Pebble counts of the streambed substrate were taken in the project reach immediately downstream of the bridge and in the channel reaches upstream and downstream of the project (Figure 6-8). The gradation of the streambed appears to become finer from upstream to downstream. The coarser bed material in the upstream reach was embedded and appeared to not be in active transport.

The channel profile is controlled by the constructed boulder weirs. The downstream channel appears to be a long glide. The channel upstream of the project is relatively steep, and its grade is controlled by roots and riffles.

6.3 Discussion

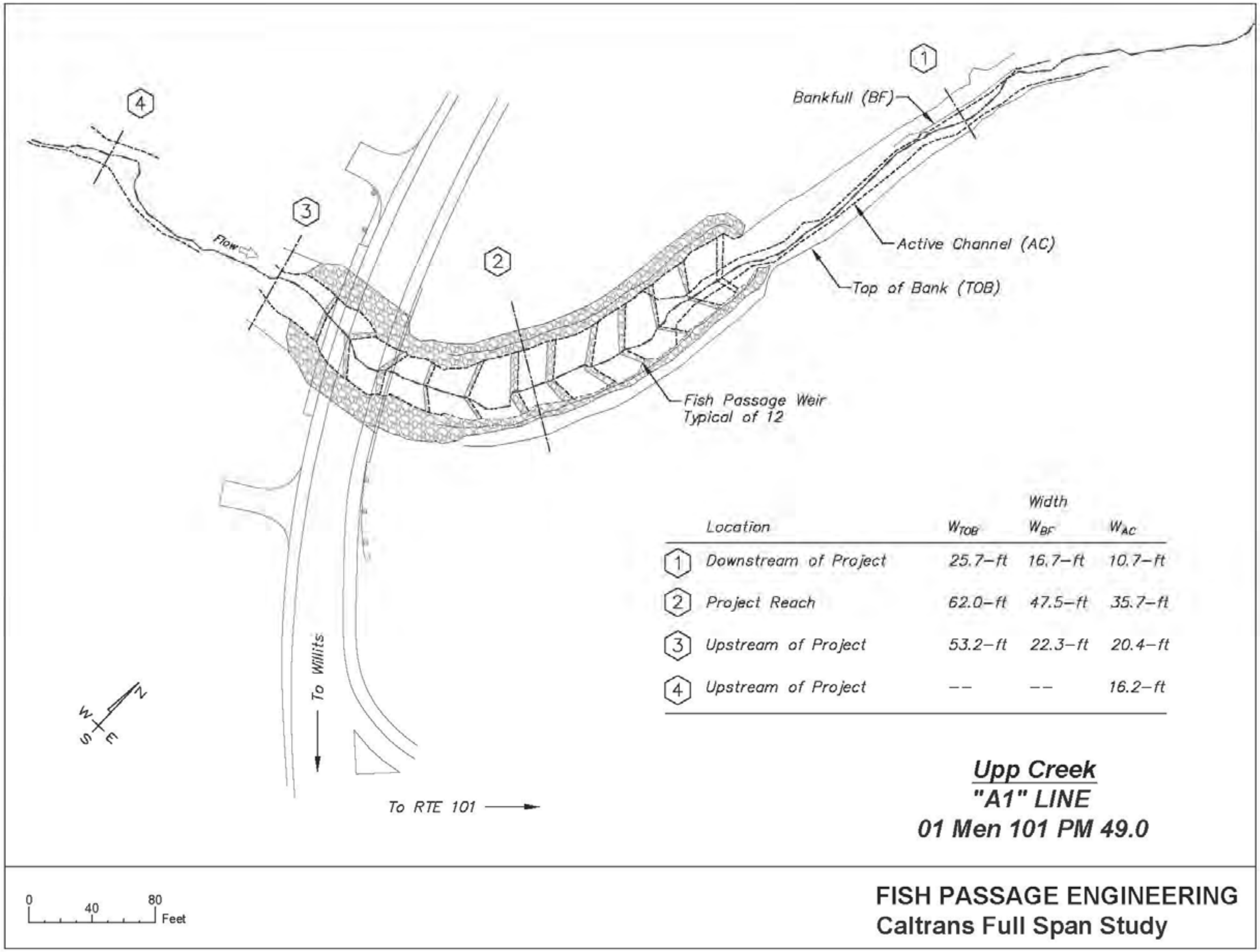
The project includes a full span bridge that will effectively allow unimpeded passage of flood flows and associated debris and sediment.

The project is at a geomorphic transition from a relatively steep confined channel flowing out onto the broad valley floor. The project reach was constructed at a slope similar to the upstream channel slope. However, unlike the upstream channel, boulder weirs were used to control grade rather than riffles and wood control (roots). Additionally, the design channel is substantially over-widened relative to the upstream channel. The width and use of boulder weirs make the constructed reach geomorphically dissimilar to the natural channel immediately upstream. It also appears that the design focused on conveying the design flood event within the confines of the channel based on the channel width and height of the RSP. Measurements of the upstream channel dimensions, and possibly the channel dimensions downstream of the pre-project box culvert, could have served as the basis for a more geomorphically appropriate channel design rather than designing for full containment of flood flows.

Datums: Horizontal: NAD83 State Plane CA Zone 1 Vertical: NAVD88	**Upp Creek** MEN 101 PM 48.18 **Site Map and Channel Stationing**		Caltrans Design Guidance for Full-Span Crossings Fish Passage Restoration Project
Aerial image from Google 2021			HSU Sponsored Programs Foundation Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing Project\4 Site Assessments\6 Upp Creek(MEN 101-

FIGURE 6-3. OVERVIEW SITE MAP FOR UPP CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.



			Width	
	Location	W_{TOB}	W_{BF}	W_{AC}
①	Downstream of Project	25.7–ft	16.7–ft	10.7–ft
②	Project Reach	62.0–ft	47.5–ft	35.7–ft
③	Upstream of Project	53.2–ft	22.3–ft	20.4–ft
④	Upstream of Project	--	--	16.2–ft

FIGURE 6-4. SCHEMATIC LAYOUT OF THE PROJECT BASED ON THE HSU 2021 FIELD SURVEY.

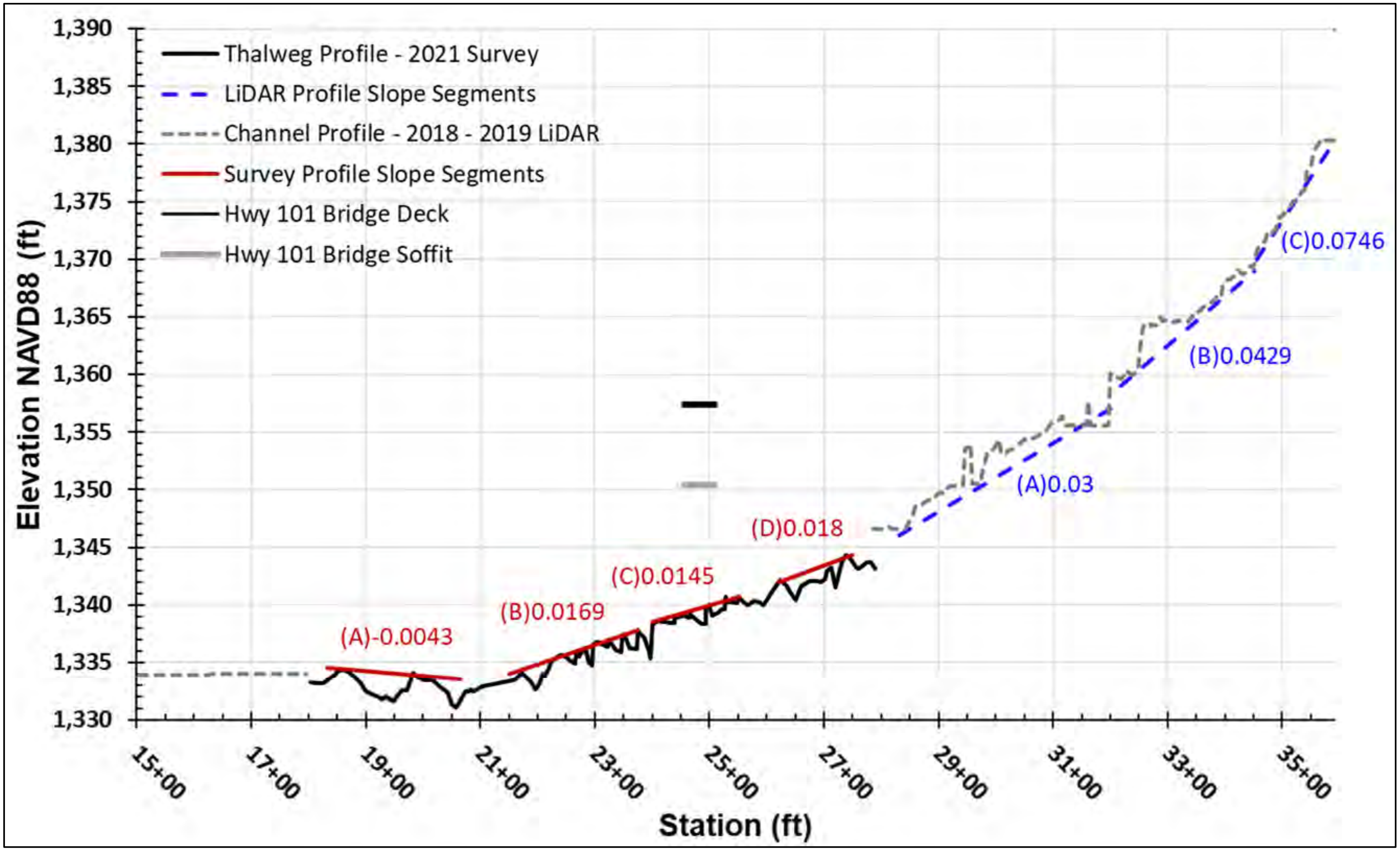


FIGURE 6-5. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED.

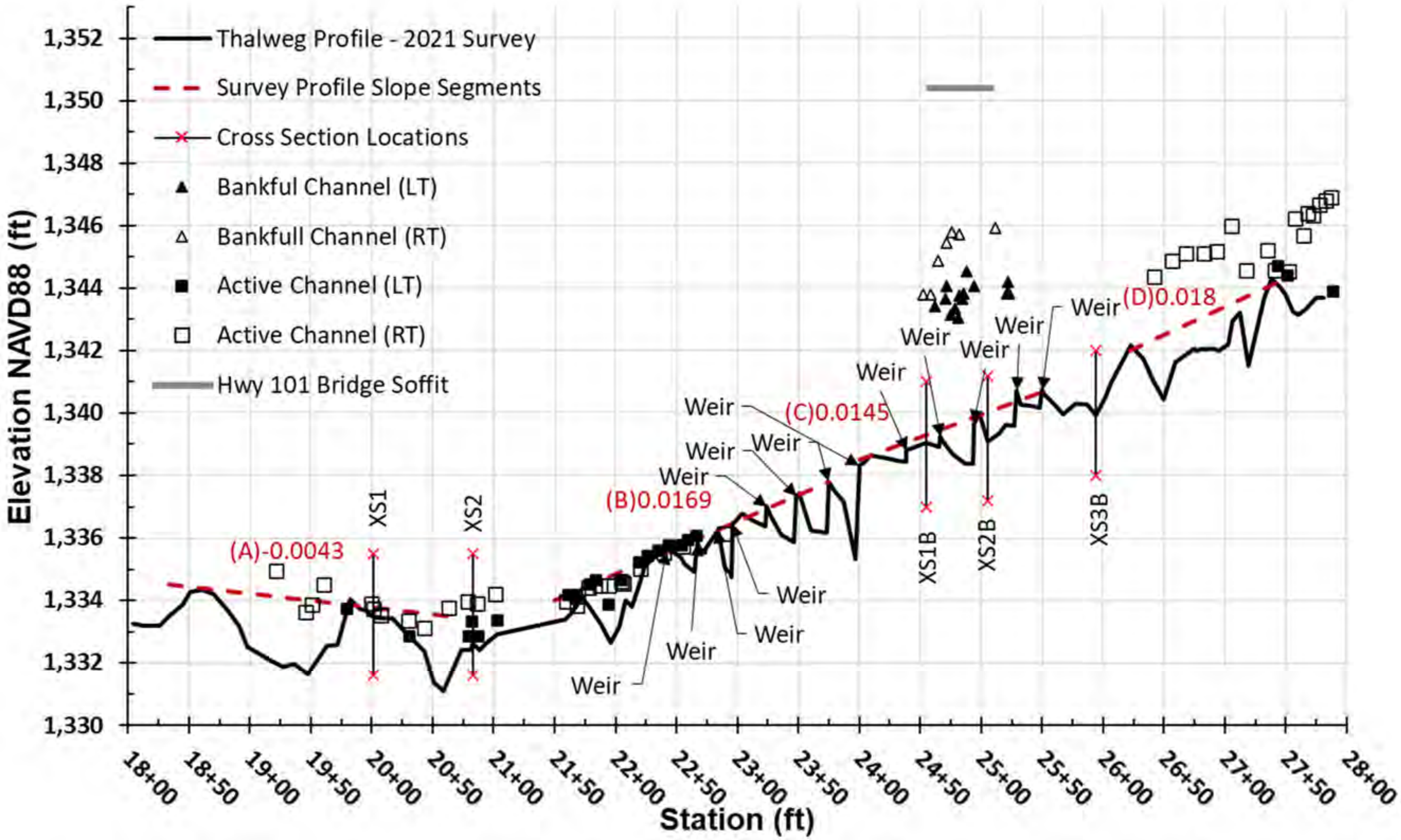


FIGURE 6-6. SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS AND THE OVERALL PROFILE (AS DEFINED BY THE LIDAR DEM) PLOTTED. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

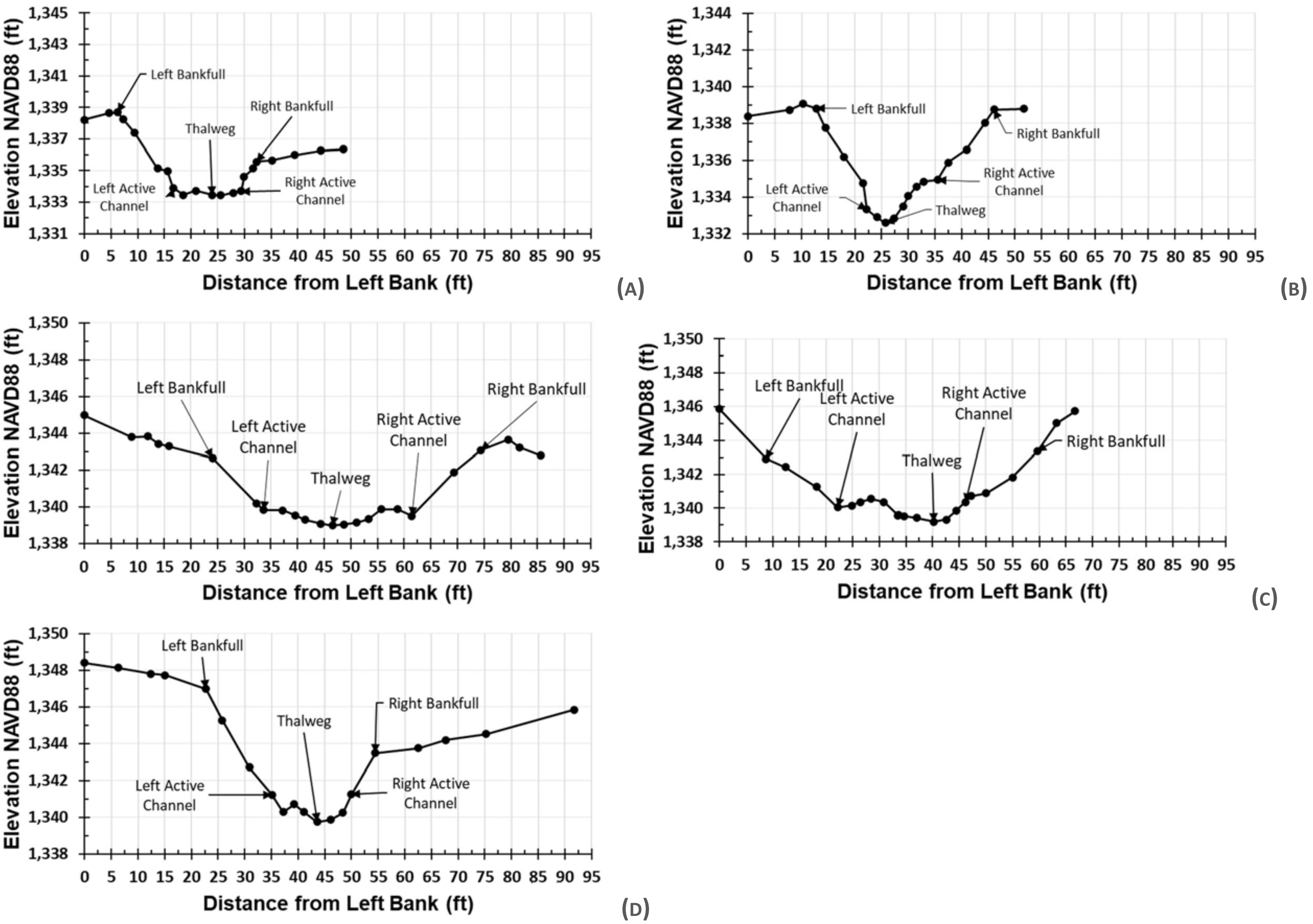


Figure 6-7. Cross-sectional surveys of the channel at cross sections downstream of project at (A) XS1 and (B) XS2, in project reach at (C) XS1B and (D) XS2B, and upstream of project at (E) XS3B.

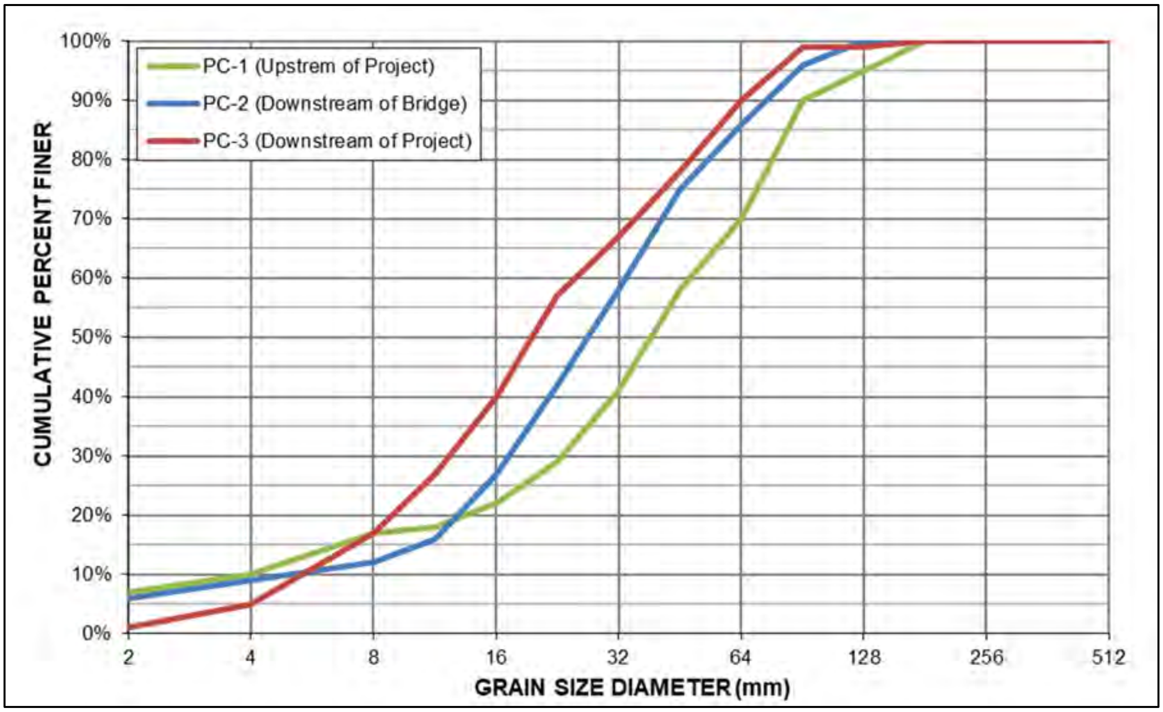


FIGURE 6-8. GRADATION OF STREAMBED MATERIAL OBTAINED FROM A SURFACE PEBBLE COUNT IN THE PROJECT REACH UPSTREAM, UPSTREAM REFERENCE REACH AND DOWNSTREAM REFERENCE REACH.

7 NF RYAN CREEK (MEN 101 – PM52.36)

7.1 Project Description

7.1.1 DESIGN AND AS-BUILT CONDITIONS

The North Fork Ryan Creek culvert replacement on Highway 101 was completed in 2017 for fish passage and as mitigation for the Willits Bypass project. The replacement crossing was a 12-foot wide by 11-ft high, 100 feet long (based on survey, as-built shows 88.3 feet) precast reinforced concrete box (RCB) culvert. The crossing was designed based on the CDFW active channel design method and intended to provide for passage of salmon and steelhead. The project involved installation of the RCB culvert embedded approximately 4 feet below the channel profile. Imported streambed material was placed into the culvert to form a 4-foot thick bed. Disrupter boulders were placed within this streambed protruding above the finished surface.

To control grade, and presumably prevent upstream channel incision, the project as-built drawings indicate six rock weirs were constructed. Two of the rock weirs were upstream and four were downstream. The as-built drawings show the upstream and downstream-most rock weir elevations matching the existing channel thalweg, and the downstream weirs having drops from crest to crest of 1.3 feet, 0.6 feet and 1.3 feet. The upstream-most weir was constructed with a drop of 2 feet.

7.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the site to evaluate and survey the current crossing and channel conditions on September 12, 2019 and January 14, 2020. Photographs from these visits are provided in Figure 7-1. Figure 7-2 shows pictures of the site pre-construction and just after construction in 2018. The weir closest to the culvert inlet was not visible but a jumble of large rock was present. The upstream-most rock weir had a 1.5-foot drop, and the bottom of the footer rocks were exposed, suggesting that its stability was compromised. On the September 12, 2019 visit surface flow was continuous upstream of the project but was observed going subsurface at the left corner of the culvert inlet, apparently due to higher porosity of the streambed material at this location. The flow remained subsurface through the culvert and resurfaced at select locations to form isolated pools in the downstream project reach. Downstream of the project the surface flow reemerged.

The channel bed within the culvert was mostly devoid of any bed structure, and characterized as plane-bed. The disrupter boulders within the culvert (typically used to provide for local variability in the streambed and prevent the thalweg from training along the smooth culvert walls) were mostly buried and having minimal influence on the form of the streambed.

7.1.3 SITE OBSERVATIONS OF REFERENCE REACH

A reference reach was selected upstream of the project reach. This reference reach was gravel-bedded with riffles and pools. Wood and roots provided bed and bank controls. Water was flowing throughout this reach during both site visits and juvenile salmonids were observed within the pools. The channel banks were relatively steep, and an established riparian forest provided ample shade over the channel (Figure 7-1).

Within the project zone there was limited riparian vegetation to provide cover and shade, downstream of the project the channel was covered in Himalayan blackberry.

7.2 Channel Morphology and Profile

The assessment area was divided into four specific reaches: downstream project reach, within the culvert crossing, upstream project reach, and upstream reference reach. The surveyed thalweg profile extended from the downstream end of the project to approximately 200 feet upstream of the project. Continuing the survey downstream of the project was infeasible due to the density of the Himalayan blackberry throughout the channel.

Channel slopes were assessed beyond these extents using the available USGS 2018 LiDAR DEM.

7.2.1 CHANNEL SLOPES

A stationed channel centerline alignment was prepared extending upstream from the confluence with the South Fork of Ryan Creek (Figure 7-3). Figure 7-4 shows a more detailed plan map including the reference reach, cross section and pebble count locations. The LiDAR DEM was then used to evaluate the overall channel profile. The overall slope is approximately 1.5% and no discontinuities in the profile were noted (Figure 7-5). The Himalayan blackberry density in the channel downstream of the project appeared to result in poor channel definition in the LiDAR DEM.

The channel profile from the LiDAR and site survey was broken into slope segments (Figure 7-5 and Figure 7-6). The reference reach slope was relatively constant at 0.9%, while the slopes within the project reaches varied from nearly flat through the culvert to 3.7% in a portion of the downstream project reach.

7.2.2 CHANNEL WIDTH AND DEPTH

The active channel width, bankfull width, and top of bank width and depth were measured in all four reaches and the mean and ranges are provided in Table 7-1. The reference reach active channel and bankfull widths were 12.3 feet and 14.5 feet, respectively. This is similar to the bankfull widths ranging between 12 and 15 feet measured as part of an earlier design effort by Prunuske Chathem, Inc. (2007) within this same reach. However, these widths differ substantially from the active channel width of 7.0 feet reported in the project design report by AECOM (2014) [no bankfull width reported].

The channel cross section within the culvert has a nearly flat channel bed, as seen in Figure 7-7. The cross sections at the riffle crests in the reference reach (Figure 7-8(a) and(b)) have more variability than within the culvert, but still have a relatively flat bottom. The channel widths in the downstream project reach (Figure 7-8(c) and(d)) are wider than both the crossing and upstream reference reach.

TABLE 7-1. CHANNEL DIMENSIONS AND SLOPE BY REACH. RANGE OF MEASUREMENTS IN PARENTHESES.

Location		Slopes	Active Channel Width (ft)	Bankfull Width (ft)	Top of Bank Channel Width (ft)	Top of Bank Channel Depth (ft)
Project	Downstream of Crossing	0.027-0.037	13.8 (11.4-17.3)	21.3	27.6 (21.0-33.0)	4.7 (3.0-6.5)
	In Culvert Crossing	0.000	12.0	12.0	12.0	NA
	Upstream of Crossing	0.020	14.8 (10.4-22)	20.0	36.8 (10.4-58.6)	8.1 (6.4-10.4)
Upstream Reference Reach		**0.0091**	**12.3 (10.1-14.1)**	**14.5**	**26.5 (23.8-31.8)**	**5.4 (3.9-6.2)**

7.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

A pebble count of the surface substrate of the channel was conducted in the upstream reference reach and in the upstream portion of the culvert bed. These gradations are plotted in Figure 7-9. The median particle size (D50) and D84 of the reference reach is 20 mm (classified as coarse gravel) and 41 mm (very coarse gravel), respectively. For the streambed in the culvert the D50 and D84 are 41 mm (very coarse gravel) and 81 mm (small cobble). The channel bed adjacent to the culvert, within the project reach, has a particle size distribution similar to the culvert bed. This coarser bed material likely contributes to surface flow going subsurface through the project reach during the drier months. There are fine sediments in the system and a portion of the downstream culvert bed has surface deposits of finer (5 – 10 mm) particle sizes but low flow observations indicate these have not yet reduced the coarse bed porosity to maintain surface low flows.

7.3 Discussion

7.3.1 CHANNEL SLOPES

The combined surveyed and LiDAR channel profile (Figure 7-5) suggests the upstream most rock weir is potentially retaining stored sediment deposited upstream of the pre-project undersized culvert. The slope segments throughout the project deviate substantially from the upstream channel slopes, and the upstream-most rock weir creates a distinct discontinuity in the stream profile that may create a partial barrier for upstream fish movement.

The slope within the culvert is nearly flat, while the downstream project reach is relatively steep. Constructing a more continuous slope through the entire project and avoiding large drops over rocks weirs would better match the overall channel slope, and thus better satisfy fish passage objectives.

7.3.2 CHANNEL WIDTHS AND STRUCTURE WIDTH

Based on the CDFW (2009) Active Channel Design option applied to design of this crossing, the crossing width must be a minimum of 1.5 time wider than the active channel width. The intent is to utilize the more identifiable active channel width while achieving a structure that is wider than the bankfull channel width, which requires a geomorphologist or more experienced designer to identify. However, the active channel width used by AECOM (2014) for sizing the crossing was only 7.0 feet, substantially smaller than the widths measured by HSU and Prunuske Chatham, Inc. (2007). The location the active width was measured is not specified in the design report. The narrow active channel width used for design resulted in a structure width of 12 feet, which is narrower than the bankfull channel width measured in the reference reach. If the HSU measured 12.3-foot active channel width was applied, the minimum structure width would be 18.5 feet, which is wider than the reference reach bankfull width.

A wider than bankfull crossing width would have allowed for construction of rock banklines within the crossing. Rock banklines create bank roughness and hydraulic variability similar to conditions in a natural channel.

The active channel width constructed upstream and downstream of the crossing is similar to the reference reach, but wider than the crossing. As a result, relatively low flows (i.e. less than the 2-year flow) contract as they enter the culvert and expand as they exit. Additionally, the approximate bankfull channel width within these upstream and downstream project reaches are substantially wider than within the reference reach. As such, the bankfull flow depths in these project reaches are likely substantially lower than within the reference reach.

7.3.3 STREAMBED MORPHOLOGY AND SUBSTRATE

The streambed within the crossing appears to have aggraded to some degree since construction. The disrupter boulders are nearly buried rather than protruding above the streambed; as such, the channel bed within the crossing is plain-bedded and relatively featureless. These changes are evident in comparing pictures showing the inlet opening and the culvert bed in Figure 7-1 and Figure 7-2.

The substrate within the culvert is substantially coarser than the bed material in the upstream reference reach. This may be in-part due to the narrow width of the culvert compared to the bankfull channel width. The flow confinement in the culvert during bedload transporting flows may result in a coarser bed. The coarseness of the bed material may be the cause of the low-flow subsurface conditions found through much of the project reach. However, this could also be due to the lack of adding sufficient fines to the installed streambed material during construction.

Figure 7-1. NF Ryan Creek (a and b) reference reach, (c) weir at upstream end of project, crossing (e) inlet and (e) outlet, and (f) downstream of crossing. Photos a, b, c, d and f taken Jan 14, 2020; photo e taken Sept 12, 2019.

Culvert Outlet Pre-Treatment. Photo taken on 12/15/2002 and taken by HSU.

Looking Through Culvert at Inlet Post-Treatment. Photo taken on 01/09/2018 and courtesy of Caltrans.

Culvert Outlet Post-Treatment. Photo taken on 01/09/2018 and courtesy of Caltrans.

Downstream Post-Treatment. Photo taken on 01/09/2018 and courtesy of Caltrans.

Culvert Inlet Post-Treatment. Photo taken on 01/09/2018 and courtesy of Caltrans.

FIGURE 7-2. NF RYAN CREEK PRE- AND POST-CONSTRUCTION PHOTOS PROVIDED BY M. MOLNAR, CALTRANS.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2021

NF Ryan Creek

MEN 101 PM 52.36

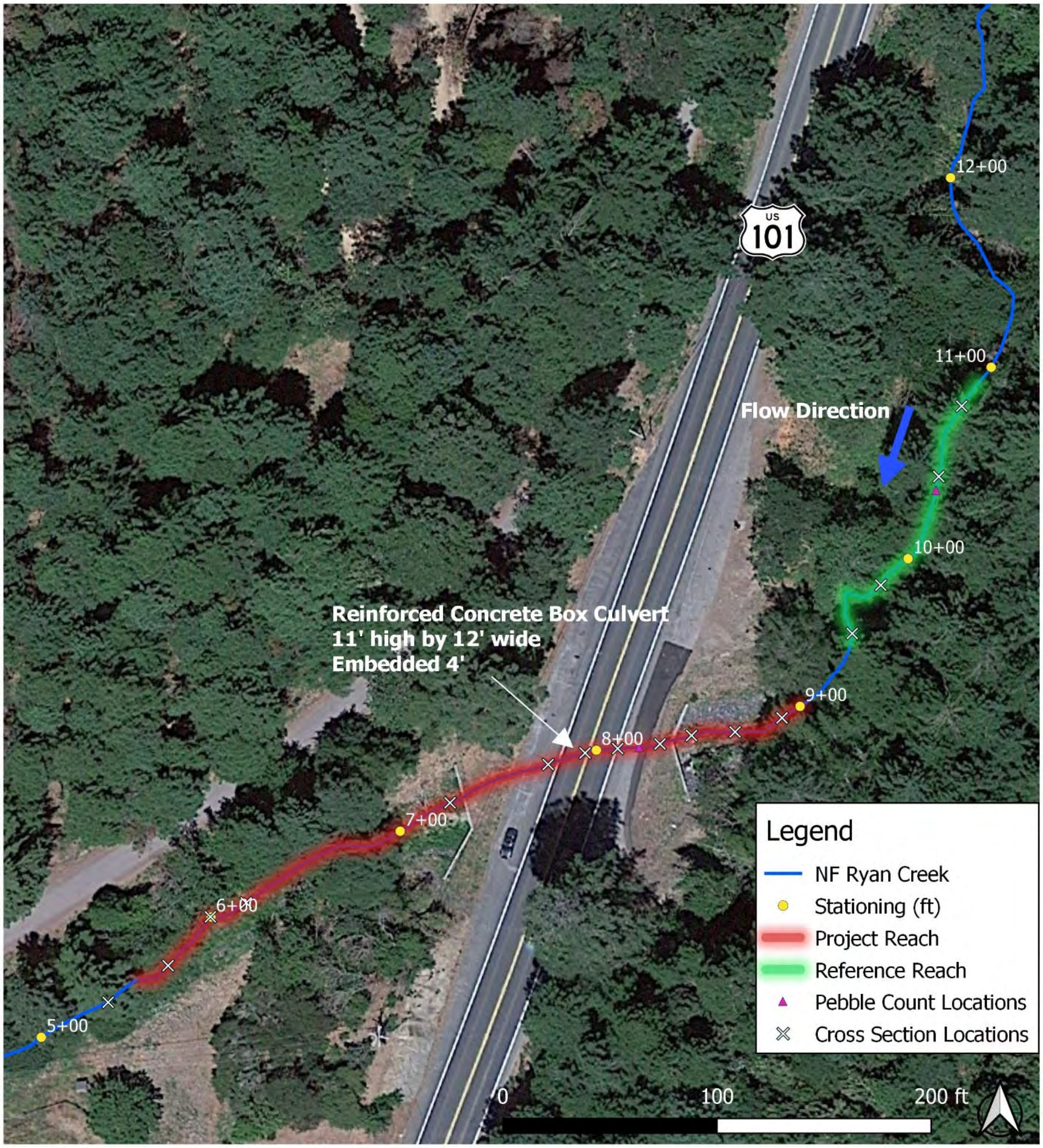
Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing Project\4_Site_Assessments\8_NF_Ryan_Creek(MEN_101-

FIGURE 7-3. OVERVIEW SITE MAP FOR NF RYAN CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2015

NF Ryan Creek

MEN 101 PM 52.36

Site Map and Channel Stationing
Project Area

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\8_NF_Ryan_Creek(MEN_101-PM52.36)\6_GIS\NF_Ryan.qgz

FIGURE 7-4. PROJECT AREA MAP FOR NORTH FORK RYAN CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION AND PEBBLE COUNT LOCATIONS.

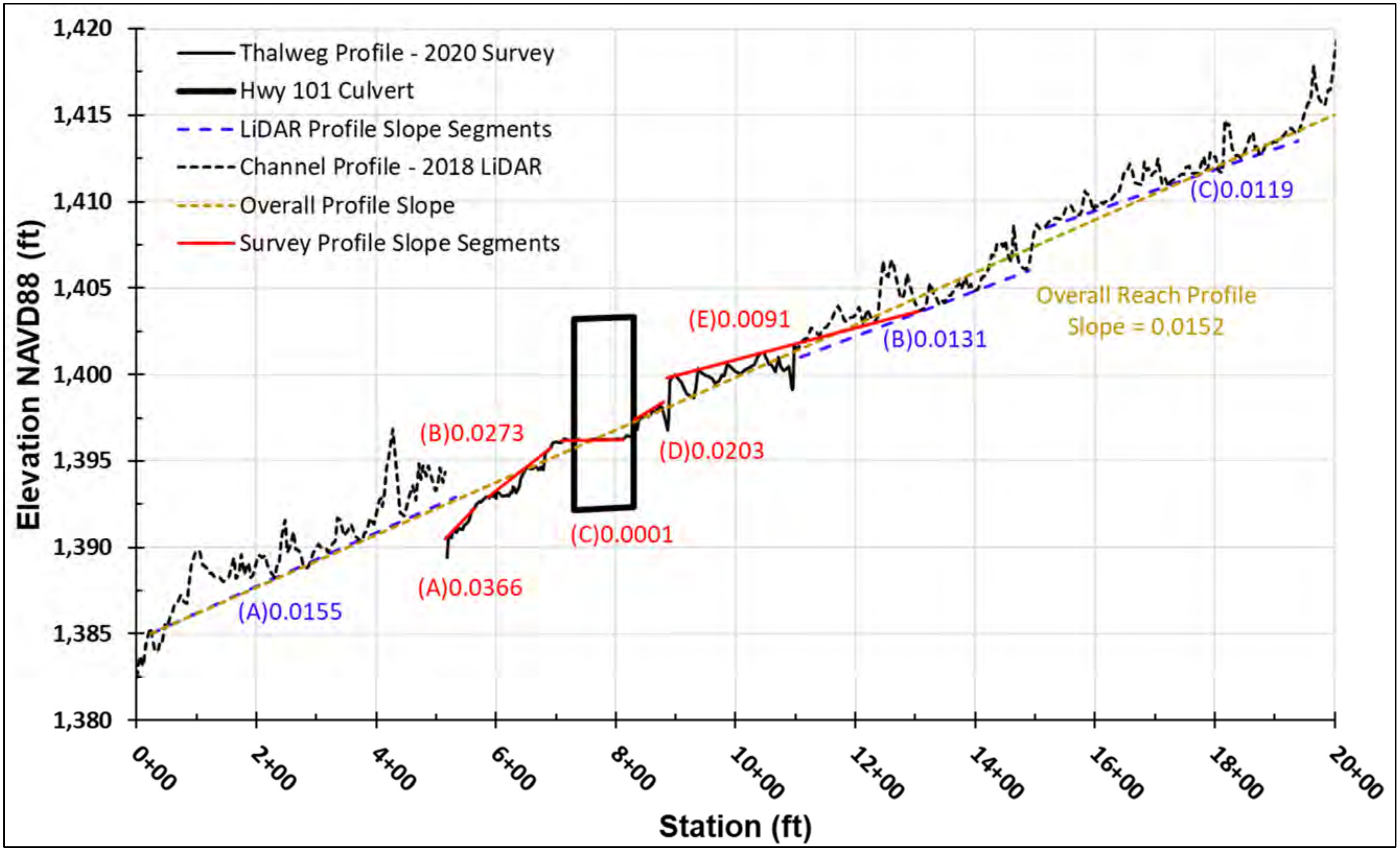


FIGURE 7-5. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED. AN OVERALL REACH SLOPE OF 0.0152 IS SUPER ONTO THE PROFILE.

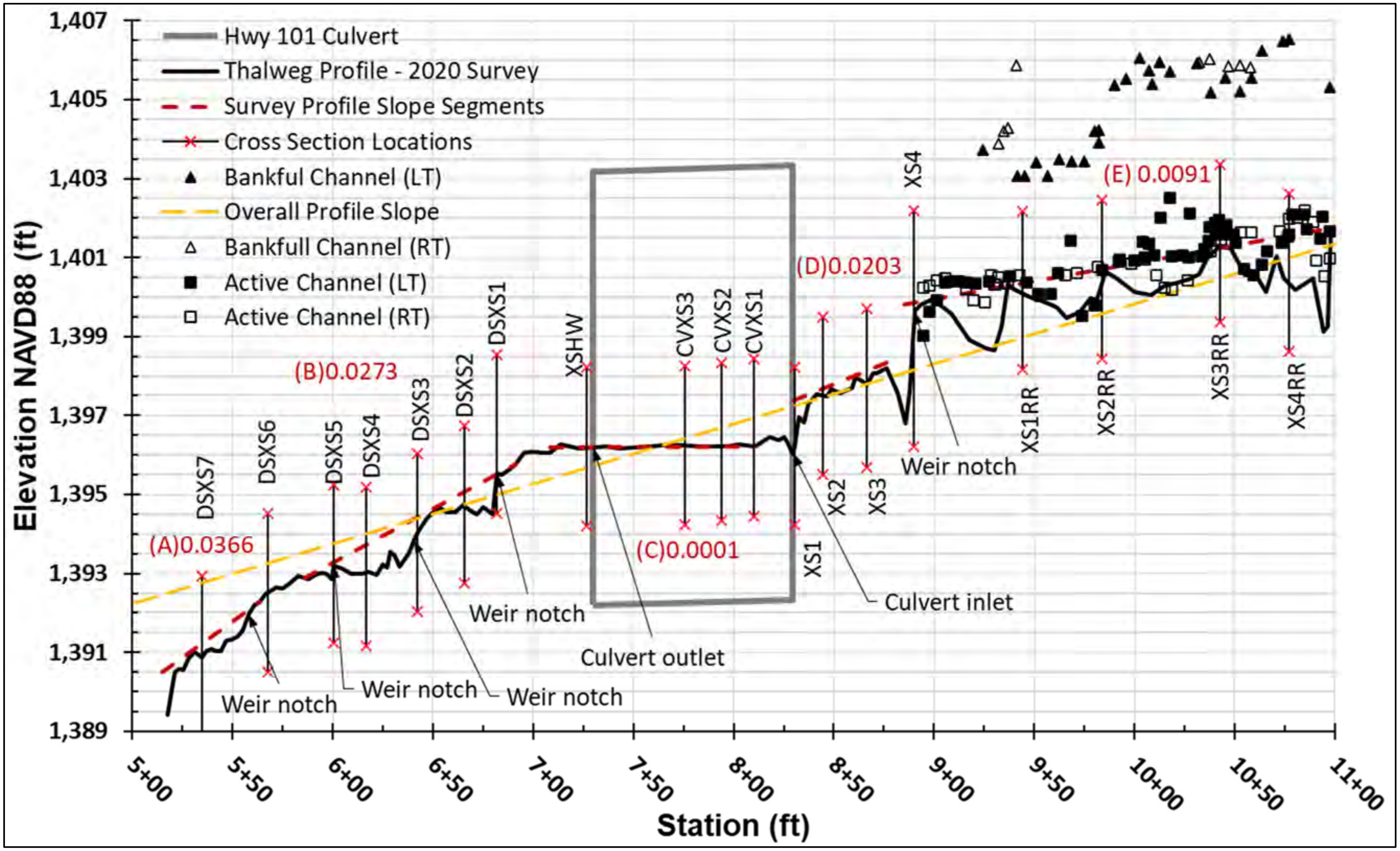


FIGURE 7-6. 2019 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH GEOMORPHIC INDICATORS, DEFINED SLOPE SEGMENTS AND THE OVERALL PROFILE (AS DEFINED BY THE LIDAR DEM) PLOTTED. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

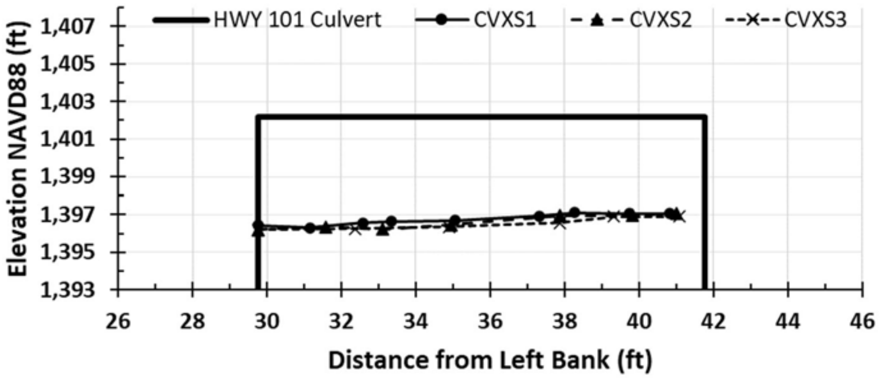


FIGURE 7-7. CROSS-SECTIONAL SURVEYS OF THE CHANNEL BED WITHIN THE 12 FOOT SPAN CULVERT.

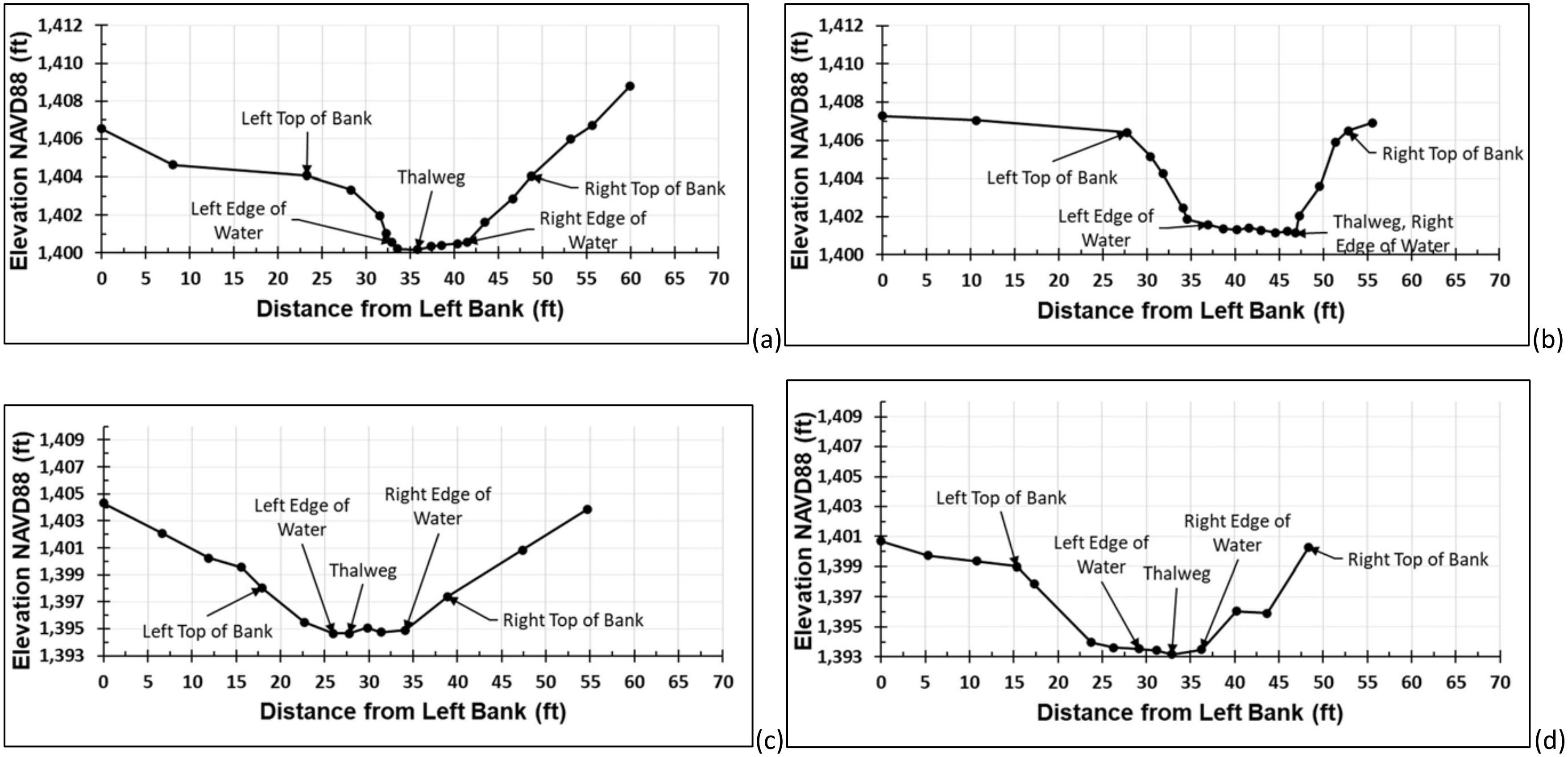


FIGURE 7-8. CHANNEL CROSS SECTIONS FOR THE REFERENCE REACH AT (A) RR1 AND (B) RR3 AND DOWNSTREAM PROJECT REACH AT (C) DS2 AND (D) DS4.

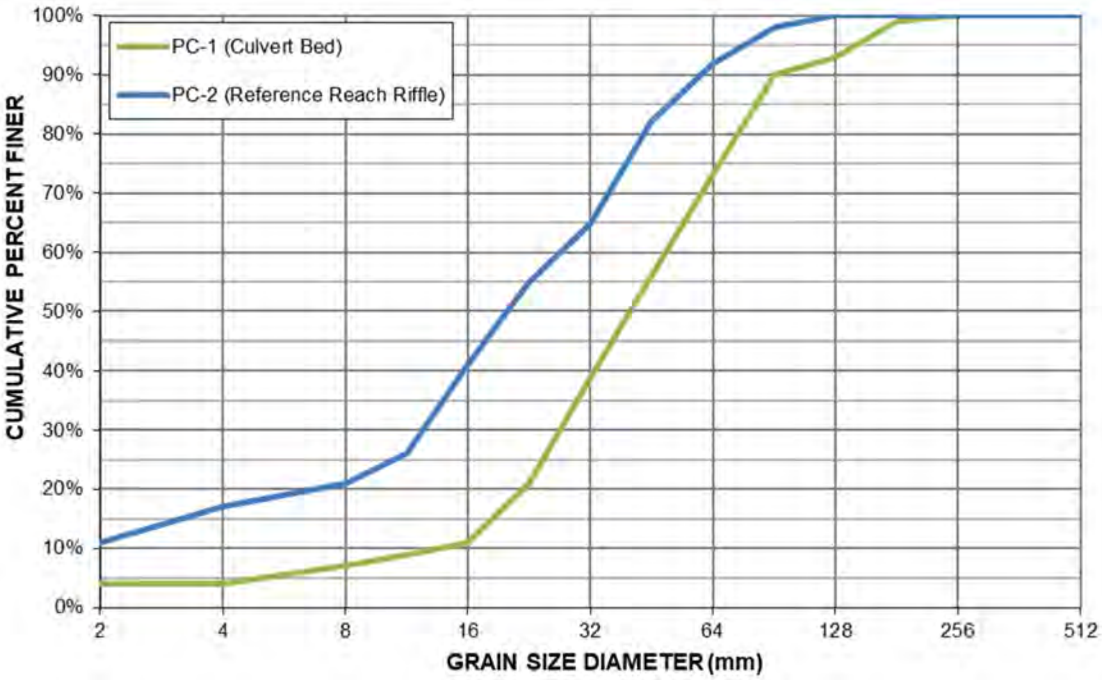


FIGURE 7-9. GRADATION OF STREAMBED MATERIAL OBTAINED FROM A SURFACE PEBBLE COUNT IN THE UPSTREAM REFERENCE REACH AND IN THE UPSTREAM PORTION OF THE CULVERT BED.

8 SF RYAN CREEK (MEN 101 – PM52.25)

8.1 Project Description

8.1.1 DESIGN AND AS-BUILT CONDITIONS

The South Fork Ryan Creek culvert replacement on Highway 101 was completed in 2017 for fish passage and mitigation for the Willits Bypass project. The project replaced a 5-foot diameter CMP with two 10-foot diameter 168 feet long steel pipes installed using jack and bore culvert replacement. This method was selected due to the fill above the culvert and high traffic volumes. One of the pipes was installed at a higher invert elevation than the other, and intended to convey high flows. Both culverts were designed to be installed flat (no slope) and backfilled with streambed material 3 feet thick. However, the as-built drawings show that the low-flow culvert was installed with a reverse grade and the thickness of the streambed material increased in the upstream direction, from 3 feet at the outlet to 5 feet thick at the inlet.

To control grade, four rock weirs were constructed downstream of the culverts and three upstream. The as-built drawings report finished crest elevations of the rock weirs, which results in drops over the downstream weirs of 1.3 feet, 0.6 feet, and 1.3 feet, and upstream weir drops of 1.0 and 2.0 feet. One of the weirs was constructed across the inlet of the culverts. The upstream most weir is shown as being installed at-grade with the upstream channel bed.

A private culvert crossing had been replaced approximately 300 feet upstream of this site prior to the project. The upstream replacement is a 14-foot structural steel plate culvert embedded approximately 6 feet below stream grade.

8.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the site to evaluate and survey the current crossing and channel conditions on September 19, 2019 and February 23-24, 2021. An additional site visit was made during high flows on February 19, 2019. Photographs from these visits are provided in Figure 8-1 and a site overview map developed from the survey data is provided in Figure 8-2. The low-flow (right) culvert had a minimal opening due to embedment and the weir across the inlet further reduced the effective opening for conveying high flows. The middle weir upstream of the inlet was no longer intact, but a jumble of large rocks was present that were creating a cascade and maintaining grade.

Within the lower half of the low-flow culvert randomly placed large rocks were present. They appeared to be intended as disrupters, to create a diversity of velocities and flow patterns while scouring a more complex channel bed. These rocks were protruding about half their height above the streambed near the outlet, but became buried by deposited gravels approaching the inlet.

Downstream of the culvert the flow went subsurface in September, resurfacing downstream of the project. The second weir downstream of the outlet was not visible and appears to have been buried by sediment.

8.1.3 SITE OBSERVATIONS OF REFERENCE REACH

The reach immediately upstream of the project and downstream of the private culvert is relatively stable but appears to have evolved as a result of frequent backwatering and deposition from the pre-project 5-foot diameter CMP under the highway. The area had a well-established riparian canopy. Much of it was pool and glide, with one distinct gravel riffle. It appeared that this section of channel had incised approximately 0.5 feet through the stored sediment since project completion, uncovering some buried rubbish.

8.2 Channel Morphology and Profile

8.2.1 CHANNEL SLOPES

The LiDAR DEM generated channel profile (Figure 8-3) reveals a relatively constant overall slope of approximately 1.4% starting at the confluence with NF Ryan Creek just upstream of Ryan Creek Road and extending over 2,500 feet upstream. Breaking the channel profile into slope segments reveals the primary deviation from the overall slope occurs between the Highway 101 culvert and the next upstream private driveway culvert. This reach is lower gradient and above the overall profile, suggesting local aggradation caused by frequent backwatering from the previous undersized culvert crossing at Highway 101. No discrete knickpoints are noted on the LiDAR DEM profile

The 2021 surveyed thalweg profile (Figure 8-4) extends a short distance downstream of the project and over 300 feet upstream of the project. The slope of the grade control upstream of the culvert crossing is approximately 4.3%, while the slope downstream is 2.7%. Inside the main flow culvert, which does not contain grade control, the overall slope of the bed material averages 1.0%. In the culvert there is a scoured pool starting at the inlet and extending 95 feet downstream through the culvert. This appears due to both the contraction at the culvert inlet and the steep drop into the inlet from upstream.

A reference reach was selected immediately upstream of the project for comparison purposes. It has a slope of approximately 0.009 (Figure 8-4). As mentioned previously, this reach appears aggraded due to backwatering from the replaced undersized culvert at Highway 101 that caused upstream sediment deposition. Thus, this section is at a lower slope than the overall profile seen in Figure 8-3.

8.2.2 CHANNEL WIDTH AND DEPTH

AECOM (2014) reported an active channel width of 8.75 feet and Caltrans reported a “channel width” of 8 feet. HSU identified a reference reach upstream of the project but downstream of the 14-foot diameter culvert just upstream of the project that is associated with a driveway crossing. In the reference reach, measurements of the active channel widths ranged from 6.2

to 10.4 feet, with an average of 9.2 feet (Figure 8-5 and Table 8-1). Bankfull channel widths in the reference reach were substantially wider, averaging 17.6 feet.

Access was limited to a single short reach downstream of the project due to dense vegetation and property ownership. Within this single reach, both active and bankfull channel widths were substantially wider than upstream.

Within the project, the constructed channel width upstream of the highway crossing was nearly double the widths measured in the reference reach. Downstream of the highway, the project channel widths were similar to those measured in the reference reach.

TABLE 8-1. CHANNEL DIMENSIONS AND SLOPE BY REACH. RANGE OF MEASUREMENTS IN PARENTHESES.

Location		Slopes	Active Channel Width (ft)	Bankfull Width (ft)
Project	Downstream of Crossing	0.0265	8.6 (6.2 – 11.1)	17.9 (14.3 – 21.5)
	Culvert Crossing	0.0104	10.0	10.0
	Upstream of Crossing	0.0429	20.1	26
Upstream of Project		**0.0092**	**9.2 (6.2 – 10.4)**	**17.6 (14.3 – 21.5)**
Downstream of Project		**0.0125**	**13.9**	**23.0**

8.2.3 Streambed Morphology and Substrate

The channel upstream of the project is gravel bedded with a pool and riffle morphology. A pebble count was conducted within a riffle in the upstream reference reach and within the low-flow culvert to characterize the native streambed material (Figure 8-6). The surface streambed gradation obtained from both pebble counts are nearly identical (Figure 8-6). The median particle size (D50) is classified as "very coarse gravel" at both locations. The D84 for both is a medium sized cobble. These results suggest that the low-flow culvert is maintaining a streambed substrate similar in size and distribution to the natural channel.

8.3 Discussion

8.3.1 Project Design and Constructed Profile

PROJECTED CHANNEL HEADCUT

A review of the provided design documents failed to reveal an analysis of the existing stream profile or the basis of the design profile. Plots of the channel profile extending downstream to the confluence with the South Fork were provided, but no analysis of these profiles was shown. There was mention of an active headcut moving upstream, causing the channel to incise.

The design plans show five rock weirs downstream of the culvert, with the downstream-most rock weir being placed approximately 2.5 feet below the existing channel bed to accommodate the “Projected Headcut.” However, the as-built drawings show only four weirs being constructed downstream of the culvert, and the downstream-most weir crest elevation is 2.8 feet higher than designed. It is unclear if this as-built condition considers the previously mentioned downstream headcutting.

UPSTREAM CHANNEL AGGRADATION

A visual assessment of the upstream channel and floodplain suggests it aggraded and evolved due to the frequent backwatering and resulting deposition from the undersized pre-project 5-foot diameter culvert. Consideration of these indicators may have resulted in a project with less grade control upstream of the culvert and that allowed the channel to incise through some of the upstream stored sediments.

DESIGN GRADE OF CULVERT

There is a natural stable slope for any alluvial gravel bedded channel. Generally, this slope should be considered when designing the slope of the crossing. However, this project design included a flat (zero) slope through the 168-foot long low-flow culvert along with placement of streambed material through the culvert at a flat slope. The typical geomorphic response to this design approach is for the channel to steepen towards its natural slope by aggrading from the inlet towards the outlet. As a result, the channel’s slope adjustment reduces the culvert inlet capacity. We can see this natural slope of the streambed material developing through the low-flow culvert in Figure 8-4; approaching a similar slope to the streambed through the upstream 14-foot diameter embedded culvert. Given the relatively small size of the low-flow culvert, it would perform better if its installed slope more closely matched the channel’s natural stable slope to avoid any loss of culvert inlet capacity.

INSTALLATION OF CULVERT AT REVERSE GRADE

The failure of the low-flow culvert to be installed as designed, but rather at a reverse slope of -2.1%, results in most of the culvert inlet being buried. The installed slope is presumably due to challenges encountered when ramming the pipe through the fill from downstream to upstream. This severe reduction in inlet cross section area constricts higher flows, reducing hydraulic capacity and making the culvert inlet highly susceptible to racking of debris.

Given uncertainty associated with installing pipes through jacking/ramming, a contingency plan should be included to address potential outcomes. For this site, the upstream-most 30 feet of pipe is not in the road fill and was not rammed. This portion of the pipe could have been placed at a positive slope to correct much of the culvert profile issue, placing the culvert inlet at an elevation close to the design grade. Modifying this inlet section of the culvert may still be considered to address the current inlet performance and capacity if flow, fish, sediment, and debris passage remain a concern.

PLACEMENT OF ROCK WEIR ACROSS CULVERT INLET

The design includes placement of a rock weir immediately upstream of the culvert inlet. This effectively reduces the culvert inlet capacity and exacerbates the flow contraction and associated energy losses as water is conveyed into the inlet. These effects can negatively influence both fish passage and conveyance of water, debris, and sediment. Weirs should generally be avoided within several culvert widths upstream of the inlet to avoid these potential negative impacts.

DESIGN AND CONSTRUCTED DROP HEIGHTS ACROSS ROCK WEIRS

The design used 1-foot drops over the weirs, with the exception of a 2-foot drop over the culvert outlet weir. The constructed drop heights varied substantially from the design, and included drops of 2.0 feet over the upstream most weir and 1.3 feet over two weirs downstream of the culvert. The energy dissipation below the 2-foot drop may have caused the failure of the next downstream weir. Drop heights should be kept to 1.0 feet or less to avoid excessive scour and creating a leap barrier for upstream fish passage.

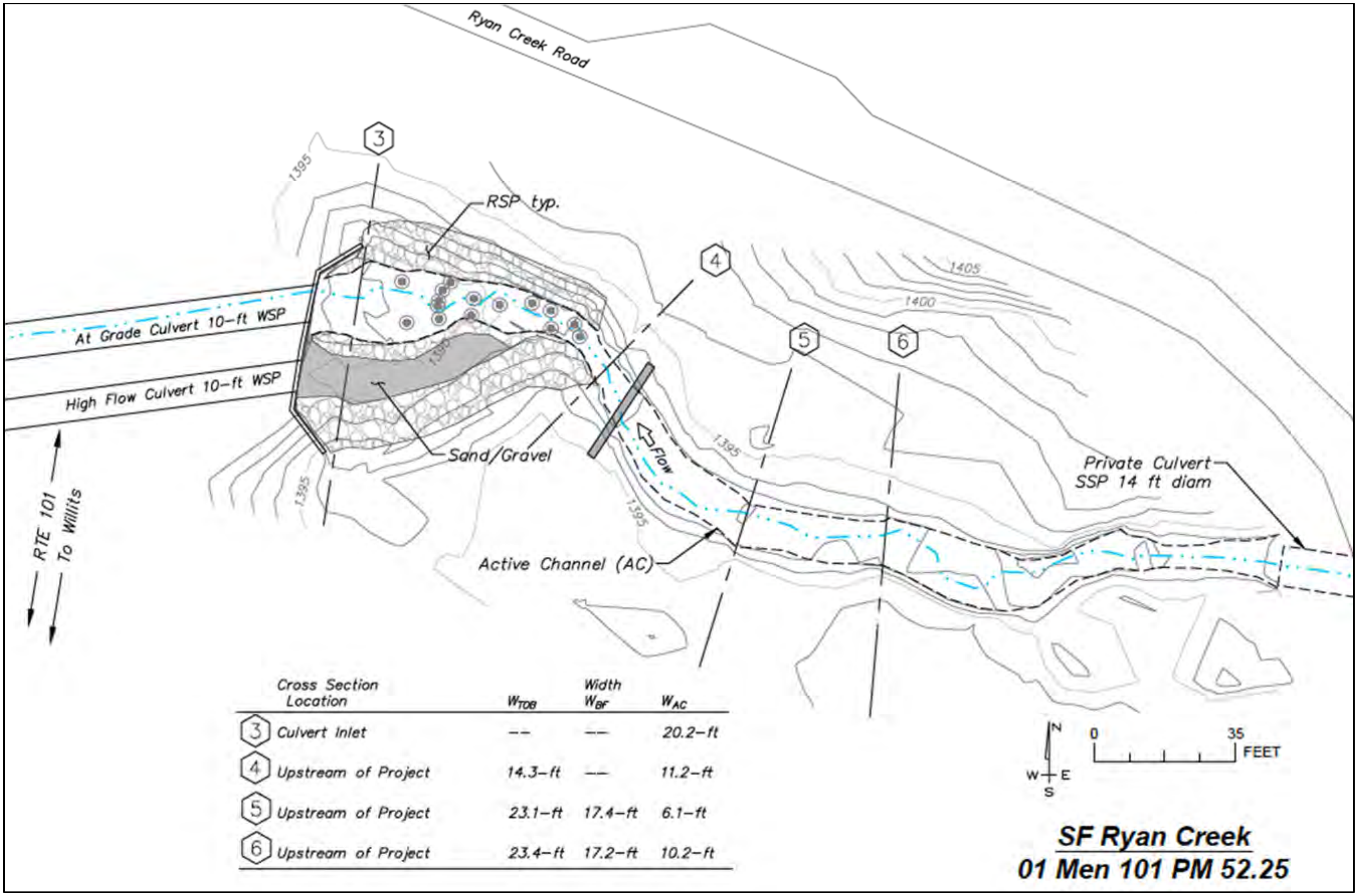
8.3.2 CHANNEL WIDTHS AND STRUCTURE WIDTH

The reference reach channel widths are substantially wider than the 10-foot diameter low-flow culvert. As such, the crossing constricts commonly occurring high flows. The channel widths upstream of the culvert were wider than the reference reach (which is immediately upstream). This may cause flow to spread out and then get constricted to enter the culvert, thus increasing the potential for debris to rack across the inlet. It can also cause flows to be shallower in this upstream project reach than in the natural channel, thus limiting low-flow fish passage conditions.

8.3.3 STREAMBED MORPHOLOGY AND SUBSTRATE

In areas without grade control substrate resembles the reference reach streambed material. The pebble counts even showed the gradation of the streambed material inside the low-flow culvert generally matched the reference reach streambed. The grade control makes the channel morphology dissimilar to the natural channel, with very steep channel segments.

FIGURE 8-1. SF RYAN CREEK (A) REFERENCE REACH, (B) UPSTREAM TRANSITION, (C AND D) INLET AT LOW AND HIGH FLOWS, (E) INSIDE CROSSING, AND (F) DOWNSTREAM OF CROSSING.



Cross Section Location	W_{TOB}	Width W_{BF}	W_{AC}
3 Culvert Inlet	--	--	20.2–ft
4 Upstream of Project	14.3–ft	--	11.2–ft
5 Upstream of Project	23.1–ft	17.4–ft	6.1–ft
6 Upstream of Project	23.4–ft	17.2–ft	10.2–ft

FIGURE 8-2. OVERVIEW SITE MAP FOR SF RYAN CREEK UPSTREAM APPROACH CHANNEL AND MEASURED ACTIVE CHANNEL (AC) BANKFULL (BF) AND TOP OF BANK (TOB) WIDTHS AT INDICATED LOCATIONS. CIRCLES IN CHANNEL REPRESENT BOULDERS PROJECTING FROM BED.

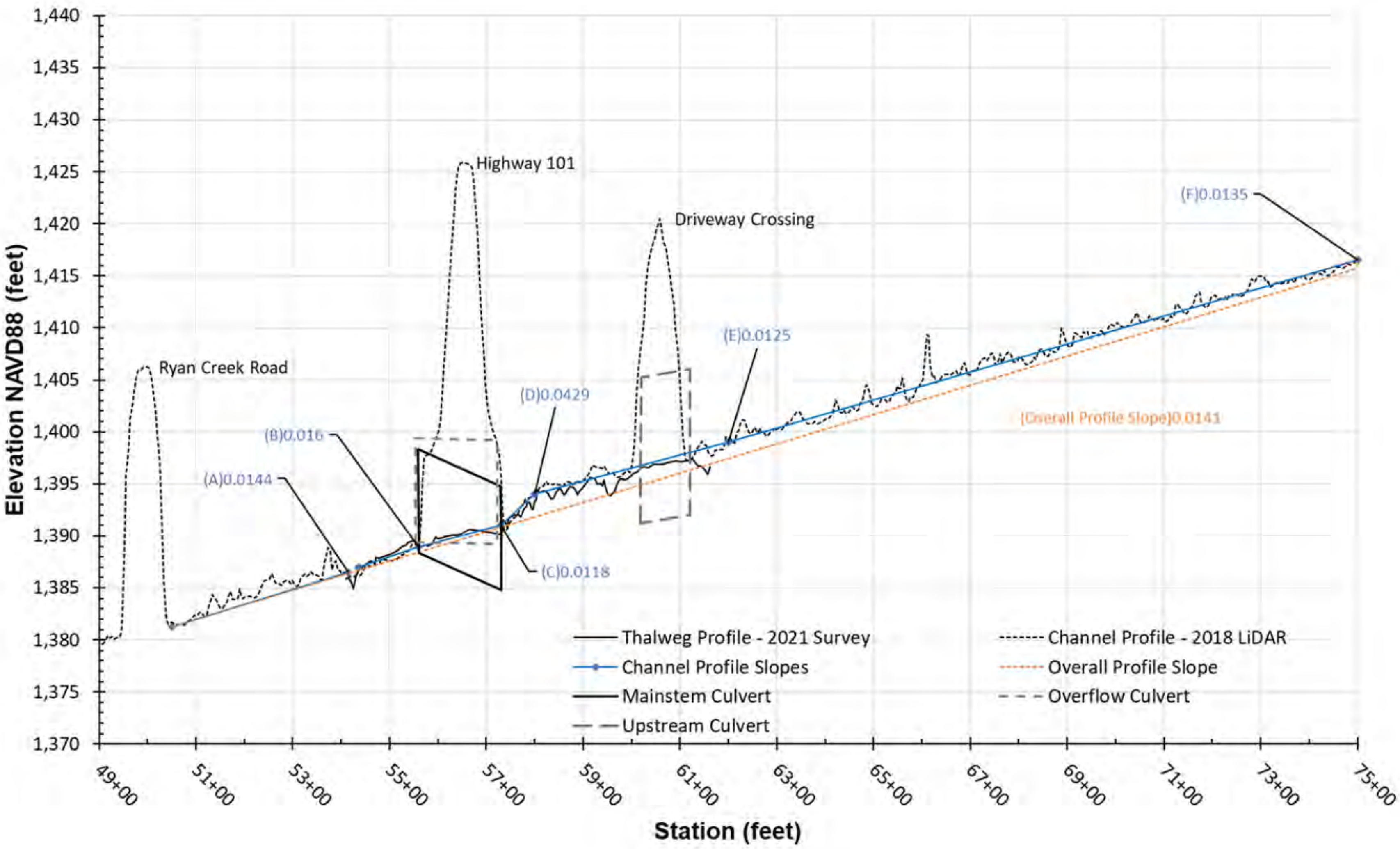


FIGURE 8-3. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED.

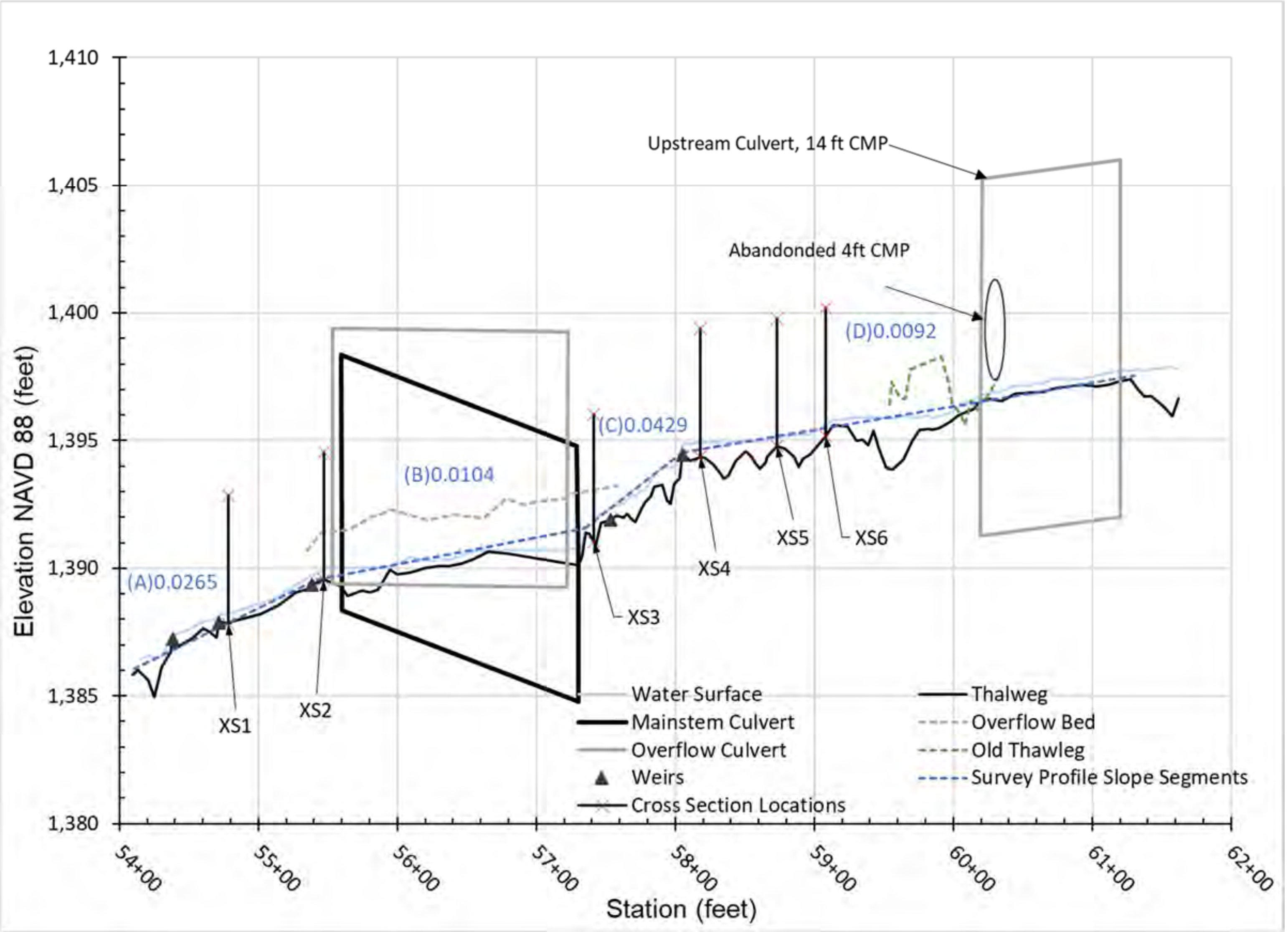


FIGURE 8-4. 2021 SURVEYED THALWEG PROFILE ALONG CHANNEL CENTERLINE ALIGNMENT, WITH DEFINED SLOPE SEGMENTS AND THE OVERALL PROFILE PLOTTED. LOCATION AND IDENTIFICATION OF CHANNEL CROSS SECTIONS DENOTED.

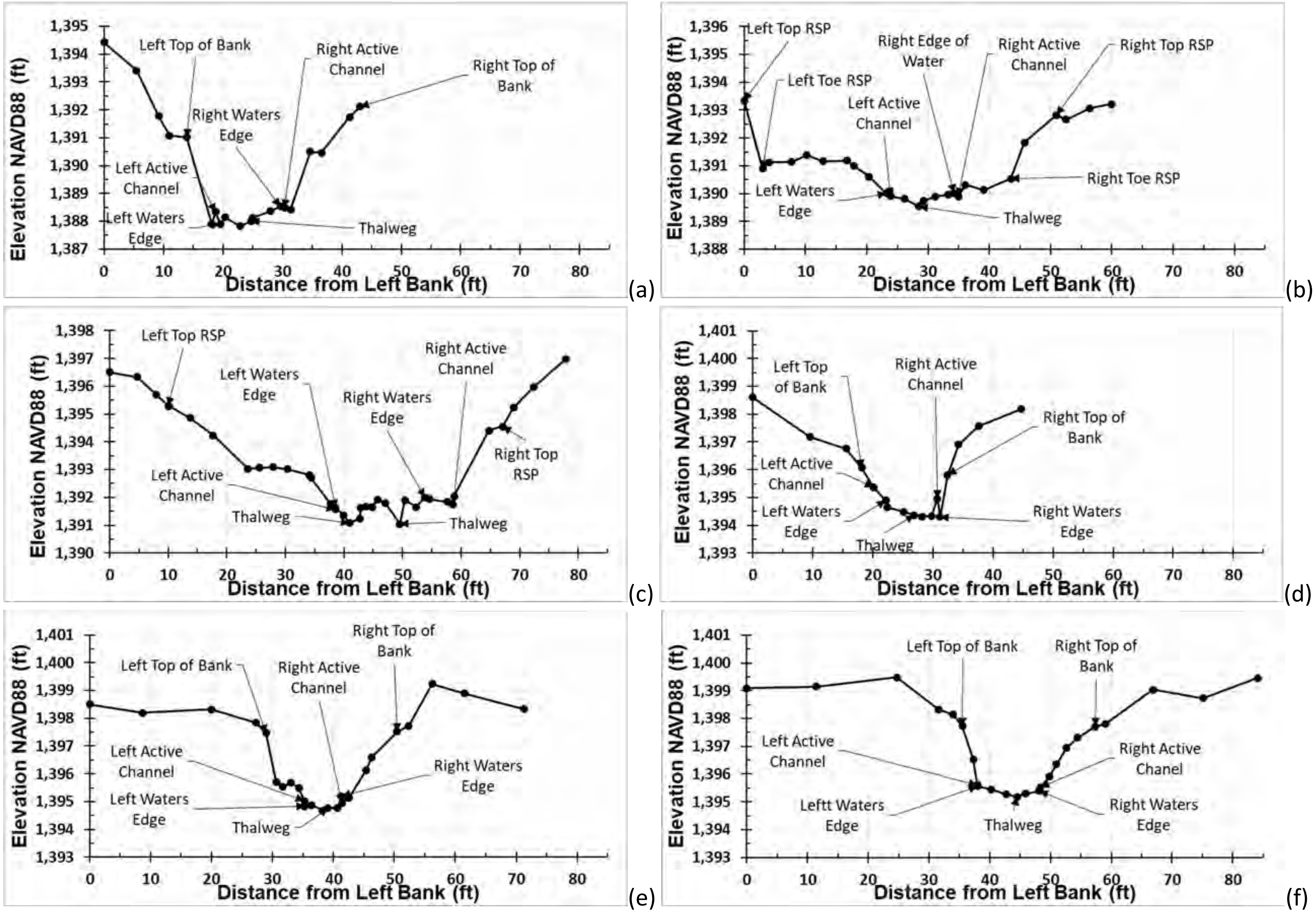


Figure 8-5. Channel cross sections for XS1 (a) through XS6 (f). XS1 (a) and XS2 (b) are of the downstream project reach, and XS3 (c) is immediately upstream of the culvert inlet. XS4 through XS6 are of the upstream reference reach.

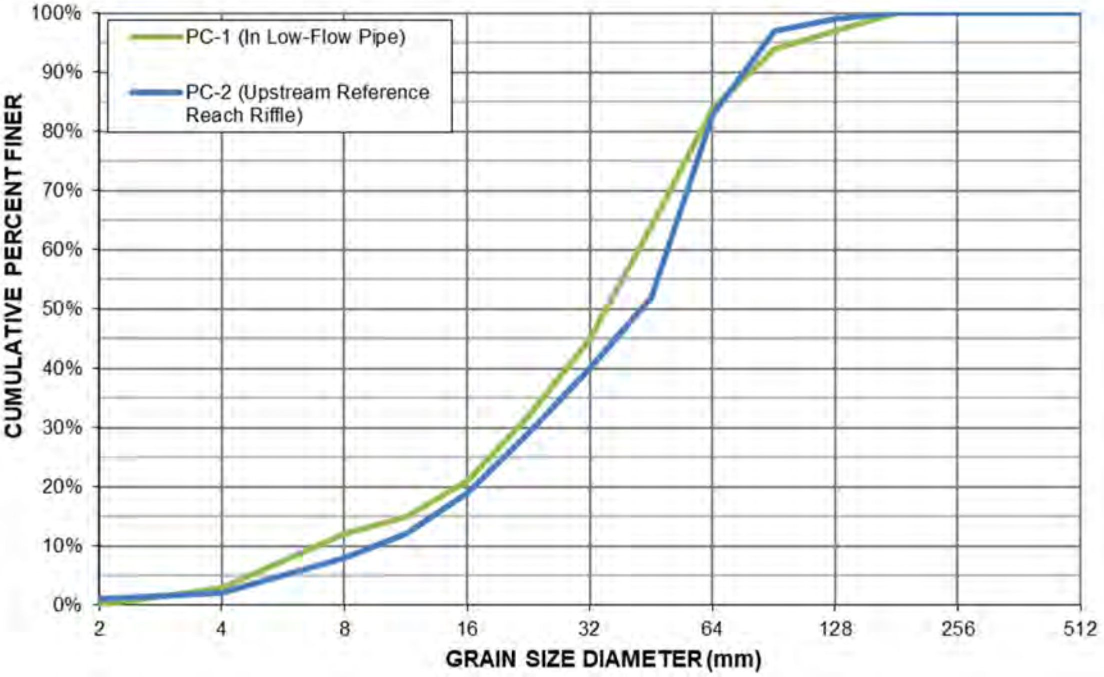


Figure 8-6. Size distribution of surface streambed substrate from pebble counts from the upstream reference reach and from within the low-flow culvert.

9 RATTLESNAKE CREEK (MEN 101 – PM 81.40)

9.1 Project Description

9.1.1 DESIGN AND AS-BUILT CONDITIONS

The Rattlesnake Creek crossing on State Route 101 in Mendocino County is a large concrete arch culvert with a base width of 21 feet, height of approximately 25 feet, and concrete floor. The crossing outlet was modified for fish passage in 2009 to replace a small fish ladder plagued by debris plugging and a failing outlet apron. Figure 9-1 shows the outlet and fish ladder prior to modification (left) and post modification (right). The outlet modification replaced the fish ladder and apron with three notched concrete weirs designed based on the layout of a pool-and-chute fishway. This is a hybrid pool-and-weir type fish ladder designed to provide passage over a wide range of flows. The weir shape includes a center rectangular notch (the "chute") and sloping shoulders on either side of the notch. At higher flows this fishway type is designed to have swift and turbulent streaming flow through the notch and slower plunging flow over the wetted edges of the sloping shoulders. The plunging flow and less turbulent pool conditions along the margins of the fishway provide a passage corridor for upstream migrating fish.

At the Rattlesnake Creek crossing the orientation of each weir is angled towards the left to direct the outlet flow away from the downstream right bank, which had been experiencing significant erosion. Additionally, the cross slope of each weir's right shoulder is steeper than the left, at 7.5H:1V verses 10H:1V. This also helps turn the flow towards the left. A steel cap has been placed over the upstream face and top of the concrete weirs to protect them from impact associated with large substrate and debris.

In addition to these modifications of the outlet, a rock weir was installed at the outlet pool tailwater control (TWC) downstream of the concrete weirs to maintain minimal drop height over the low flow notch of the most downstream weir. The as-built drawings show the weir constructed of ½ ton to 2 ton rock toed in 4 feet below the channel bed.

9.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in July 2019 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions. Photos taken during the field assessment are provided in Figure 9-2. A dead adult lamprey was observed in the outlet pool during the site visit.

The concrete weirs appeared in good physical condition and functioning as intended, with their orientation keeping the main flow downstream of the fishway to the left, thereby mitigating the erosion on the exposed right bank. Table 9-1 summarizes the pool and notch flow characteristics during the site visit. The weir notches are broad and low flow through the weir notches creates localized shallow, fast flow that may be challenging to juvenile or resident passage (Figure 9-3). The pool depths were measured upstream and downstream adjacent to the concrete weirs. The notch depths were measured at the upstream and downstream edge of each notch opening. Flows were at low summer baseflow conditions.

The upstream weir backwaters the culvert bottom and, combined with the crossing's slightly adverse slope, the crossing invert has captured and is maintaining a natural substrate bottom on top of the concrete invert throughout most of its length.

Most of the rock used to form the boulder weir constructed as the tailwater control appear to have mobilized, with existing cobbles and a few pieces of riprap currently forming a coarse riffle at the tailwater control (Figure 9-2e). At low flows this control was functioning adequately, backwatering the notch in downstream most fishway weir.

TABLE 9-1. WEIR CONDITIONS DURING FIELD SITE VISIT IN JULY 2019

	Pool Depth (ft)		Notch Depth (ft)	
Weir	**Upstream**	**Downstream**	**Upstream**	**Downstream**
1 (Most US)	**2.2**	**1.7**	**0.45**	**0.25**
2 (Middle)	**2.1**	**2.4**	**0.75**	**0.55**
3 (Most DS)	**3.2**	**3.5**	**0.75**	**0.55**

9.1.3 SITE OBSERVATIONS OF CHANNEL

Upstream of the project the creek runs parallel to state route 101 and in many sections the channel is confined by the road prism. The crossing inlet width is less than the upstream active channel width, 21 feet inlet compared to 30 feet active channel width, and high flows appear to have preferentially sorted and deposited much larger bed substrate in the upstream channel compared to the downstream channel (Figure 9-2a & f). The presence of large boulders in the upstream channel extends upstream well beyond the inlet influence likely due to higher velocities present in the more confined and steeper slope upstream channel. The outlet flow exiting the fishway follows the new fishway orientation guiding high velocities away from the right bank (Figure 9-4). The outlet pool and downstream channel appear stable.

9.2 Channel Morphology and Profile

9.2.1 CHANNEL SLOPES

The DEM from the 2018 and 2019 USGS LiDAR was used to generate an extended longitudinal profile through the project site (Figure 9-5 and

Figure 9-6). The project reach appears to be located a couple hundred feet downstream of a channel slope transition from an average slope of 0.8 percent to a steeper 1.4 percent slope through the project reach. Just upstream of the crossing inlet there is an abrupt slope section of approximately 3.3 percent (segment F,

Figure 9-6). This section of channel is characterized by steps formed by large boulder jams. It could be a result of frequent backwater from the crossing, causing boulders to deposit in the upstream channel, thus forming this knickpoint. However, it could also be a result of large material being input to the stream from an adjacent earthflow given the observed instability of the northern hillslope.

9.2.2 CHANNEL WIDTH AND DEPTH

Channel active and bankfull widths were measured in the upstream and downstream channel and at the outlet pool TWC (Table 9-2). Bankfull widths are similar throughout but the active channel widths downstream were less than upstream. This difference may reflect the secondary channel present downstream of the crossing that conveys a portion of the flow during large events. With an active channel width of 30 feet and an inlet width of 21 feet, the crossing does constrict the natural channel.

TABLE 9-2. CHANNEL DIMENSIONS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream of Project	**30**	**35**
Downstream at outlet TWC	**26**	**42**
Downstream in natural channel	**20**	**36**

9.3 Discussion

9.3.1 FISHWAY WEIRS

The fishway weirs are generally functioning as intended. The pools are capturing some sediment but are maintaining good pool depth throughout most of their volume. The drop heights from each notch into the downstream pool were all 0.5 feet or less during the site visit. Notch velocities were not measured during the site visit but it appears that the notch geometry, with its 1.5-foot thickness and flat longitudinal surface, creates fast, shallow skimming flow during low streamflows. This may pose a challenge to juvenile salmonids that attempt to move upstream, as they may leap onto the broad weir crest and then have to swim through shallow and fast water velocities. The notch condition may also pose a challenge to lamprey given the right-angles on the weir face that can block these fish. Modifying the notch geometry to replace the current rectangular shape with a more rounded top could be considered to improve passage, especially for lamprey one of which was observed at the site.

The installed orientation of the fishway weir structure is effectively redirecting high flows away from the downstream right bank and minimizing erosion (Figure 9-4). The fishway, however, does not have a right bank side wall that provides freeboard during moderate to high flows.

This allows water to overflow the weir structure at depths that fully submerge the weirs. When this overflow occurs, it is promoting erosion and erosive eddy formation on the right bank and outer edge of the outlet weir structure (Figure 9-4 and Figure 9-2d). Additionally, the lack of freeboard along the side of the fishway poses a risk that fish may leap or swim over the side of the fishway, causing fallback to downstream, physical injury, and/or stranding of the fish. Generally, at least 2 feet of freeboard should be provided along side walls for fish passage at all fish passage flows.

9.3.2 GRADE CONTROL

The tailwater control at the outlet pool appears stable at low flows. It appears that most of the rock weir installed at this location has mobilized but some components may remain and are now mostly buried. The outlet pool riffle's exposed rock is mostly deposited bedload and was maintaining the outlet pool water elevation such that good low flow passage conditions exist for entry into the fishway.

FIGURE 9-1. RATTLESNAKE CREEK CROSSING OUTLET BEFORE AND AFTER MODIFICATION. PHOTOS PROVIDED BY M. MOLNAR, CALTRANS.

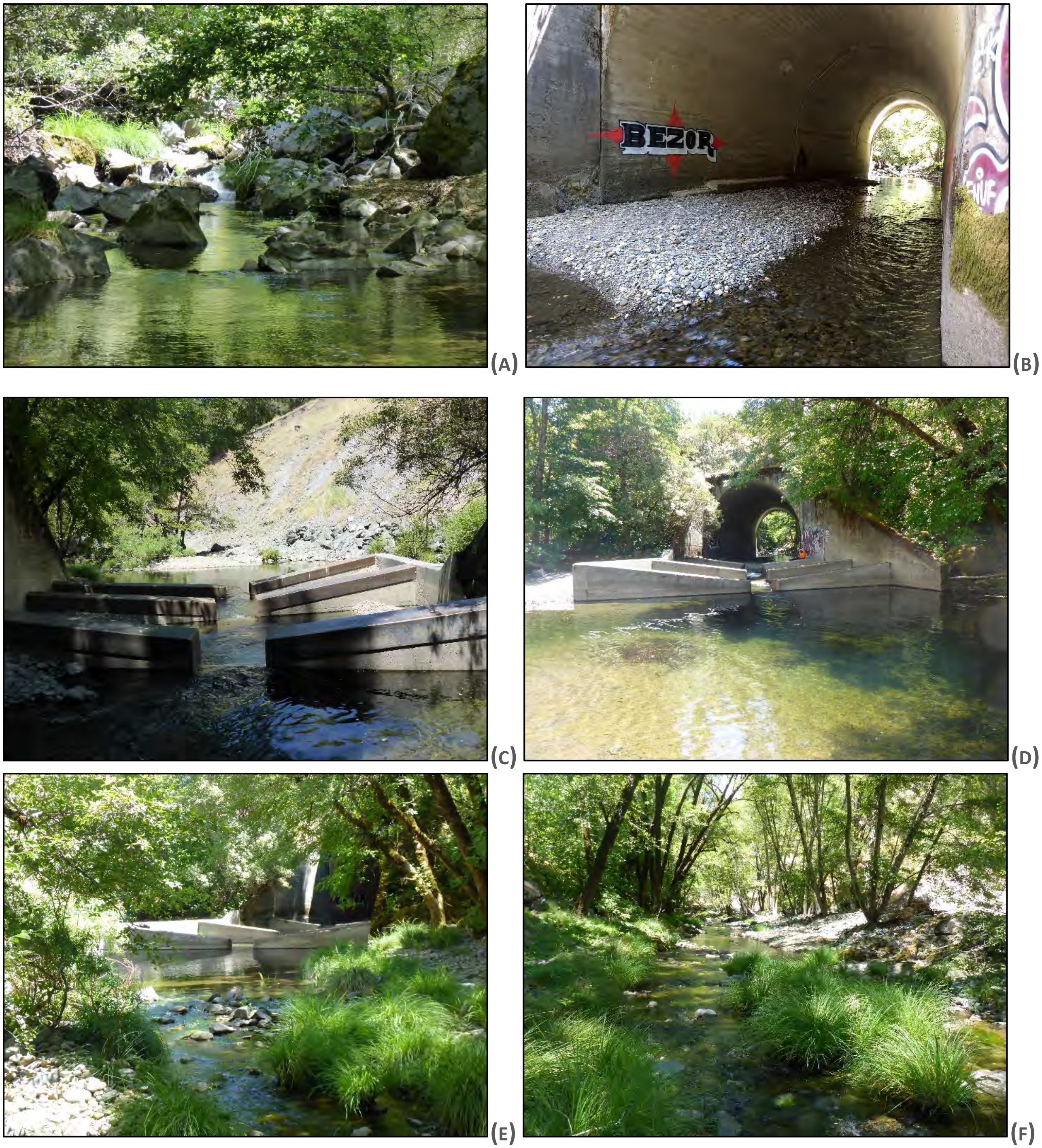
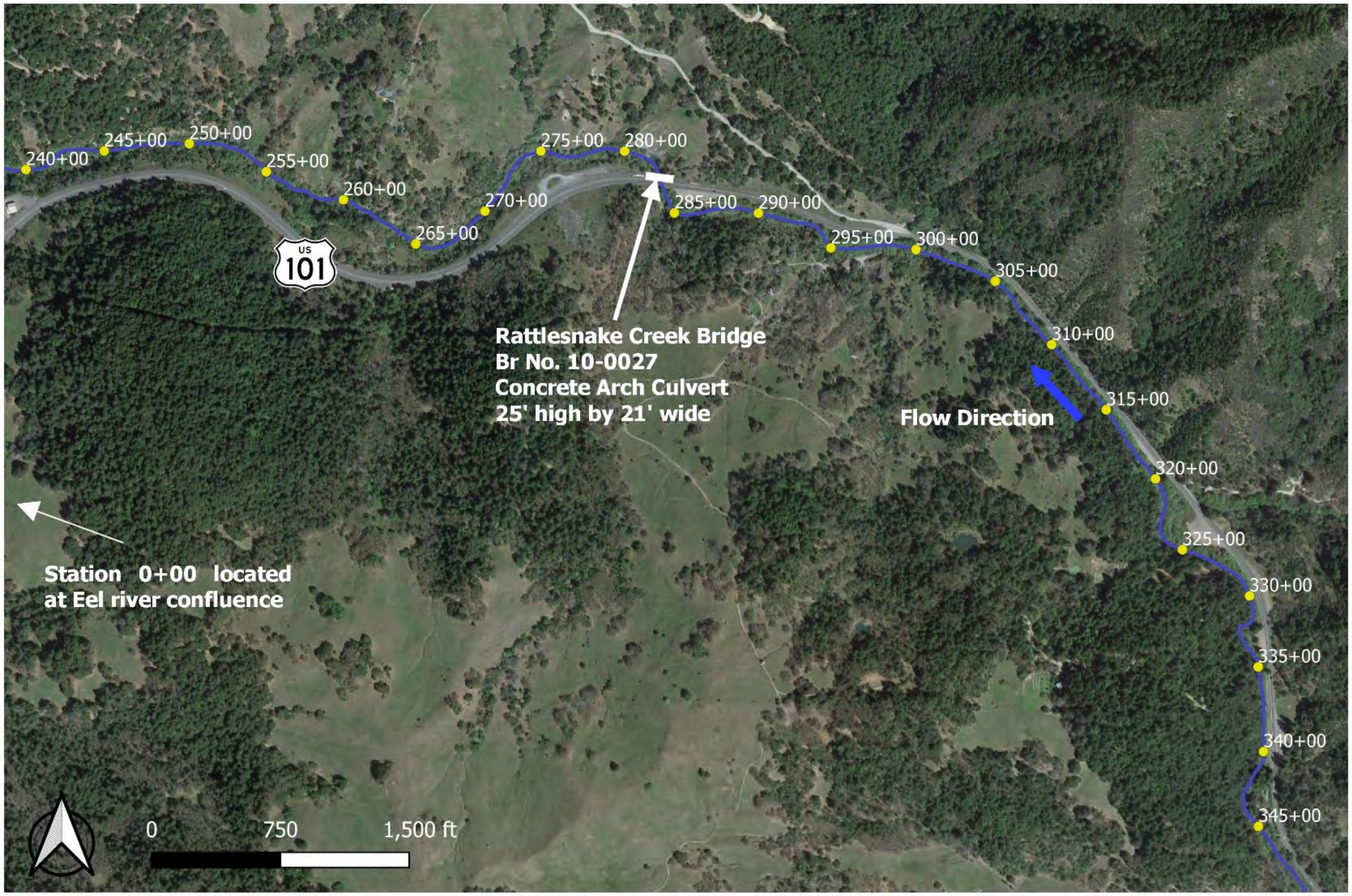


Figure 9-2. Ratttlesnake Creek (A) upstream channel (B) culvert barrel is retaining substrate and forming a low flow channel (C & D) outlet pool and weir fishway, (E) outlet and fishway looking upstream from the outlet pool TWC, and (F) downstream channel. All photos taken July 17, 2019.

Figure 9-3. The weir notches on the outlet fish ladder are broad, creating localized shallow, fast flow. Weir 1 shown here had the shallowest depths (0.45 ft on the US side, 0.25 ft on the DS side). At some flows the notch conditions might exceed fish passage swimming criteria, especially for juvenile salmonids. photos taken July 17, 2019.

Figure 9-4. Rattlesnake Creek outlet during high flow. The primary flow exiting the fishway follows the new fishway orientation away from the right bank. An eddy forms on the right creating some scour along the side of the fishway. Photo taken February 27, 2019 by M. Lang.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Image Source: Google 2015

Rattlesnake Creek
MEN 101 PM 81.40

Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing Project\4 Site Assessments\9 Rattlesnake Creek(MEN 101-

FIGURE 9-5. OVERVIEW SITE MAP FOR RATTLESNAKE CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

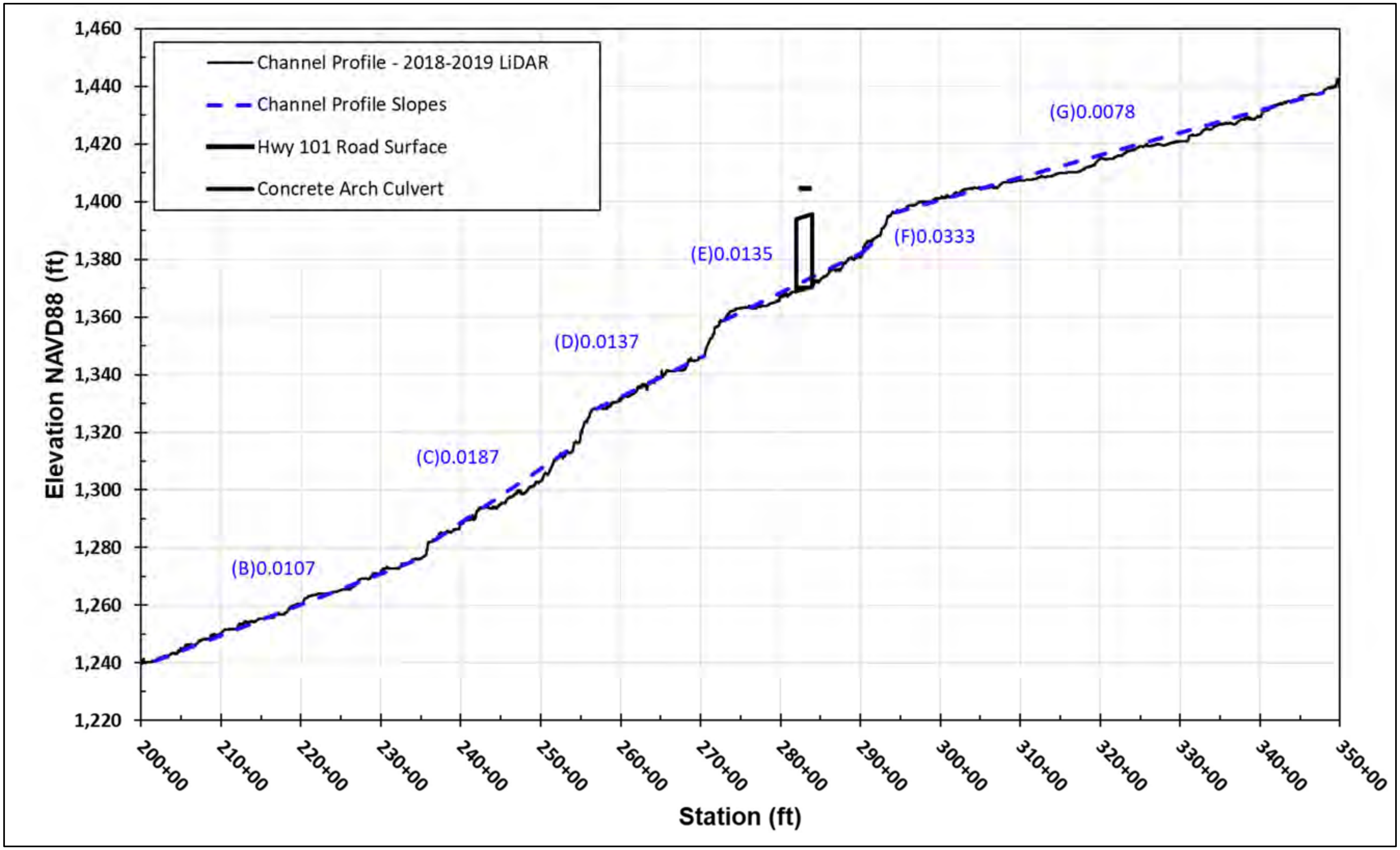


FIGURE 9-6. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE LIDAR DEM WITH CHANNEL SLOPE SEGMENTS DEFINED.

10 CEDAR CREEK (MEN 101 – PM 89.04)

10.1 Project Description

10.1.1 DESIGN AND AS-BUILT CONDITIONS

The Cedar Creek crossing on US 101 in Mendocino County is a large concrete arch culvert with a base width of 22 feet and height of approximately 21 feet. The crossing was built in 1967 with a Denil fish ladder at the outlet (Figure 10-1). The original fish baffles in the culvert were rehabilitated in 1999 and replaced in 2018. The 2018 modifications included 24 weirs within the culvert. In 2017 the outlet was rebuilt as a concrete pool and weir fishway that spans the entire channel. The fishway consists of 13 weirs and two channel spanning rock weirs downstream of the fishway for grade control to maintain the design weir drop height. The concrete weir lengths vary. In the culvert they are 20 to 22 feet in width. In the outlet fishway the widths increase in the downstream direction as the apron and channel width increases, from 20 feet to approximately 60 feet. The concrete weir crests have a trapezoidal shape with a horizontal or notched section in the middle and 5H:1V sloping shoulders that extend outward. The fishway weirs are aligned perpendicular to the stream alignment as it makes a 90-degree channel bend downstream of the culvert. The slope shoulder of the weirs has a rounded crest on the left side and a square crest on the right side. The rounded crest was designed to provide for upstream passage of Pacific lamprey while the square crest along the right side was designed to create a plunging nappe that supports leaping of juvenile salmonids over the weirs. Design drawings provided by Caltrans indicate that the weirs inside the culvert had variable drop heights while the fishway weirs were designed with 8-inch (0.67 ft) drop heights and spaced 10 feet on-center. The spacing between boulder weirs was designed as 25 feet and the drop height over the downstream most concrete weir and the boulder weirs was designed to be 1-foot.

10.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in April and June 2021 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions. Figure 10-1 shows the perched grouted rock apron outlet and fish ladder prior to the 2017 modifications. Photos taken during the two field assessment site visits are provided in Figure 10-2. The concrete weirs appear to be functioning well for fish passage, however, the drop heights over adjacent weirs are somewhat variable ranging from 0.5 to 0.8 feet as measured during the June 3, 2021 site visit (Table 10-1). The rock weirs installed downstream of the fishway have failed and the rocks forming the weir portions within the active channel having been displaced downstream (Figure 10-2e). Despite the weir rock displacement, the channel bed elevation controlling the tailwater level at the fishway entrance (downstream end) remains close to the intended design elevation, creating a drop height of 1.25 feet at the most downstream fishway weir compared to the design 1-foot drop. The tailwater control is being maintained by natural streambed substrate and fish passage through this section is not compromised.

The pool depths within the fishway were visually assessed and the tailwater pool below the fishway was measured at just over 5 feet deep. This pool contained abundant juvenile salmonids during the June 2021 site visit. The pools between weirs were not retaining significant sediment which may indicate high turbulence within the fishway that keeps them scoured. Fishway hydraulics at higher fish passage flows was not observed as part of this project.

TABLE 10-1. WEIR CONDITIONS DURING FIELD SITE VISIT IN JUNE 2021.

Weir	Drop Ht (ft)		Weir	Drop Ht (ft)
1 (Upstream)	0.5		8	0.5
2	0.6		9	0.5
3	0.7		10	0.5
4	0.8		11	0.5
5	0.6		12	0.5
6	0.8		13 (Downstream)	1.25
7	0.5			

10.1.3 SITE OBSERVATIONS OF CHANNEL

The upstream and downstream channels are both confined in a steeply sloped valley. They have nearly identical active and bankfull channel widths and similar substrate (Figure 10-2A and F). There are bedrock outcrops that form pools and control grade, with the frequency of these features increasing moving downstream from the crossing towards the confluence of Cedar Creek with the South Fork Eel River. In general, the existing culvert crossing width, at 22 feet, is substantially narrower than the active and bankfull channel widths.

TABLE 10-2. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream of Project	37.5	45
Culvert	22	22
Downstream at outlet TWC	36	45

10.2 Channel Morphology and Profile

The DEM from the 2018 and 2019 USGS LiDAR was used to generate an extended longitudinal profile extending through the project site (Figure 10-3 and Figure 10-4). The crossing is located approximately 500 ft upstream of the confluence of Cedar Creek with the South Fork Eel River and the overall project and channel slope is very consistent at an average of 1.5 percent over the entire extended longitudinal profile. The culvert slope matches the natural channel slope and there is no indication of distinct slope breaks. The channel slope consistency and similarity of the channel substrate and active and bankfull channel widths in both the upstream and downstream reaches suggest a stable stream channel.

10.3 Discussion

FISHWAY

The 13-weir fishway installed at the culvert outlet appears to function as intended but does have some condition issues and characteristics that could be improved. These are primarily related to the quality and integrity of the concrete work and patching around the steel weir protection plates. As shown in Figure 10-5 and Figure 10-6, several of the weirs have abrupt, sharp corners that create flow separation of the nappe. On other weirs, this edge appears to have been chiseled smooth and grouted to create better flow conditions over the weir crest. The potential issues with the flow separation are two-fold:

1. The rounded weir top section installed to promote adult lamprey passage is not maintained as a continuously wetted surface.

2. The flow separation creates a nappe that begins approximately 0.25 feet below the actual weir crest. This may cause a signal that hinders passage by leaping as commonly used by juvenile and resident salmonids.

Observation and modification of the weir tops is recommended. In addition, sections of the concrete work, especially patchwork at section intersections or changes in material, appear to be crumbling and should have periodic inspection.

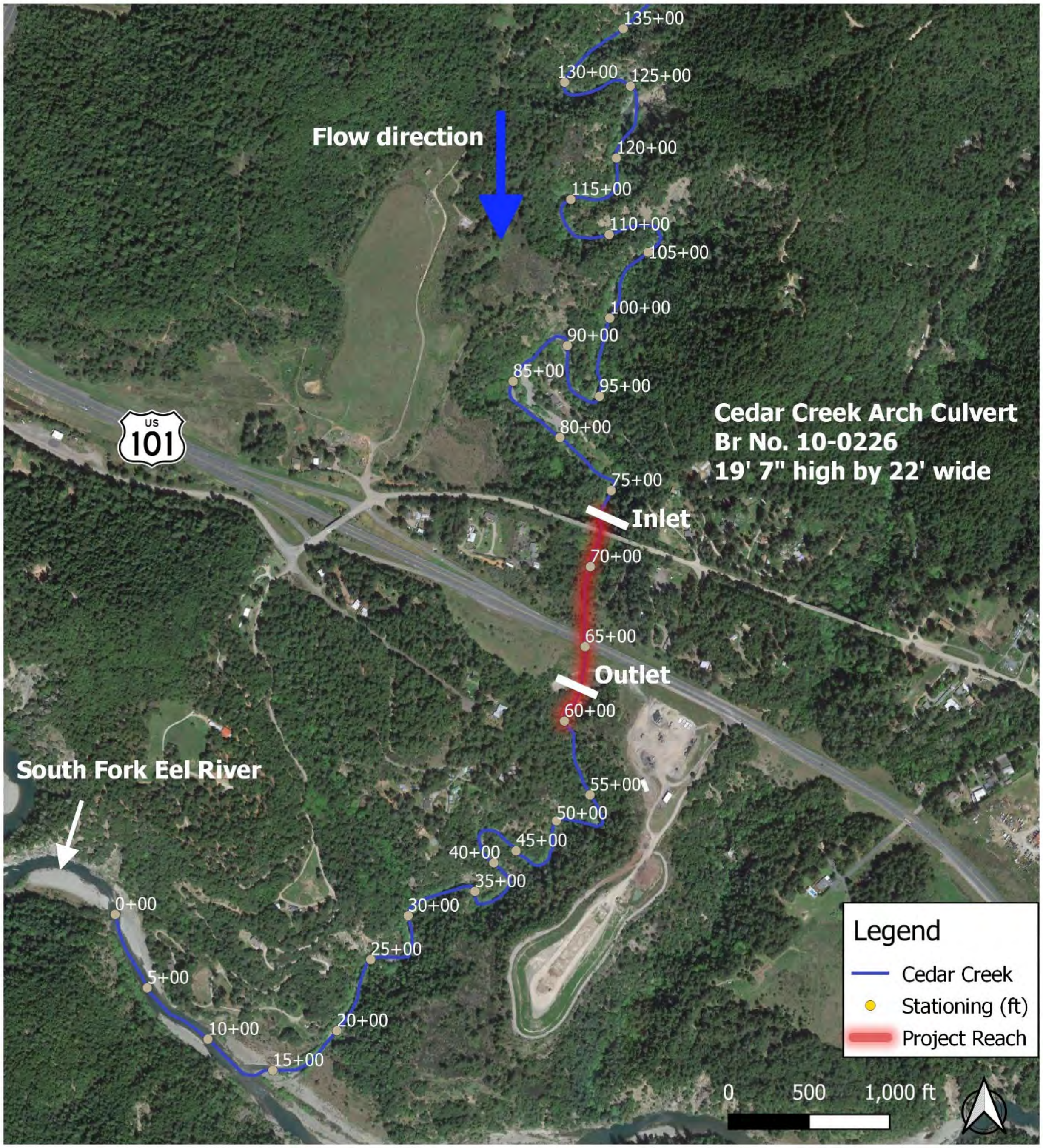
Hydraulics of the weirs inside the culvert and the fishway at higher fish passage flows have not been observed to verify that passage conditions are suitable and turbulence is not excessive. Additional monitoring and observations would also be valuable at this site to characterize the influence of the rounded and square weir crests on fish passage hydraulics and pool circulation patterns at various flows. Evaluation of lamprey usage of the rounded weir crests is also needed given the uniqueness of this design feature and its potential for application at additional sites if it provides a solution that promotes both salmonid and lamprey passage.

ROCK WEIRS

The rock weirs installed to maintain grade control and a drop of 1 foot over the fishway entrance have partially failed. However, the existing downstream cobble/gravel tailout is maintaining a low flow drop height of 1.25 feet at the fishway entrance weir. Downstream of this control is a large pool confined by bedrock outcrops on both sides. This pool and confined channel (Figure 10-2f) likely become the control at high flow, backwatering the rock weir location. Under these conditions, deposition of bedload at the low flow tailout would occur such that it should remain stable over the long-term. A site visit and photographs from the culvert outlet at flood flows could confirm these flow conditions.

FIGURE 10-1. CEDAR CREEK CROSSING OUTLET AND FISH LADDER BEFORE THE 2017 MODIFICATIONS. PHOTO ON LEFT PROVIDED BY M. MOLINAR CALTRANS, PHOTO ON RIGHT BY M. LANG.

FIGURE 10-2. CEDAR CREEK (A) UPSTREAM CHANNEL, (B) CULVERT BARREL SHOWING INSTALLED WEIRS, (C) OUTLET POOL AND WEIR FISHWAY, (D) CLOSEUP OF THE SQUARE (LEFT) VS. ROUNDED (RIGHT) WEIR CRESTS, (E) LOOKING UPSTREAM AT THE OUTLET POOL TAILOUT AND ROCK WEIR REMNANTS, AND (F) DOWNSTREAM CHANNEL.



Datums: Horizontal: NAD83 State Plane CA Zone 1 Vertical: NAVD88	**Cedar Creek** MEN 101 PM 89.04	Caltrans Design Guidance for Full-Span Crossings Fish Passage Restoration Project
Image source: Google 2015	**Site Map and Channel Stationing**	HSU Sponsored Programs Foundation Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\10_Cedar_Creek(MEN_101-PM89.04)\4_GIS\cedar.qgz

FIGURE 10-3. OVERVIEW SITE MAP FOR CEDAR CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA AND STATIONING.

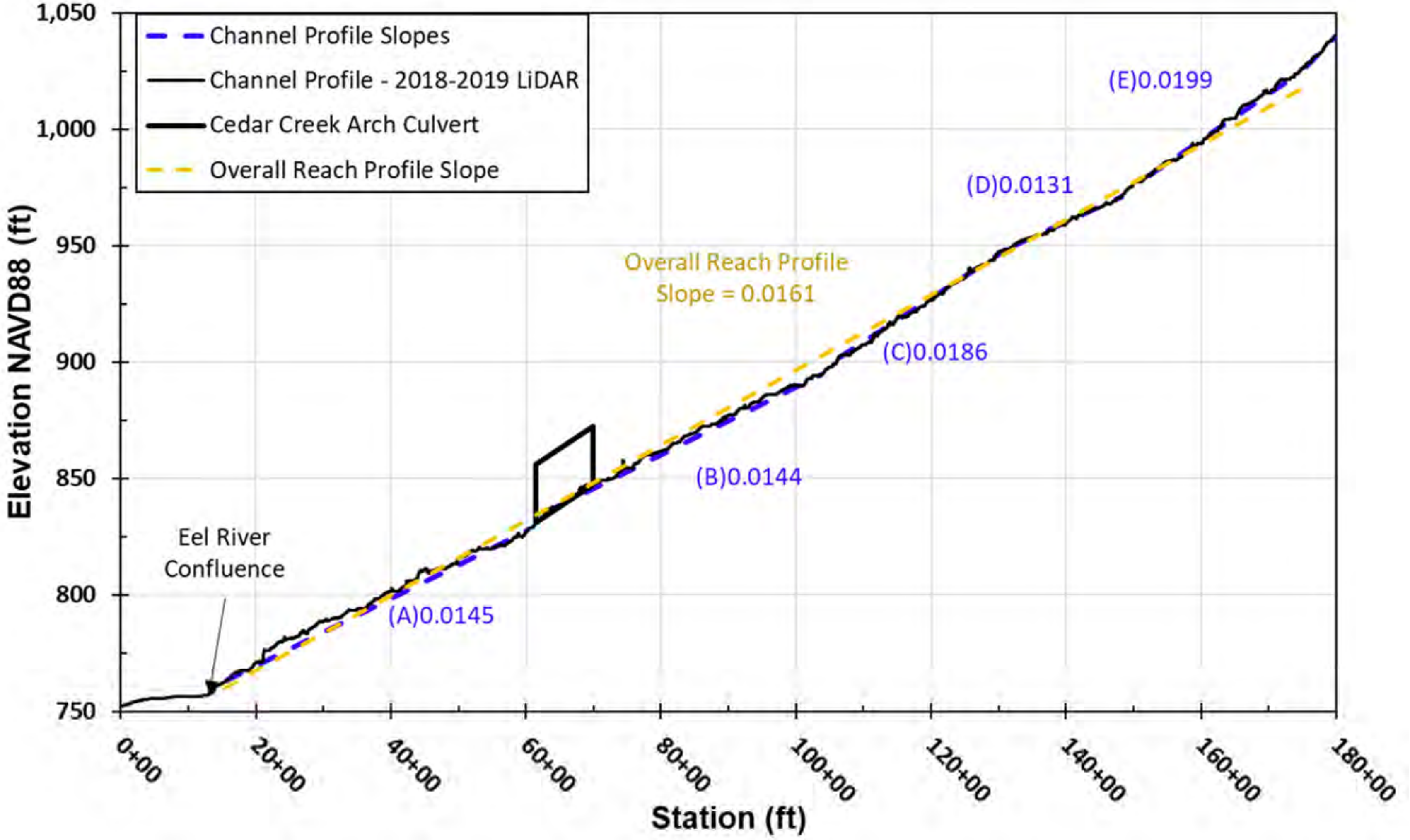


FIGURE 10-4. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE LIDAR DEM WITH CHANNEL SLOPE SEGMENTS DEFINED.

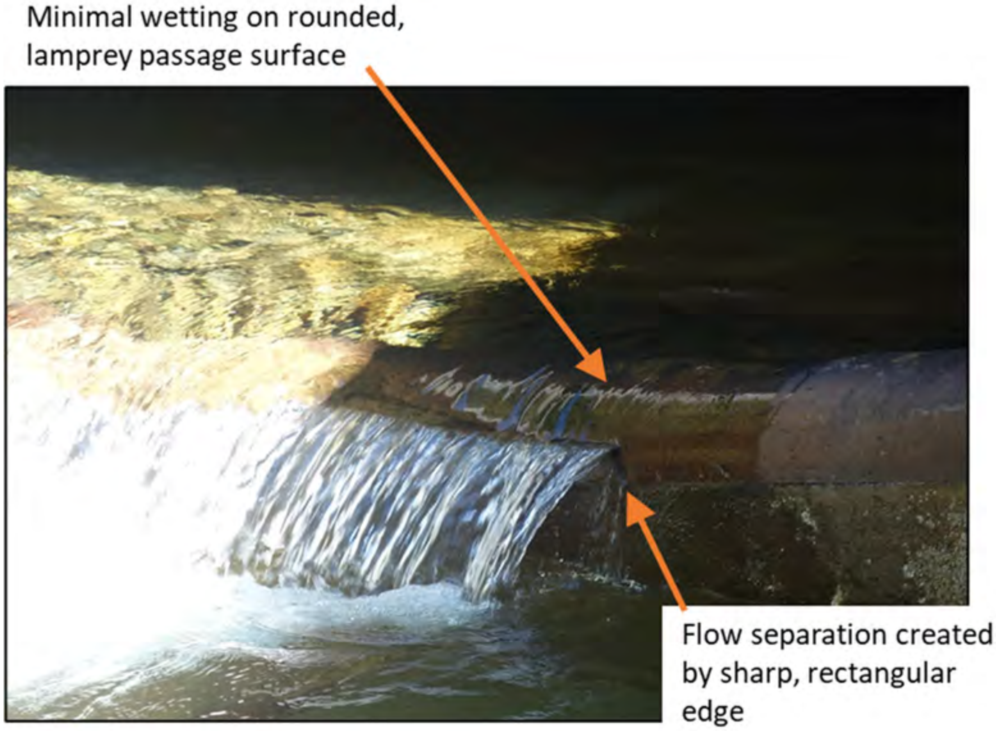


FIGURE 10-5. SOME OF THE OUTLET FISHWAY WEIRS HAVE SHARP EDGES AND PROTRUSIONS THAT MAY NOT BE EFFECTIVELY WETTING THE LAMPREY PASSAGE PORTION OF THE WEIR AND CREATE FLOW SEPARATION THAT COULD HINDER JUVENILE SALMONID PASSAGE. PHOTO TAKEN JUNE 3, 2020 BY M. LANG.

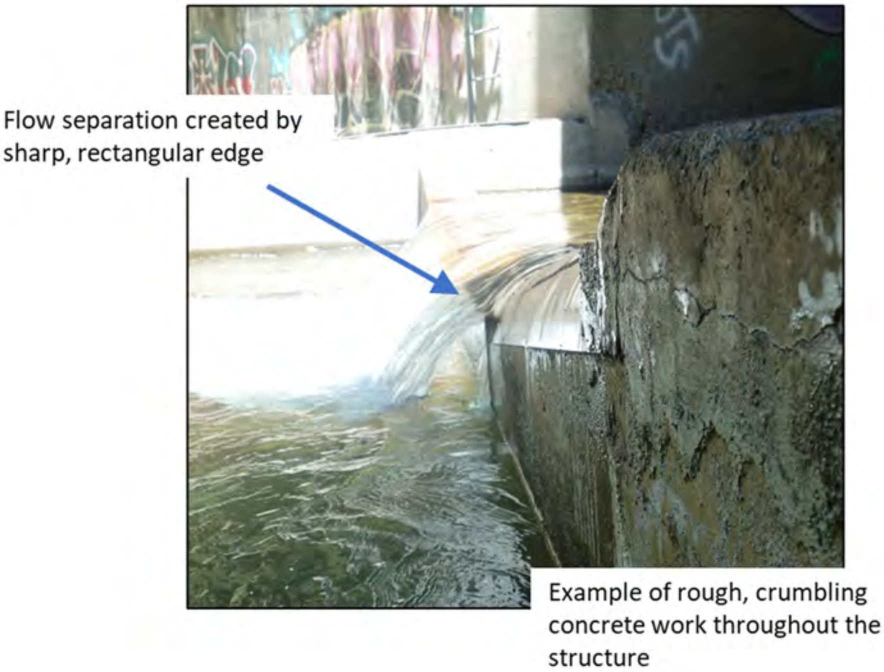


FIGURE 10-6. SIDE VIEW OF FLOW SEPARATION DUE TO A SHARP, RECTANGULAR EDGE ON WEIR 1, THE MOST UPSTREAM WEIR AT THE CULVERT OUTLET. PHOTO TAKEN JUNE 3, 2020 BY M. LANG.

11 YANK (LEMM) CREEK (SHA 299 – PM32.25)

11.1 Project Description

11.1.1 DESIGN AND AS-BUILT CONDITIONS

Yank Creek crosses under State Route 299 just downstream of the confluence with Little Valley Creek. The combined drainage area for these two streams is approximately 5.45 square miles. The Yank (Lemm) Creek crossing on State Route 299 in Shasta County was replaced by a full spanning bridge in 2015 as part of the Bella Diddy Rehabilitation Project. Prior to the replacement, the crossing consisted of three concrete box culverts; two were 8 feet wide by 6 feet high and one was 10 feet wide by 6 feet high constructed in 1933 (Figure 11-1). The original crossing was not capable of conveying the 100-year return period flood without overtopping the roadway and beyond its service life. The 2012 Caltrans Structures Hydraulics analysis of the site estimated the water surface elevation at the 100-year return period flow and recommended a minimum bridge soffit elevation that provides 1.2 feet of freeboard. The new bridge increased the crossing capacity with more than four times the previous crossings cross sectional open area and improved the channel alignment relative to the crossing.

The original channel of Yank Creek was skewed approximately 20 degrees to the roadway. The channel was modified to enter the 1933 box culverts with a 90-degree realignment at both the inlet and outlet, resulting in abrupt turns in the flow to enter and exit the culverts. The new bridge crossing restored the historical alignment in the upstream channel and through the bridge opening using skewed bridge abutments, but the downstream channel remains problematic. Just downstream of the bridge, the channel is forced through a 90-degree bend to the right as it impacts an armored RSP streambank protecting adjacent private property.

11.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in October 2019 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions. Photos taken during the field assessment site visit are provided in Figure 11-2. Figure 11-1 shows the original box culvert crossing and the bridge replacement constructed in 2015. The channel through the bridge crossing is wide and flat in cross section compared to the upstream and downstream channel reaches, which could result in shallower flows through the crossing than in the natural channel. Also of note was the abrupt bend in the channel alignment and migration of the channel thalweg, especially downstream of the crossing, which might influence the crossing conveyance and create localized sediment aggradation and erosion issues.

At high flows, water moves through the crossing at an angle from the left bank upstream to the right bank downstream. The channel thalweg is adjusting through the crossing to re-orient to the historic channel alignment (Figure 11-2B&C, Figure 11-1). The channel is not aligned with its historic thalweg at the outlet and undergoes a sharp, 90-degree right bend just downstream of the crossing (Figure 11-2E&F). Downstream of the outlet, the channel appears to be attempting to realign by depositing sediment on the left bank causing the channel thalweg to migrate to the right. However, the channel is constricted in migrating to the right by the outlet wingwall and a downstream channel confined by claystone and bedrock.

Debris from a recent high flow event was observed wracked on the cable railing at the crossing's left inlet and right outlet wingwalls (Figure 11-2b&d). The railing on the inlet side had been bent and there was scour around the wing wall due to overtopping. These locations are notably on the inside of the abrupt channel bends as flows enter and exit the bridge crossing. The 2015 bridge inspection report showed that a high flow event shortly after construction caused substantial scour around the back of the inlet wingwall and into the roadway embankment, leading to placement of RSP in this area.

11.1.3 SITE OBSERVATIONS OF CHANNEL

Upstream and through the project site, the channel substrate is well graded sand and gravel transitioning into some claystone and bedrock-controlled channel sections downstream. The channel cross section is more confined and steeper downstream of the bridge and associated 90-degree bend, which limits substrate deposition in these locations.

The active and bankfull channel widths upstream and downstream of the crossing are similar. Under the bridge, where the channel is reorienting to its historic alignment, the channel thalweg is less defined and shallower than in the adjacent natural channel. The slope through the crossing is also lower than in the adjacent channel so the channel under the bridge has widened as is evident from the larger active and bankfull channel widths (Table 11-1). The channel under the bridge has well defined depositional bar along the right side but no bankline along the left (Figure 11-2C).

TABLE 11-1. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream channel above crossing influence	23	28
Just upstream of inlet wingwalls	22.5	28
Under bridge measured perpendicular to flow to match the channel thalweg realignment	38	46.5
Downstream channel after 90-degree bend	24.5	25.5

11.2 Channel Morphology and Profile

The DEM from the 2019 USGS LiDAR was used to generate a longitudinal profile extending through the project site (Figure 11-3 and Figure 11-4). The channel upstream and through of the Yank Creek crossing has a consistent slope of approximately 0.4 percent. At the crossing outlet, there is some aggradation with a 2- to 3-foot bed elevation increase evident in the longitudinal profile. This zone of aggradation matches field observations of sediment deposition and channel thalweg migration to the right at the bridge outlet. Downstream of this zone, there is a short, steep channel section that likely represents the claystone, bedrock-controlled channel sections noted during the field site visit Figure 11-5.

11.3 Discussion

11.3.1 BRIDGE SKEW AND RESULTING CHANNEL RESPONSE

Except for isolated, stagnant pools along the channel thalweg, the channel was dry at the time of the site visit. The channel thalweg was well defined through the crossing and matching elevation, high flow debris deposits were present on the left, inlet wingwall and right, outlet wingwall (Figure 11-2B&D). These debris deposits suggest that the crossing alignment, though improved, still restricts the channel from reoccupying its historical alignment. High flow partially submerges and spills over the left wingwall creating a scour pool and RSP has been added upstream to mitigate wingwall erosion (Figure 11-2B). Flow enters the crossing on the left bank then the thalweg migrates left-to-right through the crossing to exit adjacent to the outlet right bank wingwall. The matching debris deposit on the outlet wingwall indicates that high flows also partially submerge the outlet wingwall and that the channel is attempting to continue to migrate to the right at and downstream of the outlet.

Channel migration to the right at the outlet could be beneficial as this flow orientation directs high energy flows away from the armored left bank and could decrease the bank erosion potential for adjacent landowners. A possible mitigation might be to increase the wingwall skew (left at the inlet and right at the outlet) to better accommodate and guide the channel's realignment tendencies and move flow further away from the armored left bank downstream of the outlet.

11.3.2 USE OF 2D HYDRAULIC MODELS TO BETTER INFORM DESIGN

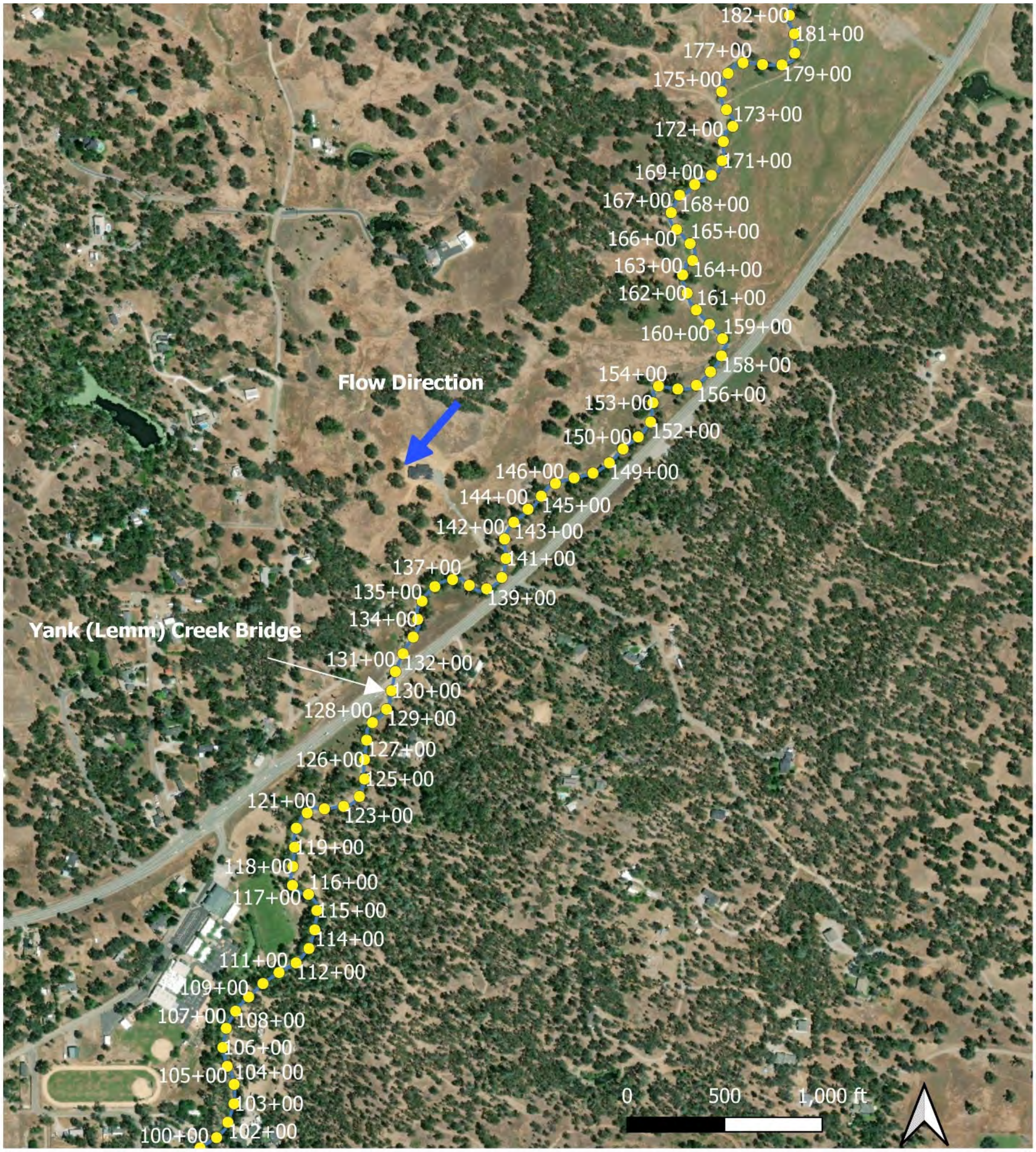
According to the project's hydraulic report, the crossing hydraulics were evaluated using a one-dimensional HEC-RAS model. Crossings with abrupt bends or issues concerning skewed inlets and outlets often warrant using two-dimensional hydraulic analysis, such as the HEC-RAS 2D and SRH-2D models. These tools can inform the designer of specific areas that may be prone to scour and erosion or sedimentation. At this site, the 2D results could have informed the layout of the wingwalls to improve the flow transition into and out of the bridge crossing.

11.3.3 STREAM WIDTH THROUGH CROSSING

The active channel through the bridge opening is substantially over-widened compared to the adjacent upstream and downstream channel, which could lead to insufficient depth through the crossing when the rest of the channel is passable. Based on photos from 2015 and 2017 bridge inspection reports, the channel bed under the bridge has been actively changing, with both aggradation and scour occurring at different times. The constructed project appears to have not included the construction of streambanks through the crossing, although a line of riprap was placed along the toe of the right bridge abutment. Building rock-filled streambanks through the bridge opening to confine the bankfull channel may have helped maintain a channel width through the crossing that is more similar to the adjacent natural channel width.

Figure 11-1. Yank (Lemm) Creek crossing before the bridge construction (top) and looking downstream at the replacement bridge in 2015 (bottom). The top, left photo is looking downstream at the crossing and the top, right photo is looking upstream showing the perched apron. Note the high water mark debris on the inlet, left wingwall. Photos provided by M. Molinar, Caltrans.

Figure 11-2. Yank (Lemm) Creek (a) upstream channel, (b) looking downstream at the bridge- note high water debris on left bank, (c) channel under the bridge showing skew from left to right bank (d) looking upstream at the bridge – note high water debris on right bank, (e) looking upstream at bridge and 90-degree channel bend, and (f) armored downstream channel after 90-degree bend. Photos taken Oct 4, 2019 by M. Love and M. Lang.



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88
Image Source: Google 2021

Yank (Lemm) Creek

SHA 299 PM 32.25

Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing

FIGURE 11-3. OVERVIEW SITE MAP FOR YANK (LEMM) CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

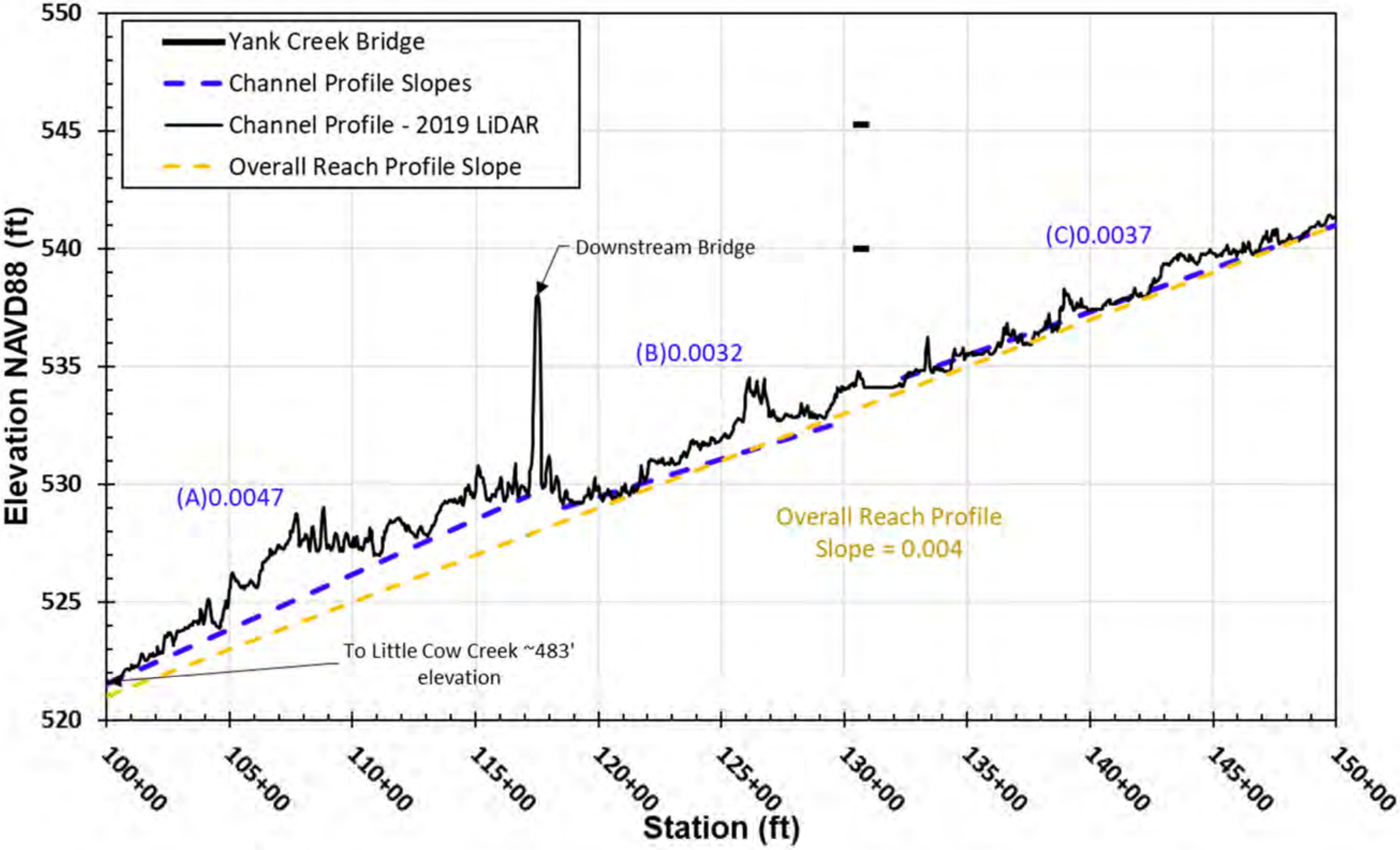


FIGURE 11-4. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE USGS 2019 LIDAR DEM, WITH CHANNEL SLOPE SECTIONS DEFINED.

Figure 11-5. Yank (Lemm) Creek (a & b) more confined downstream channel section with exposed claystone and bedrock controls. Photos taken Oct 4, 2019 by M. Love and M. Lang.

12 FORT GOFF CREEK (SIS 96 – PM 56.00)

12.1 Project Description

Fort Creek crosses under State Route 96 just upstream of its confluence with the Klamath River. The stream drainage area is approximately 13 square miles. Prior to replacement, the SR96 Fort Goff Creek crossing consisted of a 15-foot diameter corrugated metal pipe (CMP) culvert.

12.1.1 DESIGN AND AS-BUILT CONDITIONS

The Fort Goff Creek crossing is now a full spanning bridge with a 51-foot long clear-span, built in 2014 to replace the 15-foot diameter SSP that impeded fish passage (Figure 12-1). The bridge is a 36-foot wide, single span precast concrete structure constructed using a prefabricated bridge element system. The new bridge was designed to fully span the bankfull channel and allow for continuity of fish passage and geomorphological processes. The new bridge provides for conveyance of the 100-year flood, accounting for backwatering from the Klamath River located 250 feet downstream.

In addition to the bridge construction, 200 feet of streambed was constructed extending 75 feet upstream of the bridge centerline and 125 feet downstream. The channel grading raised the streambed elevation approximately 3 feet and filled the culvert's inlet drop and outlet pool. The as-built plans show a design channel slope through the project of 4.8 percent, with an upstream channel slope of 2.8 percent and downstream slope of 6.5 percent. The restored streambed consisted of 6-foot long by 2.5 feet thick grade control rock at the upstream and downstream boundaries and an engineered streambed material mixture between. The grade control rock size mixture was dominated by larger rock sizes while the streambed was slightly smaller (Table 12-1). The engineered streambed material mixture was developed based on measurement of the particle size distributions of gravel, sand and fines collected at the site. The streambed construction used specific placement of the largest RSP size classes to vary the position of large keystone rock locations along the channel cross section and create a more natural pattern of large boulders (Figure 12-2).

TABLE 12-1. GRADE CONTROL AND STREAMBED ROCK MIXTURES

Location	4-ton (%)	2-ton (%)	1-ton (%)	1/4-ton (%)	Backing #1 (%)	Backing #2 (%)	Engineered Bed (%)
Grade Control	**20**	**20**	**10**	**10**	**5**	**5**	**30**
Streambed	**5**	**5**	**10**	**30**	**10**	**10**	**30**

12.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in September 2019 for preliminary assessment and review. This site had a full field survey conducted in March 2021. Photos taken during the 2019 field assessment site visit are provided in Figure 12-3. Overall, the crossing and restored streambed were intact and functioning well. The streambanks constructed along the channel abutments have persisted. They form a bankfull channel that has similar dimensions to the natural channel. The channel bed through the project reach appeared to have similar structure, slope, and hydraulic conditions as the adjacent channel.

The upstream portion of the left abutment footing has scoured and was exposed and undercut for a length of approximately 10 feet (Figure 12-3d and Figure 12-4). The bank material on the left bank just upstream of the bridge was also experiencing some scour. The approaching channel bends to the right, likely resulting in higher velocity on the left bank at the upstream face of the bridge. The approaching channel bend appeared to be more pronounced in the field than shown in the as-built drawings. The extent of scour at the bridge and upstream bank showed no change between the September 2019 initial assessment and the March 2021 survey.

12.1.3 SITE OBSERVATIONS OF REFERENCE REACH

For assessment purposes, an upstream section of channel was selected as a reference reach, which was used to compare its morphology to that of the project reach. The upstream channel has similar step pool morphology as the project reach, consisting of large boulders and boulder clusters as controls (Figure 12-3a). The reference reach slope was slightly lower than the project channel slope, at just under 3 percent compared to approximately 5 percent. The cross-sectional shape of the reference reach (Figure 12-5) does not have as high of banks or as distinct of a bankfull channel as the project reach. This channel shape difference is likely due to the reference reach being upstream of the depositional zone at the stream-river confluence, which results in aggradation during backwater events followed by the stream incising through these sediment deposits. The reach was free of wood controls.

Measured stream channel active and bankfull widths in the project reach are similar to those in the reference reach (Table 12-2). The 51-foot bridge span allows natural channel banks throughout the crossing, with the exception of the upstream scoured section (Figure 12-4).

12.2 Channel Morphology and Profile

Figure 12-6 and Figure 12-7 show the channel alignment and more detailed plan map of the project extent and locations of cross sections and pebble count, respectively. The DEM from the 2018-2019 USGS LiDAR was used to generate an extended longitudinal profile extending through the project site (Figure 12-8). The crossing is located approximately 250 feet upstream of the confluence of Fort Goff Creek with the Klamath River (Figure 12-6).

12.2.1 CHANNEL SLOPES

The combined survey and DEM channel profiles in Figure 12-8 shows an overall channel slope of approximately 3.9% beginning at the Klamath River confluence and extending upstream for

5,500 feet. Local slope segments generally have lower slopes, with steeper control segments between them.

The crossing is located at approximately the upper extent of backwater from the Klamath River during high flows, resulting in a dynamic and steeper channel segment downstream of the project. Beginning at the bridge, the channel has a steep transition slope as it cascades into the river when not backwatered (Figure 12-9). Three slope segments were identified in this channel reach ranging from 5.3 to 10.8 percent slope. This channel reach contained deep pools and chutes through large boulders with very diverse velocity conditions.

From the bridge, extending upstream, the channel slope is relatively uniform at an average slope of 3.7%. The reference reach, a straight channel segment upstream of the bend, had three distinct slope segments ranging from 2.6 to 5.3%. The reference reach slope is slightly lower than the project reach slope but both channel sections have similar morphology and dimensions.

12.2.2 CHANNEL WIDTH AND DEPTH

Two cross sections were surveyed in the project reach and one in the upstream reference reach (Figure 12-5). The actively scoured bottom widths (active channel width) and bankfull channel widths were measured (Table 12-2), and key points are noted on the cross sections (Figure 12-5).

In general, the active channel (bottom) and bankfull widths in the project and reference reaches were approximately 23 feet and 27 feet, respectively. The exception are the channel widths just upstream of the bridge. There is some bank scour in the channel bend and just upstream of the bridge that has widened the channel. As noted above, the cross sectional shape of the reference reach (Figure 12-5) does not have as high of banks as the project reach.

TABLE 12-2. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream in reference reach	**23**	**26.5**
Upstream at channel bend apex	**23**	**29**
Immediately upstream of bridge	**33**	**44.5**
Under the bridge	**29**	**34**
Downstream of bridge	**23.5**	**27**

12.2.3 STREAMBED MORPHOLOGY AND SUBSTRATE

The channel substrate throughout the surveyed reach is dominated by cobble and boulder with very coarse gravel. The bed material generally appears stable. The channel contains steps and boulder clusters that provide structure and channel profile control and velocity diversity. The surface substrate size measured by pebble counts (Figure 12-10) in the project and reference reaches show that the project reach is coarser than the reference reach (Table 12-3).

TABLE 12-3. PROJECT AND REFERENCE REACH PARTICLE SIZES.

Location	D_{50} (mm)	D_{84} (mm)
Upstream in reference reach	**61**	**149**
Under the bridge	**72**	**177**
Downstream of bridge	**80**	**195**

12.3 Discussion

The stream channel at the crossing and beyond is a boulder controlled, step pool channel. The site hydraulics are dynamic and influenced by high flow backwatering from the Klamath River. Significant degradation, aggradation or evidence of major sediment transport events were not present in the project or reference reaches. The 51-foot full span bridge appears to provide sufficient capacity to accommodate stream processes and high flows. However, a slightly longer bridge would move the abutments further from the active channel and provide additional protection from abutment scour.

The 200 feet length of restored streambed appeared stable and intact during both site visits. The project reach design slope (4.8%) through the bridge opening matched the average surveyed slope of approximately 5%. The channel widths were similar to the channel widths measured in the reference reach. The large boulders placed in the project reach create similar hydraulic diversity as in the adjacent natural channel, which supports fish passage through these relatively steep channel segments. The streambanks constructed through the bridge crossing provide a slow-water margin at all stages, similar to the natural channel. They also provide a pathway for some terrestrial organisms to move up and downstream without going over the road.

The project reach maintained low flows on the surface similar to the reference reach during assessment at low flow conditions in September 2019 indicating that the engineered streambed material contained sufficient fines to prevent low flow dewatering by infiltration into the substrate. Overall, the streambed restoration appears to be very successful and maintains hydraulic continuity and habitat conditions comparable to the reference reach and upstream channel.

The only observed issue was scour of the bank and placed bank rock along the upstream, left bank. In this region, there was scour along the bank toe and loss of approximately 10 feet of placed rock over the bridge footing (Figure 12-3d and Figure 12-4). This location is the outer bank of a channel bend entering the project reach with bank scour also evident upstream of the project. Thus, it is likely that this bank is exposed to higher velocities that impinge the bank and promote scour. Large RSP was placed in the channel and along the bank during project construction to mitigate potential bank and footing scour but has not completely prevented scour (Figure 12-2a and Figure 12-4). During design development use of a two-dimensional hydraulic model to analyze flow conditions may have highlighted this area as needing larger and/or thicker rock or a change in the grading of the upstream bank and headwall to better protect this area from scour.

FIGURE 12-1. FORT GOFF CREEK CROSSING BEFORE THE BRIDGE CONSTRUCTION IN 2014. PHOTOS PROVIDED BY CALTRANS.

FIGURE 12-2. FORT GOFF CREEK BRIDGE AND STREAMBED FOLLOWING CROSSING REPLACEMENT (A) LOOKING DOWNSTREAM AT BRIDGE AND (B) LOOKING UPSTREAM AT BRIDGE. PHOTOS PROVIDED BY CALTRANS.

Figure 12-3. Fort Goff Creek (A) upstream channel, (B) looking downstream at the bridge, (C) Looking upstream at step pools in the project reach, (D) Local scour at upstream of left bank footing, (E) looking upstream at bridge, and (F) downstream channel. Photos taken Sept 19, 2019 by M. Love and M. Lang.

Figure 12-4. Upstream left bank scour (a) Looking downstream at scoured bank beneath the bridge and (b) looking upstream at rock possibly added later to protect the footing. photo taken Sept 19, 2019 by M. Lang.

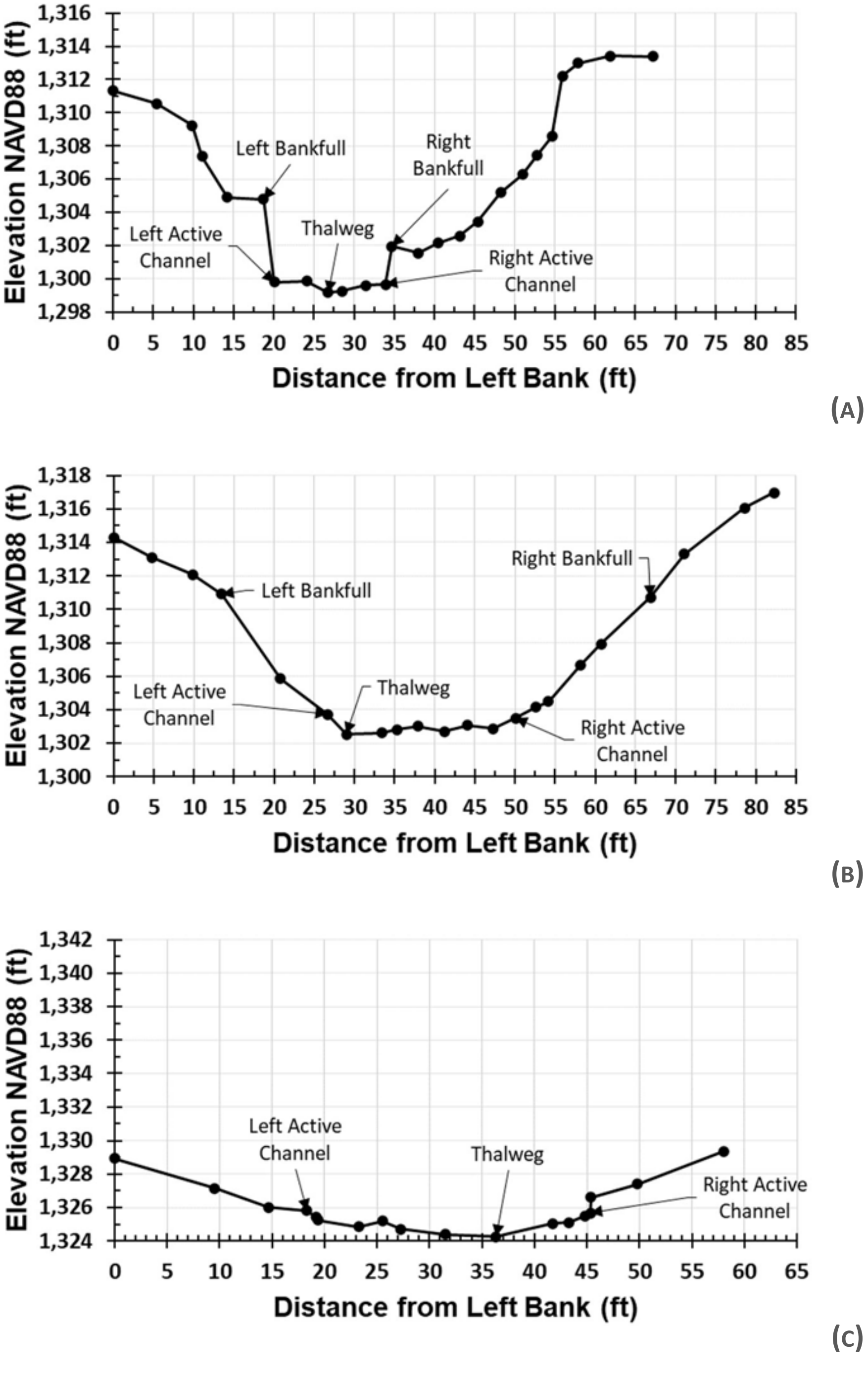


FIGURE 12-5. CROSS-SECTIONAL SURVEYS OF THE CHANNEL (A) DOWNSTREAM CHANNEL (XSDS1), (B) AT THE DOWNSTREAM OF THE BRIDGE (XSBDS), AND (C)IN THE UPSTREAM REFERENCE REACH (XSUSREF).

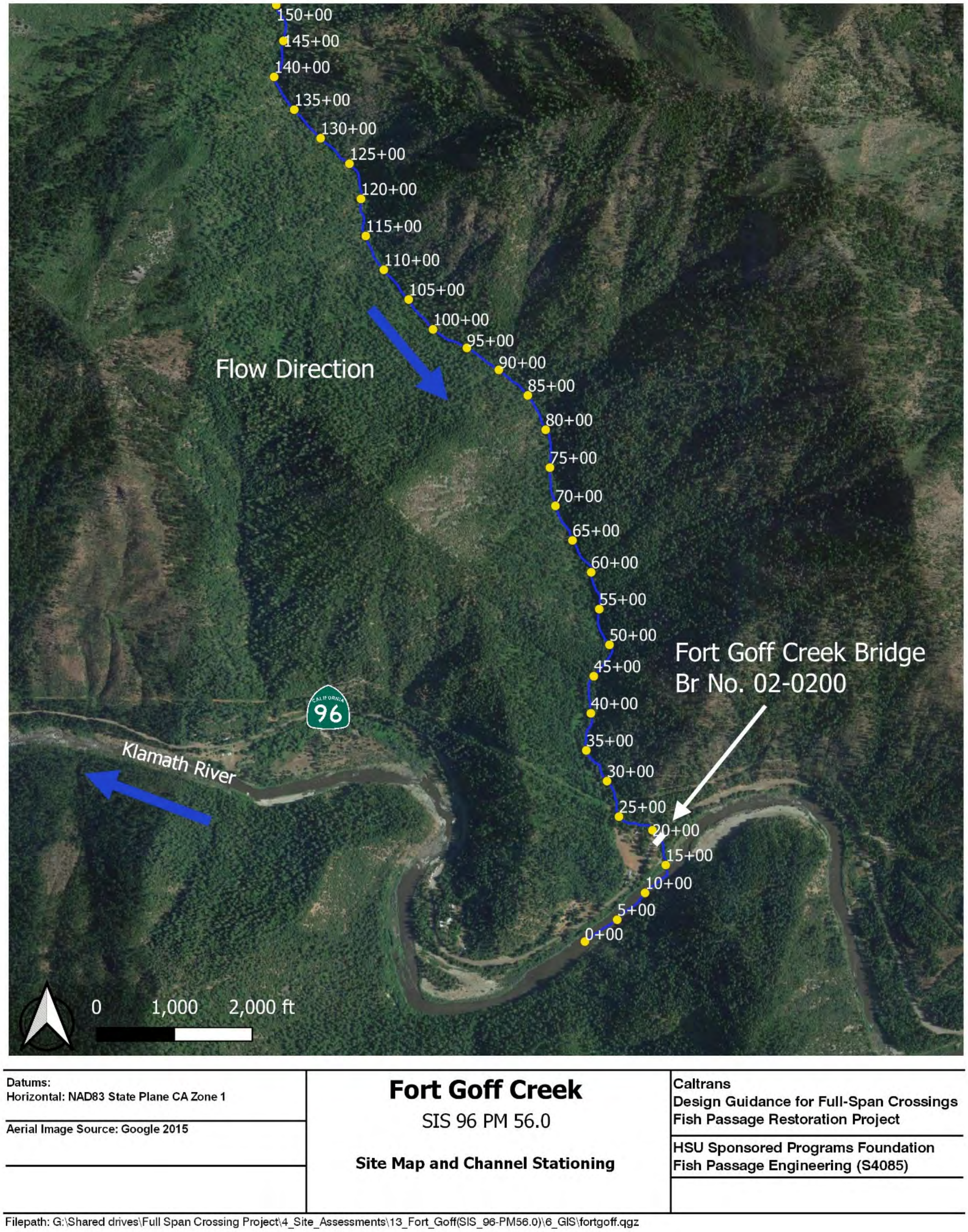


FIGURE 12-6. OVERVIEW SITE MAP FOR FORT GOFF CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

Datums:
Horizontal: NAD83 State Plane CA Zone 1

Aerial Image Source: Google 2015

Fort Goff Creek

SIS 96 PM 56.0

Site Map and Channel Stationing
Project Area

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project

HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: Q:\Caltrans_Full_Span_Study\GoogleDrive\4_Site_Assessments\13_Fort_Goff(SIS_96-PM56.0)\6_GIS\fortgoff.qgz

FIGURE 12-7. PROJECT AREA MAP FOR FORT GOFF CREEK SHOWING CHANNEL ALIGNMENT, PROJECT AREA, REFERENCE REACH, AND CROSS SECTION AND PEBBLE COUNT LOCATIONS.

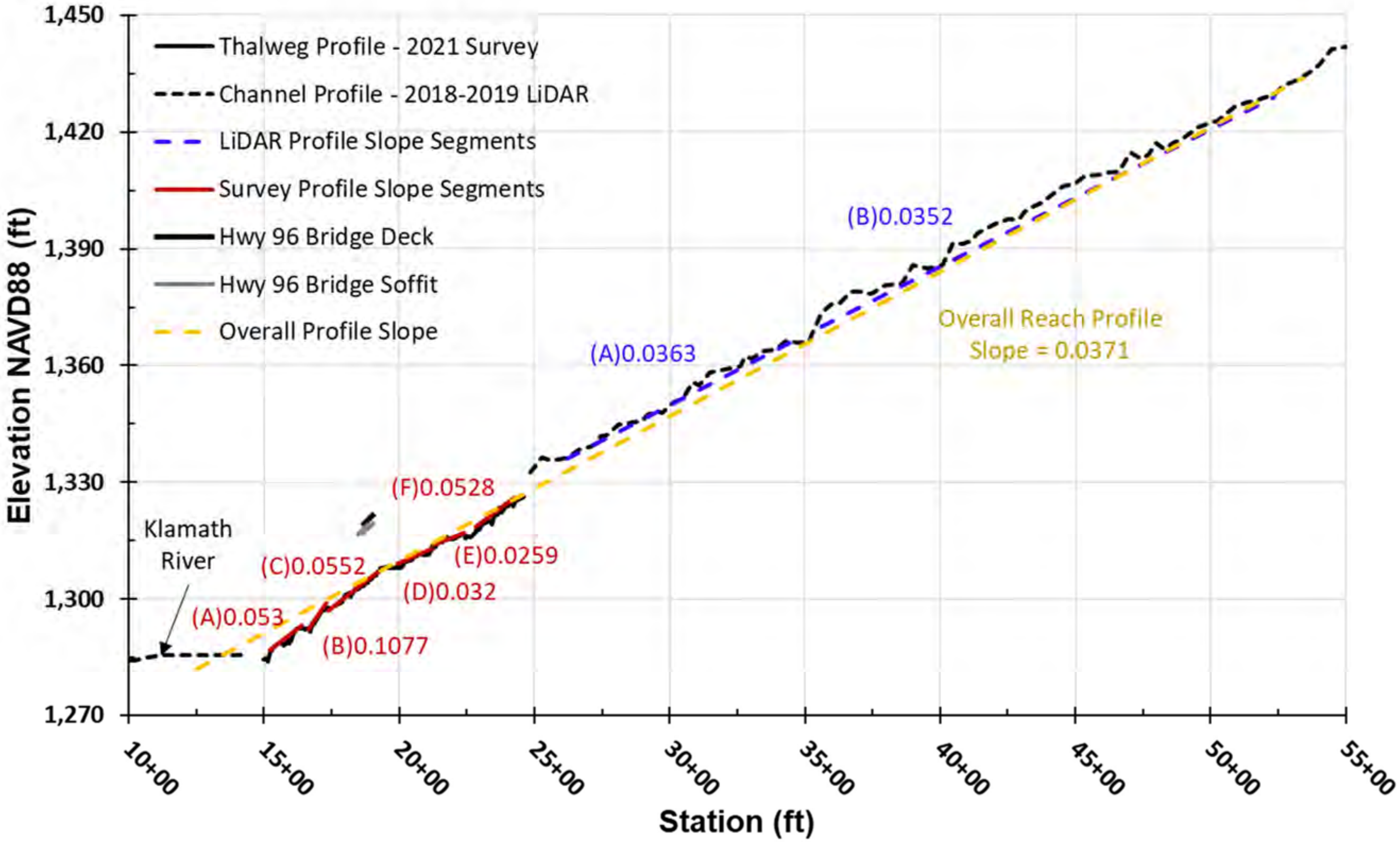


FIGURE 12-8. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM COMBINED LIDAR DEM AND GROUND SURVEY POINTS, WITH CHANNEL SLOPE SEGMENTS DEFINED. DOTTED LINES ARE EXTRAPOLATION OF THE CHANNEL PROFILE SEGMENT.

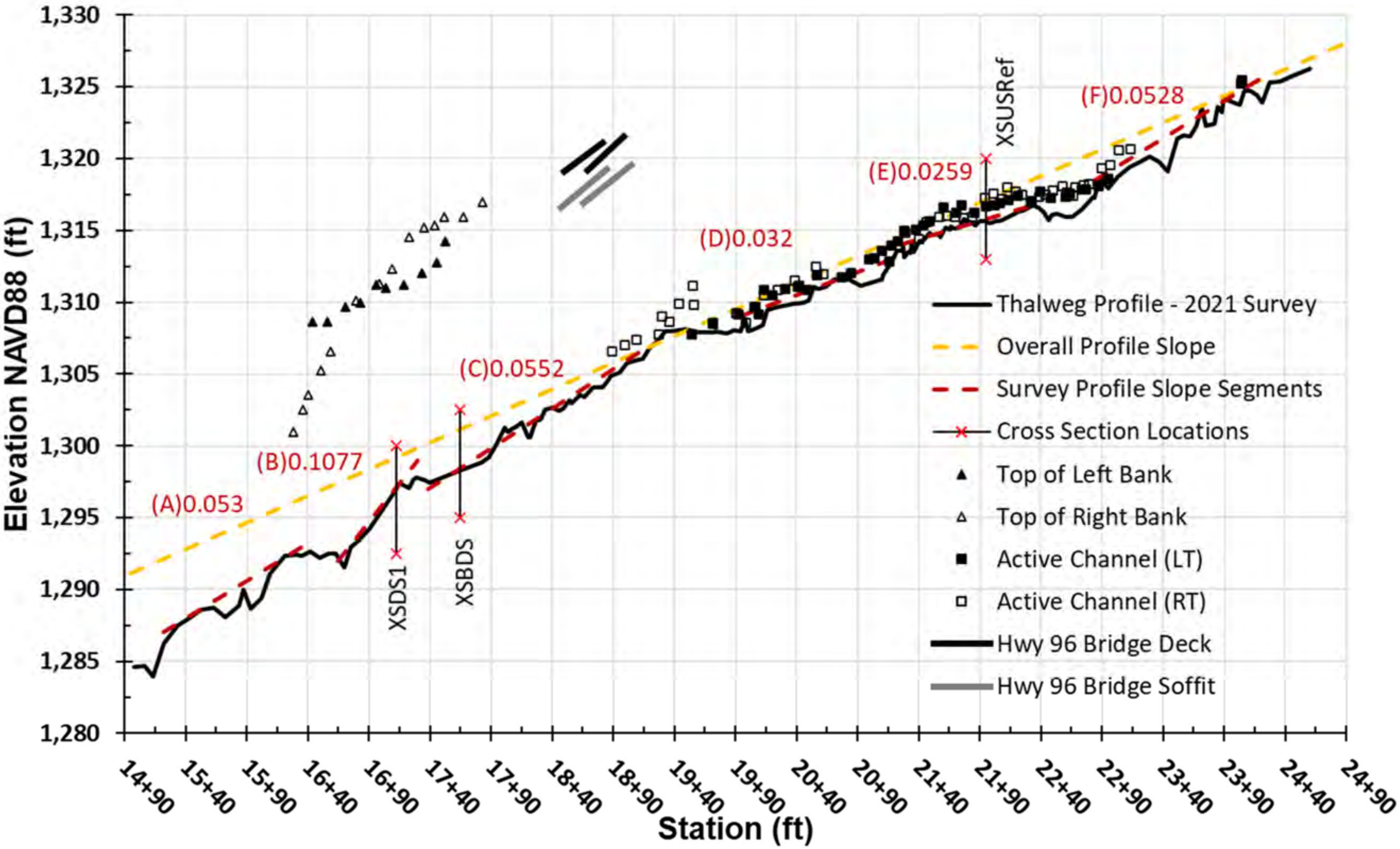


FIGURE 12-9. SURVEYED CHANNEL PROFILE THROUGH PROJECT AND REFERENCE REACH.

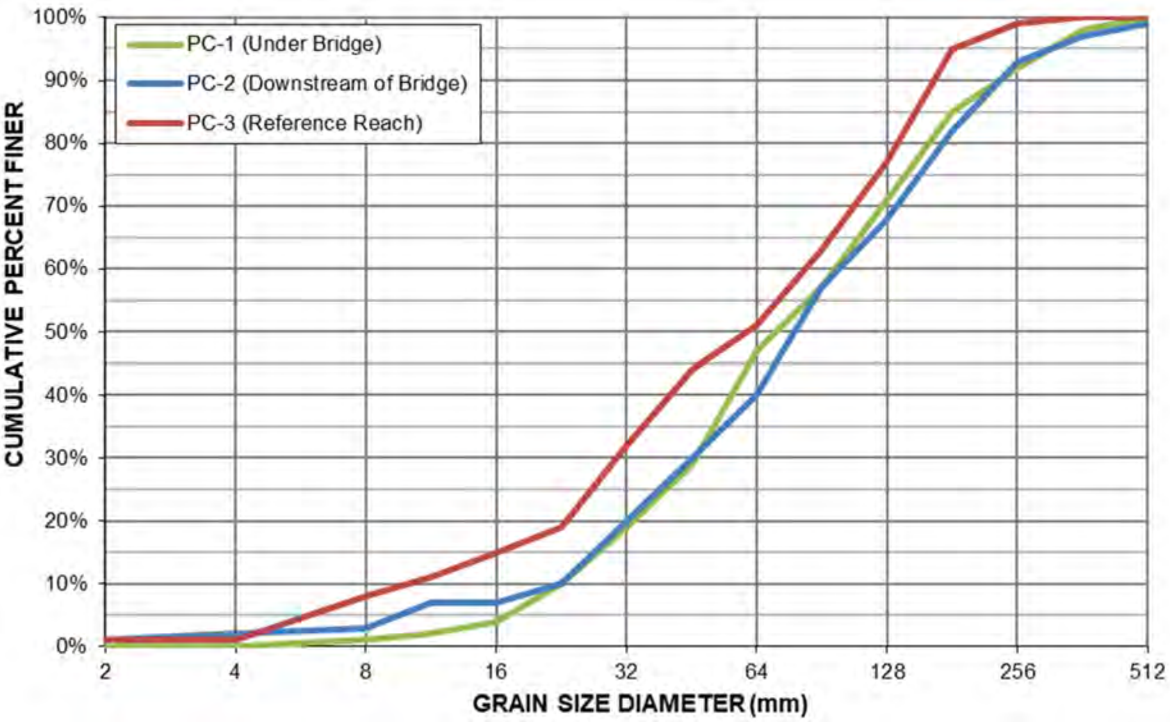


FIGURE 12-10. STREAMBED GRADATION BASED ON SURFACE PEBBLE COUNTS TAKEN DOWNSTREAM AND UPSTREAM OF THE CROSSING AND UPSTREAM OF THE LARGE WOOD JAM.

13 O’NEIL CREEK (SIS 96 – PM 65.39)

13.1 Project Description

13.1.1 DESIGN AND AS-BUILT CONDITIONS

The O’Neil Creek crossing on State Route 96 in Siskiyou County is a full spanning bridge built in 2007 to replace the two existing culverts, 54- and 84-inch CMPs and upstream debris rack (Figure 13-1). The new 41-foot span bridge provided fish passage and additional capacity for flood and debris passage, but post-project observations noted that the streambed was too porous and low flows went subsurface through the project. In 2013, the streambed was remediated by removing the existing material, mixing in finer grained substrate and replacing the streambed in compacted lifts (Figure 13-2). The streambed remediation project replaced the streambed directly beneath the bridge and extended 30 feet upstream and 25 feet downstream for a total length of approximately 90 feet. The width and depth of the replaced material was 4 feet and 24 feet, respectively.

13.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in September 2019 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions.

Figure 13-2 shows the post-streambed remediation in 2013. Photos taken during the 2019 field assessment site visit are provided in Figure 13-3. Comparing the photos, it is clear that a significant bedload transport event occurred between 2013 and 2019, most likely during the extremely wet water year of 2017. The streambed beneath the bridge is now much larger rounded substrate presumably transported from upstream. The streambed is at a higher elevation and a narrow low-flow channel exists closer to the left bank compared to the thalweg centered beneath the bridge. The deposited sediments created a boulder-jam that forms a steep drop at lower flows (Figure 13-3c), presenting a temporal passage barrier.

13.1.3 SITE OBSERVATIONS OF CHANNEL

The upstream channel is a step-pool channel formed by boulders and wood, and may be prone to debris flows. There are regular wood debris jams (Figure 13-4) that retain sediment but are likely not permanent. The upstream channel also appears to be incising through sediment deposits or mine tailings (Figure 13-4c).

The downstream channel has similar step-pool structure to the upstream channel but all steps are boulder formed and not wood. Approximately halfway between the bridge and the Klamath River confluence, there is a channelized water diversion (see left side of Figure 13-3F). This channel section also experienced backwatering from the Klamath River during one or more recent flood events, resulting in sediment and debris transported by O’Neil Creek depositing in the channel and onto the adjacent banks (Figure 13-4).

Measured stream channel active and bankfull widths are similar in the project reach to those in the adjacent natural channel (Table 13-1). The bridge span is 41 feet and allowing natural channel banks and a terrace to form beneath and through the project (Figure 13-3E).

TABLE 13-1. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream above wood jam	**7.5**	**12.7**
Upstream just above bridge	**8.5**	**14.5**
Downstream just below bridge	**14.4**	**19**
Downstream above diversion	**9**	**13.5**
Downstream near diversion	**9**	**13**

13.2 Channel Morphology and Profile

The DEM from the 2018-2019 USGS LiDAR was used to generate an extended longitudinal profile extending through the project site (Figure 13-5 and Figure 13-6). The crossing is located approximately 400 feet upstream of the confluence of O'Neil Creek with the Klamath River (Figure 13-5) and the overall project and channel slope is between 9 and 10 percent. The project reach slope appears consistent with the channel slope throughout the entire longitudinal profile and no significant slope breaks are notable. The longitudinal profile does show some localized sediment deposits, evident as mounds in the profile, that likely represent sediment stored behind wood debris jams or additional upstream road crossings. There also appears to be stored sediment directly under the bridge which could be a sediment pulse migrating downstream or indicate a depositional zone formed by Klamath River high flows backwater O'Neil Creek.

13.3 Discussion

The 41-foot span bridge appears to have provided adequate open area to freely convey the streamflow and associated sediment and debris during one or more large flood events, thus supporting a natural channel morphology to persist under the bridge.

The passage conditions through the new bridge crossing resemble those observed in the upstream natural channel. The low flows are currently remaining on the surface through the project area, as intended following the 2013 remediation. However, the site has clearly been impacted by one or more large bedload transport events. The sediments deposited beneath the bridge are much coarser than after the 2013 remediation and the channel bottom elevation is higher. The steep step transition created by the boulder jam formed under the bridge is similar in height and morphology as the boulder and wood debris steps outside the project area in the upstream channel.

The upstream channel has locations of sediment stored upstream of wood debris jams in channel and on the banks. These structures are likely to break up and reform over time providing periodic sediment pulses through the project. The sediment size range in these deposits ranged from fine to coarse but overall appear finer than the downstream streambed. The transport of additional fines to the project reach should improve the streambed characteristics through the project channel section.

(A) UPSTREAM CHANNEL

(B) CULVERT INLET

(C) CULVERT OUTLET

(D) DOWNSTREAM CHANNEL AND KLAMATH RIVER

FIGURE 13-1. O'NEIL CREEK CROSSING BEFORE THE BRIDGE CONSTRUCTION IN 2006. PHOTOS PROVIDED BY CALTRANS.

Figure 13-2. O’Neil Creek bridge and streambed in 2013 following streambed remediation to introduce fine sediments and compact the bed material to mitigate for low flows going subsurface. Photos provided by Caltrans.

Figure 13-3. O'Neil Creek (a) upstream channel, (b) large substrate under the bridge with low flow channel following left bank, (c) close up of drop shown in (b), (d) downstream channel, (e) looking downstream from under bridge, and (f) downstream channel there is a higher elevation channel on the left that appears to be maintained to deliver a water supply. Photos taken Sept 19, 2019 by M. Love and M. Lang.

Figure 13-4. Upstream channel (a) Looking upstream at logjam above the bridge, (b) looking downstream at consecutive logjams retaining sediment, and (c) upstream channel sediment deposits showing erosion through sediment deposits upstream of temporary logjams. Photo taken Sept 19, 2019 by M. Lang.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88
Image Source: Google 2015

O'Neil Creek
SIS 96 PM 65.4
Site Map and Channel Stationing

Caltrans
Design Guidance for Full-Span Crossings
Fish Passage Restoration Project
HSU Sponsored Programs Foundation
Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing Project\4_Site_Assessments\14_O'Neil_Creek(SIS96-PM65.4)\4_GIS\oniell.qgz

FIGURE 13-5. OVERVIEW SITE MAP FOR O'NEIL CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

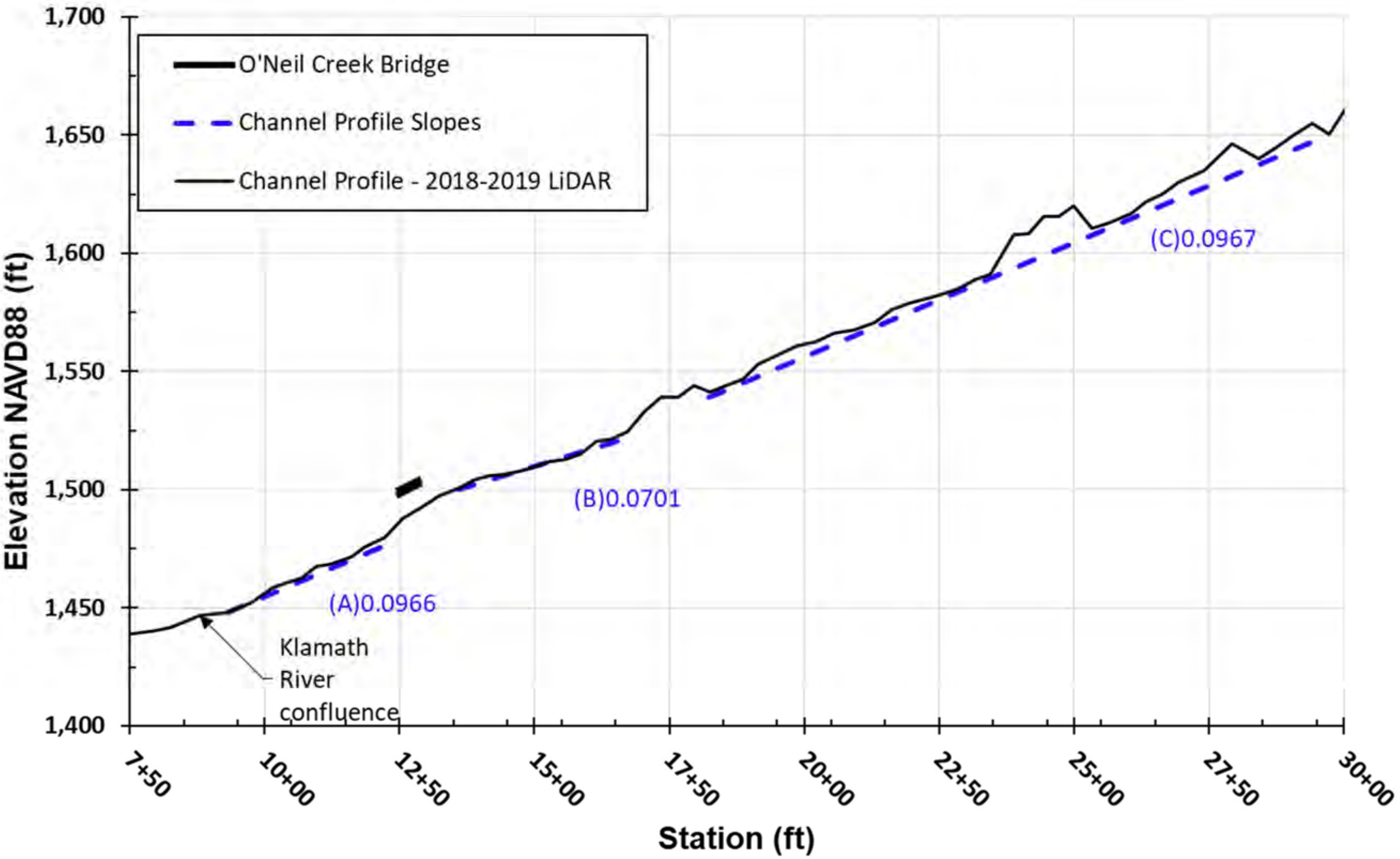


FIGURE 13-6. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE LIDAR DEM WITH CHANNEL SLOPE SEGMENTS DEFINED.

14 DIBBLE CREEK (TEH 005 – PM 28.10)

14.1 Project Description

14.1.1 DESIGN AND AS-BUILT CONDITIONS

Dibble Creek crosses under Interstate Route 5 in Tehama County at the north end of Red Bluff, California. The Dibble Creek drainage area is approximately 30 square miles, and the I-5 bridges are located approximately one mile upstream of the confluence of Dibble Creek with the Sacramento River and are the most downstream crossings on Dibble Creek. At this location the interstate is a four lane, dual roadway and there are two bridges spanning the channel for the north- and southbound lanes, respectively. Both bridges are three pile frame structures with three piers within the channel. The bridges were seismically retrofit in 1982 and a rock check dam was installed downstream as a scour countermeasure against channel degradation. However, continued scour had begun exposing the pile caps potentially leaving the bridges vulnerable to seismic loading (Caltrans 2003).

To mitigate the bridge pier scour, Caltrans installed a sheet pile check dam in 2008 that fully spans the channel just downstream of the eastern (northbound) bridge and a rock weir fishway in the active, low flow channel to direct lower flows and allow fish passage over the check dam. The channel thalweg upstream of the bridges follows close to the right bank (Figure 14-1a) and the main/lower flow channel flows through the two southern-most bridge piers. The channel bottom elevation just upstream of the fishway is controlled by the channel spanning sheet piling and RSP (Figure 14-1b). Four rock weirs spanning a 28-foot wide, low-flow channel were constructed downstream of the sheet piling. The rock weirs were installed on 15-foot intervals and are 10 feet in longitudinal length and 6.5 feet high. To confine flow in the rock weir fishway, a lateral berm was constructed as the left boundary, extending approximately 15 feet downstream of the last rock weir. Both the rock weirs and lateral berm are constructed of 2-ton rock with voids filled with permeable material. The weir rocks were placed onto a bed of Backing No. 2 RSP and the pools between weirs were filled with Backing No. 1 RSP overlain by 0.10 m of permeable material. Figure 14-2 shows the project shortly after construction and its performance during higher flows.

14.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in October 2019 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions. Photos taken during our field assessment site visit are provided in Figure 14-1.

In 2019, the basic structure of the rock weir fishway and the four rock weirs were essentially intact but some structural elements were missing or displaced. Two primary changes to the site as-built were noted. The first was loss of Backing No. 1 and permeable material used to form the streambed between the rock weirs. The second was that a downstream portion of the lateral berm was missing and appears to have been overtopped and displaced by flow entering from the high flow, left channel (Figure 14-1c). In addition, material used to fill the voids between the 2-ton rocks forming the weirs was mostly scoured out making the weirs more porous. The remnants of the Backing No. 1 rock (~1-ft diameter) are present within the pools (Figure 14-1b) and do continue to act as roughness elements within the fishway. Despite these changes, the fishway appeared to be able to function as intended but, because of these structural changes, its effective length may be reduced.

14.1.3 SITE OBSERVATIONS OF CHANNEL

The channel upstream and downstream of the bridges is a wide gravel and sand channel with no prominent large substrate or bedrock control features. The thalweg is currently located near the right side of the channel following the outer bank of the channel bend through the crossing and rock weir fishway. The natural channel substrate appears quite mobile and the thalweg in this reach would be expected to migrate over time.

The span between in-channel bridge piers was measured at 53 feet and the rock weir fishway width is 28 feet. The active channel widths (Table 14-1) ranged from 49 feet upstream of I-5 to 98 feet just downstream of the rock weir fishway. The active and bankfull channel widths in the downstream channel, outside of the crossing influence, widen as the channel becomes less entrenched and more aggraded approaching the confluence of Dibble Creek with the Sacramento River.

TABLE 14-1. CHANNEL ACTIVE AND BANKFULL WIDTHS.

Location	Active Channel Width (ft)	Bankfull Width (ft)
US channel approximately ½ way between the I5 crossing and frontage road	49	59
DS channel just below the rock weir fishway	98	110
DS channel outside of the project influence	87	93

14.2 Channel Morphology and Profile

The DEM from the 2019 USGS LiDAR was used to generate an extended longitudinal profile through the project site (Figure 14-3 and Figure 14-4). The confluence of Dibble Creek with the Sacramento River is approximately one mile downstream from the I5 crossing and the rock weir fishway is the most downstream structures in Dibble Creek moving upstream from this confluence. The channel is low gradient with overall slope of 0.5 percent. There appear to be some steeper slope segments downstream that may indicate regions of deposition, possibly from backwatering of the Sacramento River into Dibble Creek, but these were not confirmed with a survey or site visit.

14.3 Discussion

The channel spanning, sheet pile grade control structure installed to address scour at the bridge piers appears to be functioning as intended. The bridge piers are armored with RSP and still experience local scour but not to depths that expose footings. The rock weir fishway constructed downstream in the low flow channel to allow passage over the grade control structure is mostly functioning as intended but has experienced some alterations. Most of the permeable fill installed to backfill voids in the primary rock weir elements (2-ton RSP) and in the Backing No. 1 placed between weirs has been scoured out. Thus, the weirs are now much more porous and less able to maintain water depths. The loss of fill within the material placed between weirs has left a jumble of exposed large rock, ~1- to 2-foot diameter, that provide velocity diversity but are also vulnerable to additional mobilization.

In addition to changes within the rock weir fishway, the lateral berm defining the left bank of the fishway has lost some of its structural rock. It appears that as flow in the channel is receding from a flow that fills the active channel, the lateral berm is overtopped from flow moving from left to right. This flow appears to have rolled some of the berm rock to the outer channel bank effectively shortening the overall length of the rock weir fishway.

The site experiences only seasonal, intermittent flow and forms isolated pool as the it dries out. A large pool at the downstream end of the rock weir fishway has previously stranded fish and required rescue of fall-run juvenile chinook (Pers. Comm. D. Killam CDFW). High flow and dropping flow observations are recommended to confirm that the weirs continue to function over the range of flows intended as the rock locations and porosity vary.

Figure 14-1. Dibble Creek (A) upstream channel looking downstream at crossing (main channel on left of picture), (B) looking downstream at the rock ramp (sheet piling grade control in foreground), (C) looking upstream at rock ramp (D) looking downstream at rock ramp and channel, (E) looking upstream at crossing, and (F) example of armored bridge piers in main channel. Photos taken Oct 2019 by M. Love and M. Lang.

Figure 14-2. Dibble Creek fishway and grade control. (a) fishway looking upstream February 2012, (b) fishway at higher flow in January 2017, (c) fishway panorama with flow only in main channel, February 2012. Photos provided by M. Molinar, Caltrans.

Datums: Horizontal: NAD83 State Plane CA Zone 1 Vertical: NAVD88	**Dibble Creek** TEH 005 PM 28.10	**Caltrans** **Design Guidance for Full-Span Crossings**
Image Source: Google 2021	**Site Map and Channel Stationing**	**HSU Sponsored Programs Foundation** **Fish Passage Engineering (S4085)**

Filepath: G:\Shared drives\Full Span Crossing Project\4_Site_Assessments\16_Dibble_Creek(TEH005_PM28.10)\4_GIS\Dibble.qgz

FIGURE 14-3. OVERVIEW SITE MAP FOR DIBBLE CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

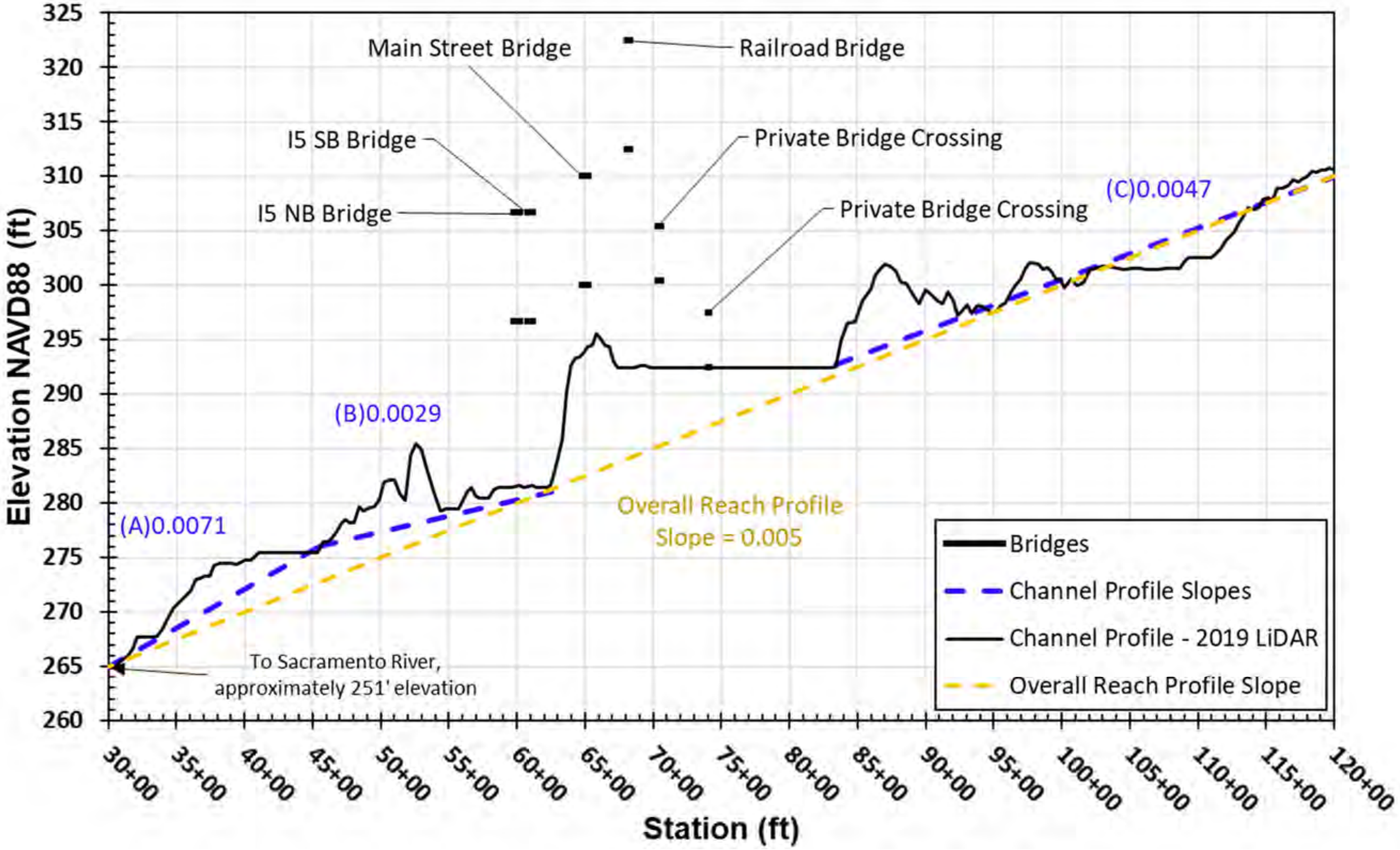


FIGURE 14-4. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE LIDAR DEM WITH CHANNEL SLOPE SEGMENTS DEFINED.

15 CRAIG CREEK (TEH 099 – PM21.10)

15.1 Project Description

15.1.1 DESIGN AND AS-BUILT CONDITIONS

The Craig Creek crossing on State Route 99 in Tehama County was replaced by a new full spanning bridge in 2012. This new bridge replaced an existing bridge that was identified as scour critical with a long history of erosion at the abutments. The old bridge was 89 feet long and 42 feet wide, with three spans and two bridge piers in the active channel of the stream. It was replaced by a single span, precast, prestressed slab bridge that is 108 feet long and 58 feet wide (Caltrans, 2008). The design plans do not indicate any project elements for grade control or fish passage. Channel work consisted of rock slope protection on both banks under the bridge and placement of a washed sand and gravel streambed beneath the structure. As-built photos of the crossing were provided by Caltrans (Figure 15-1).

15.1.2 SITE OBSERVATIONS OF PROJECT REACH

HSU visited the crossing in October 2019 for preliminary assessment and review. This site did not have a full field survey due to the project restructuring following COVID19 work and travel restrictions. Photos taken during our field assessment site visit are provided in Figure 15-2.

The channel gradient through the project is low and most of the site is backwatered by shallow riffles or constriction by the bank RSP (Figure 15-2). The RSP on the left bank is undercut by scour and appears to have been previously grouted to mitigate the scour progression (Figure 15-2C). The right bank RSP has also scoured and some of the large rock along the toe has been displaced. This scour is not compromising the bridge structure or adversely affecting fish passage conditions.

15.1.3 SITE OBSERVATIONS OF CHANNEL

The channel substrate is a mix of fine silt, sand, and gravel. There are gravel patches and occasional riffles (Figure 15-2A and E). The entire channel through the project reach and beyond is highly incised and this is more prevalent downstream (Figure 15-2D, F). This incision appears to be regional and is consistent with channel scour and degradation observations and estimates used in the project design. Caltrans (2008) estimated the scour potential from combined degradation and local scour at 8 feet at the new bridge foundation and recommended another 6 feet of depth, for a total of 14 feet, for the new bridge abutments.

Craig Creek is a direct tributary to the Sacramento River flowing in from the east. It drains Antelope and Little Antelope creeks and diversions from New Creek into Antelope Creek. There are additional diversions and channelization upstream that divert high flows into Craig Creek as needed. Thus, Craig Creek can experience higher flows than direct hydrologic analysis of its watershed might predict. These periodic high flows from the rerouting of stream into Craig Creek may contribute to the observed incision.

Stream channel active and bankfull widths are similar throughout most of the stream reach upstream of the project. At the crossing it appears the RSP has hardened the banks beneath the bridge, constrict the channel as indicated by the narrowest active and bankfull widths mid-channel beneath the bridge (Table 15-1). The streambed also appears locally scoured, forming a pool, beneath the bridge in response to the RSP constriction. This constriction backwaters the channel just upstream of the bridge and has created a zone of gravel deposition. The localized channel elevation increase has promoted some channel widening just upstream of the bridge, but this has also created a more diverse channel structure and substrate than the rest of the stream, including the only observed gravel bedded riffle and bar upstream of the bridge (Figure 15-2A).

TABLE 15-1. CHANNEL ACTIVE AND BANKFULL WIDTHS UPSTREAM (US) AND UNDER BRIDGE.

Location	Active Channel Width (ft)	Bankfull Width (ft)
US channel beyond project area	**29**	**35.2**
US channel in deposition zone	**40**	**43**
US channel at bridge	**36**	**41**
Mid-channel under bridge	**23.5**	**29.5**

15.2 Channel Morphology and Profile

The DEM from the 2019 USGS LiDAR was used to generate an extended longitudinal profile through the project site (Figure 15-3 and Figure 15-4). The Craig Creek bridge is about equidistant from the Antelope Creek confluence with Craig Creek and Craig Creek's confluence with the Sacramento River. Throughout most of the channel, the average slope is 0.3 percent. However, approximately 1,000 ft upstream of the bridge there is a steeper channel section approaching 1.3 percent. A review of aerial photographs shows this steeper reach being controlled by exposed bedrock. The channel downstream of the bridge and through the project reach is highly incised. This steeper channel section appears to be the current knickpoint.

15.3 Discussion

The Craig Creek crossing is functioning as designed and not an impediment to fish passage. The project motivation was primarily mitigation of bridge foundation scour which was addressed with the installation of a wider bridge with deeper abutments. The crossing is within a channel that is highly incised and there appears to be additional scour occurring beneath the bridge as evidenced by mobilization of RSP on the right bank (Figure 15-2D) and undercutting of grouted rock/RSP on the left bank (Figure 15-2C).

The RSP placed beneath the bridge to protect the footings constricts the active and bankfull channel widths and has caused localized scour under the bridge. This may cause elevated velocities relative to the adjacent channel during high flow events, but unlikely affects fish passage. The constriction has also created a deposition zone just upstream of the bridge (Figure 15-2A and B). This zone has built a gravel bar and riffle sequence. The active and bankfull channel widths in this zone are 20 to 25 percent wider than the upstream channel outside of the project influence.

The extended longitudinal profile (Figure 15-4) suggests that the majority of the incision and scour potential has migrated upstream of the crossing. However, sediment transport from a migrating headcut, regional influences that might be altering connected channel elevations and water diversions may continue to be an influence on the stream morphology in this reach. The site should be periodically monitored for additional incision, scour and possible influences of the RSP constriction at the crossing creating a depositional zone and higher slope channel segment upstream of the bridge.

Looking Upstream at Bridge Outlet Post-Remediation. Photo taken on 09/12/2018 and courtesy of PSMFC.

Looking Downstream at Channel Post-Remediation. Photo taken on 09/12/2018 and courtesy of PSMFC.

Channel Upstream of Bridge Post-Remediation. Photo taken on 09/12/2018 and courtesy of PSMFC.

Bridge Inlet Post-Remediation. Photo taken on 09/12/2018 and courtesy of PSMFC.

FIGURE 15-1. CRAIG CREEK CROSSING IN 2018. PHOTOS PROVIDED BY CALTRANS.

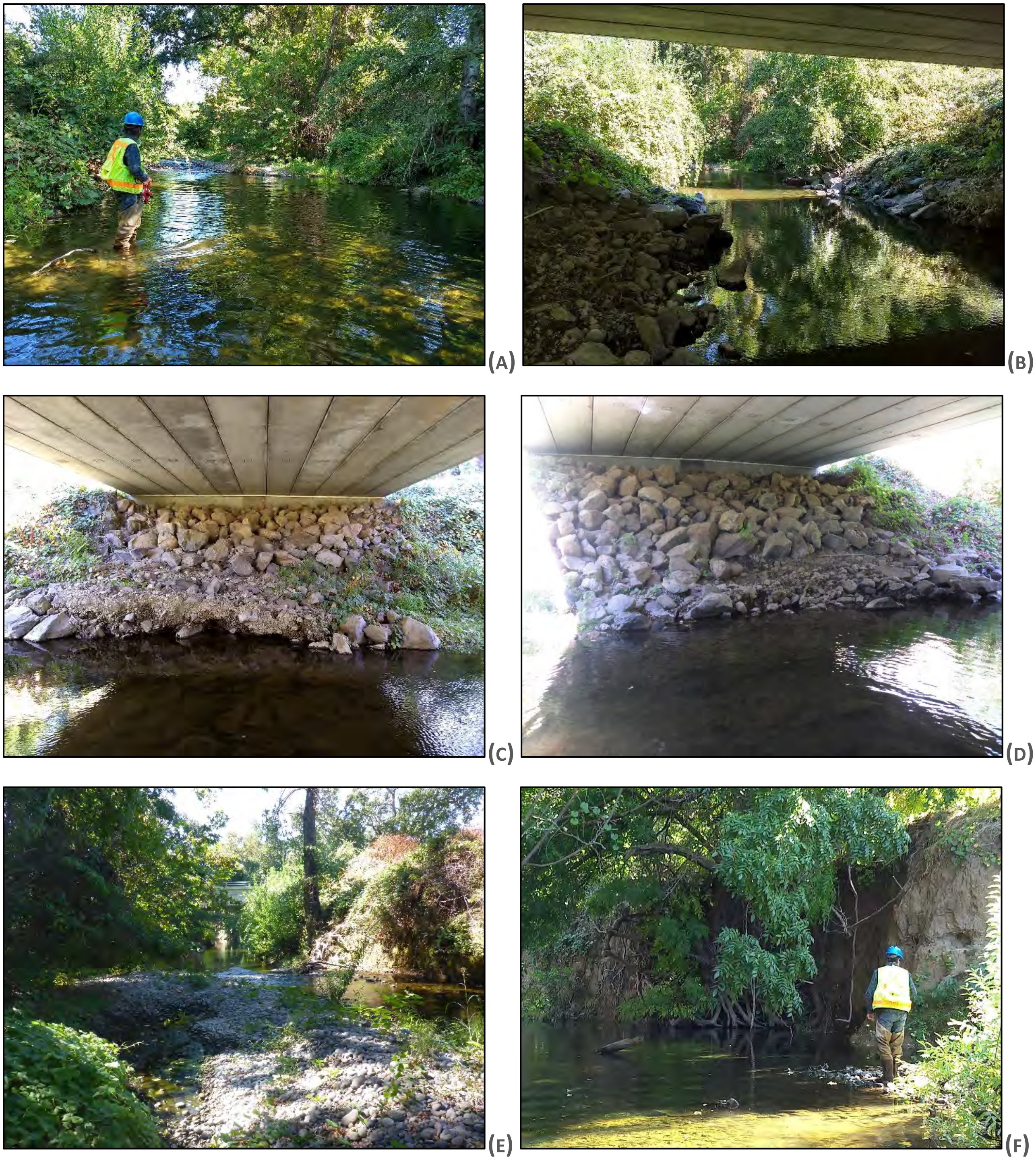
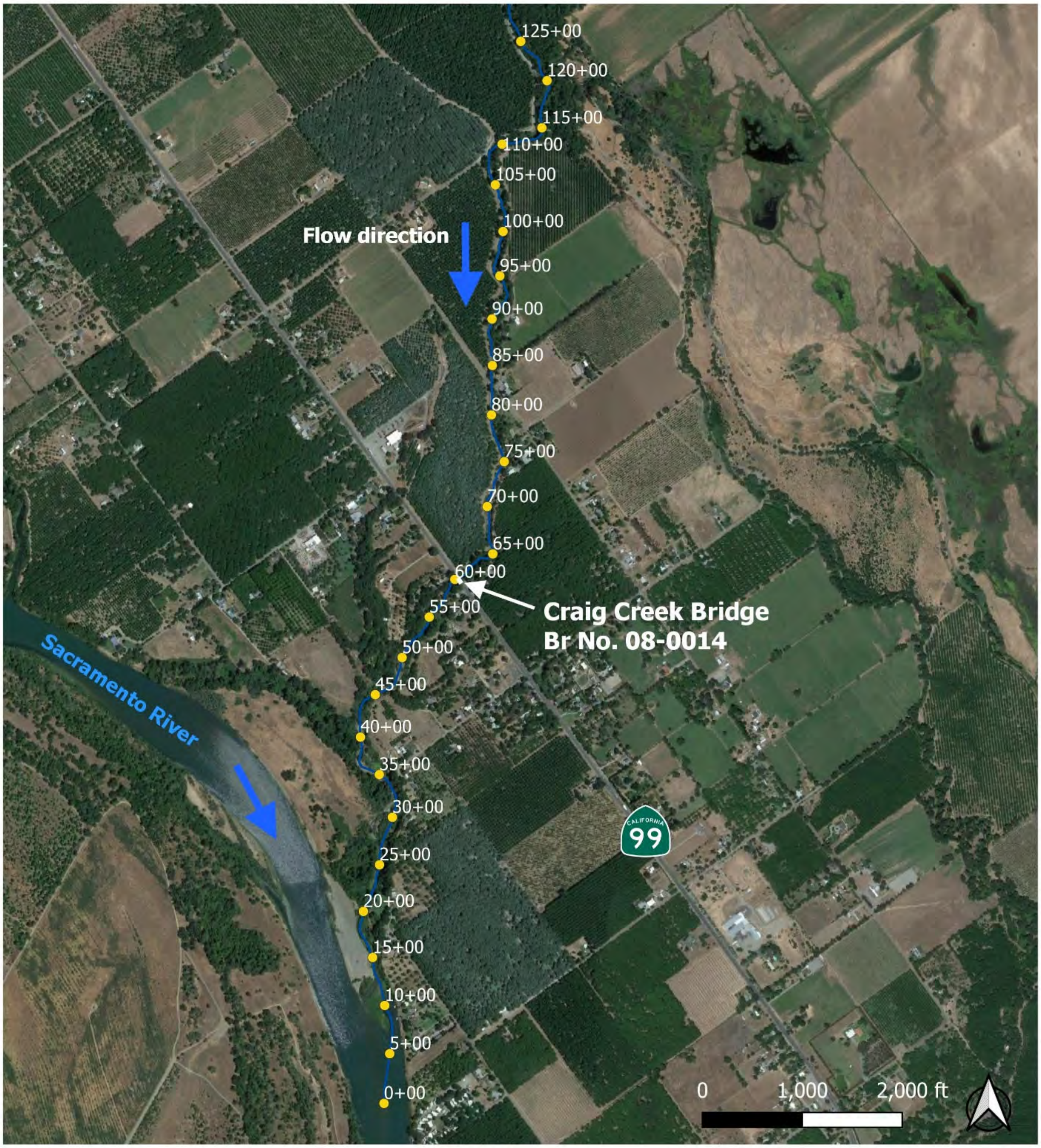


Figure 15-2. Craig Creek (A) upstream channel with coarse substrate deposits looking downstream at bridge, (B) upstream channel looking upstream from bridge, (C) left bank is undercutting under the bridge, (D) right bank under the bridge has some scour, (E) downstream channel looking upstream at bridge, and (F) downstream channel is highly incised. Photos taken Oct 4 19, 2019 by M. Love and M. Lang.



Datums: Horizontal: NAD83 State Plane CA Zone 1 Vertical: NAVD88	**Craig Creek** TEH 99 PM 21.1	Caltrans Design Guidance for Full-Span Crossings Fish Passage Restoration Project
Image source: Google 2015	**Site Map and Channel Stationing**	HSU Sponsored Programs Foundation Fish Passage Engineering (S4085)

Filepath: G:\Shared drives\Full Span Crossing Project\4_Site_Assessments\15_Craig_Creek(TEH099-PM21.10\4_GIS\craig.qgz

FIGURE 15-3. OVERVIEW SITE MAP FOR CRAIG CREEK SHOWING CHANNEL ALIGNMENT AND STATIONING.

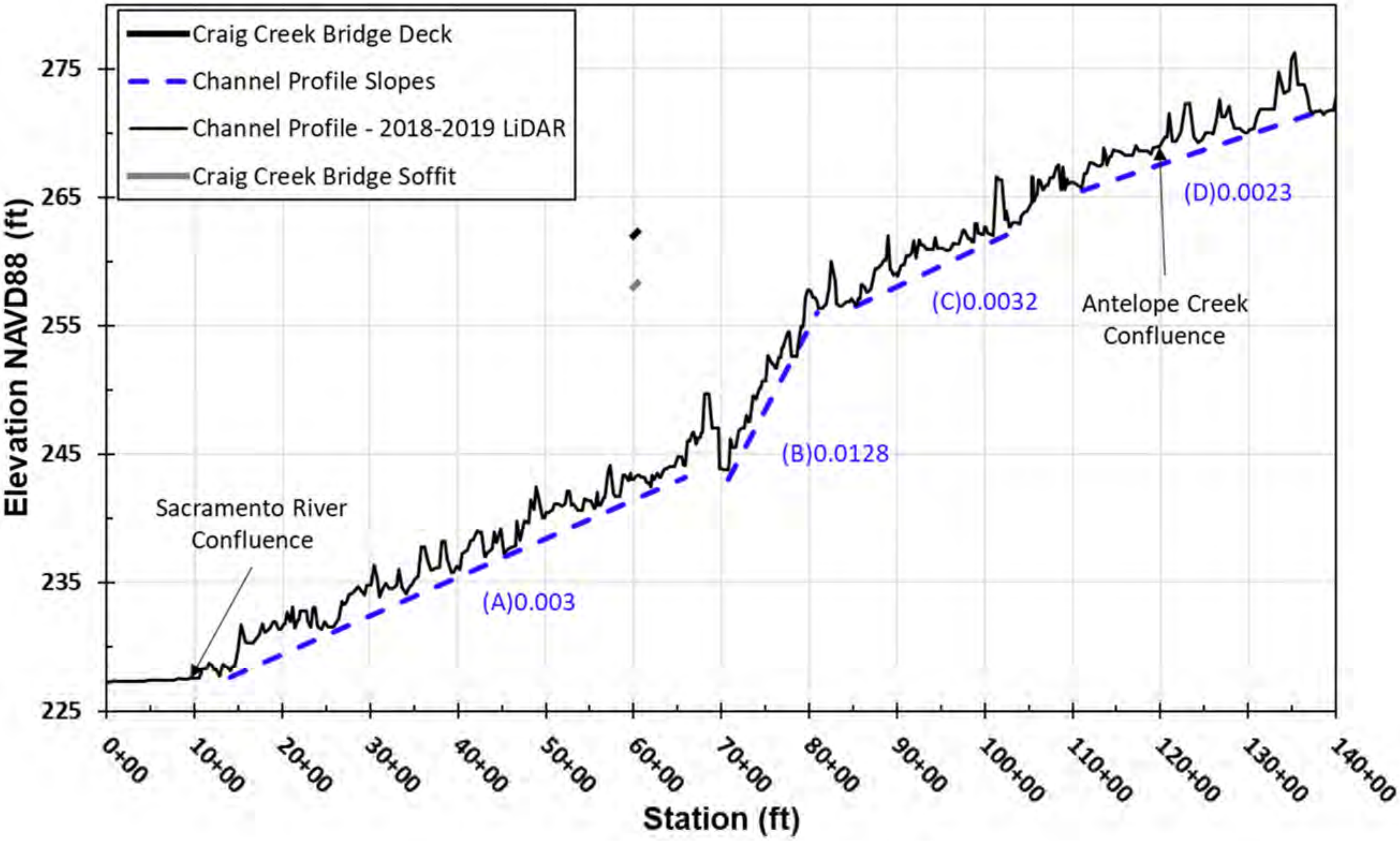


FIGURE 15-4. CHANNEL PROFILE THROUGH PROJECT REACH GENERATED FROM THE LIDAR DEM WITH CHANNEL SLOPE SEGMENTS DEFINED.

APPENDIX B – PRELIMINARY SITE ASSESSMENT FIELD NOTES

APPENDIX B – PRELIMINARY SITE ASSESSMENT FIELD NOTES

MAP OF SITE LOCATIONS

Map of field sites indicating site type and level of analysis conducted. Surveyed sites received an initial assessment and a full field survey. Assessment sites received only the initial assessment site visit.

Site Name: __Peacock Creek_________

Location (County-Road-Postmile)	DN 197, PM 2.12		
PAD ID Number:	720982	Date:	9-May-19
Stream Name:	Peacock Creek		
Evaluator (1):	M. Love		
Evaluator (2):	M. Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Retrofit corrugated metal pipe arch culvert. The baffle retrofits are steel baffles angled to the flow direction and slanting top elevation to form a concentrated low flow channel along the right bank. Drops between baffles at low flow is 4 inches. Baffles have captured a lot of sediment on the left bank (looking downstream) but are maintaining pools downstream. There is less accumulated sediment in the more upstream sections of the culvert. The outlet has a notched weir with a drop of approximately 1 ft. The concrete weir has a metal cap in the low flow notch is eroded on both the right and left banks. The culvert width is 13 feet.

Is the crossing performing as designed?	***Yes***	No			
Comments					
Structural condition	Excellent	***Good***	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	***No***
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	***Yes***	No
if yes, take photos and describe:	Baffles are trapping some sediment which may increase local velocity and reduce depth but the sediment doesn't appear to be impairing passage hydraulics.	

Picture name	Description
Figures 3 & 4	Attached Figures 3 and 4 show the culvert baffles and trapped sediment

Site Name: __Peacock Creek_________

What is the potential for sediment delivery from the crossing? [✓ Low] Moderate High

Comments

If a project objective, was potential for future sediment delivery reduced? Yes No [✓ N/A]

Are grade control structures functioning as desired? [✓ Yes] No N/A

If there was channel incision/scour downstream of the crossing, has it stabilized? Yes No

No incision is apparent but, compared to earlier surveys, it looks like the channel as incised approximately 0.5 feet since 2013. There is a concrete vortex weir fish ladder at the downstream county culvert providing excellent grade control.

Were there unintended effects on the channel? Yes [✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

Should this location be monitored for changes in performance? Yes [✓ No]

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __Peacock Creek_________

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

No

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

The constricted width of the culvert compared to the channel width does create a backwater upstream of the culvert as evidenced by bank deposits and high water marks on the inlet wingwalls.

The upstream channel has lots of redwood logs in it that clearly back up water onto the banks. These may be a debris concern.

The culvert might have caused the channel to migrate towards the left bank and scour a tree. The tree has now fallen into the channel, backwatering the culvert inlet during high flow events, and is beginning to accumulate some debris. Channel aggradation has occurred upstream of this debris/logjam.

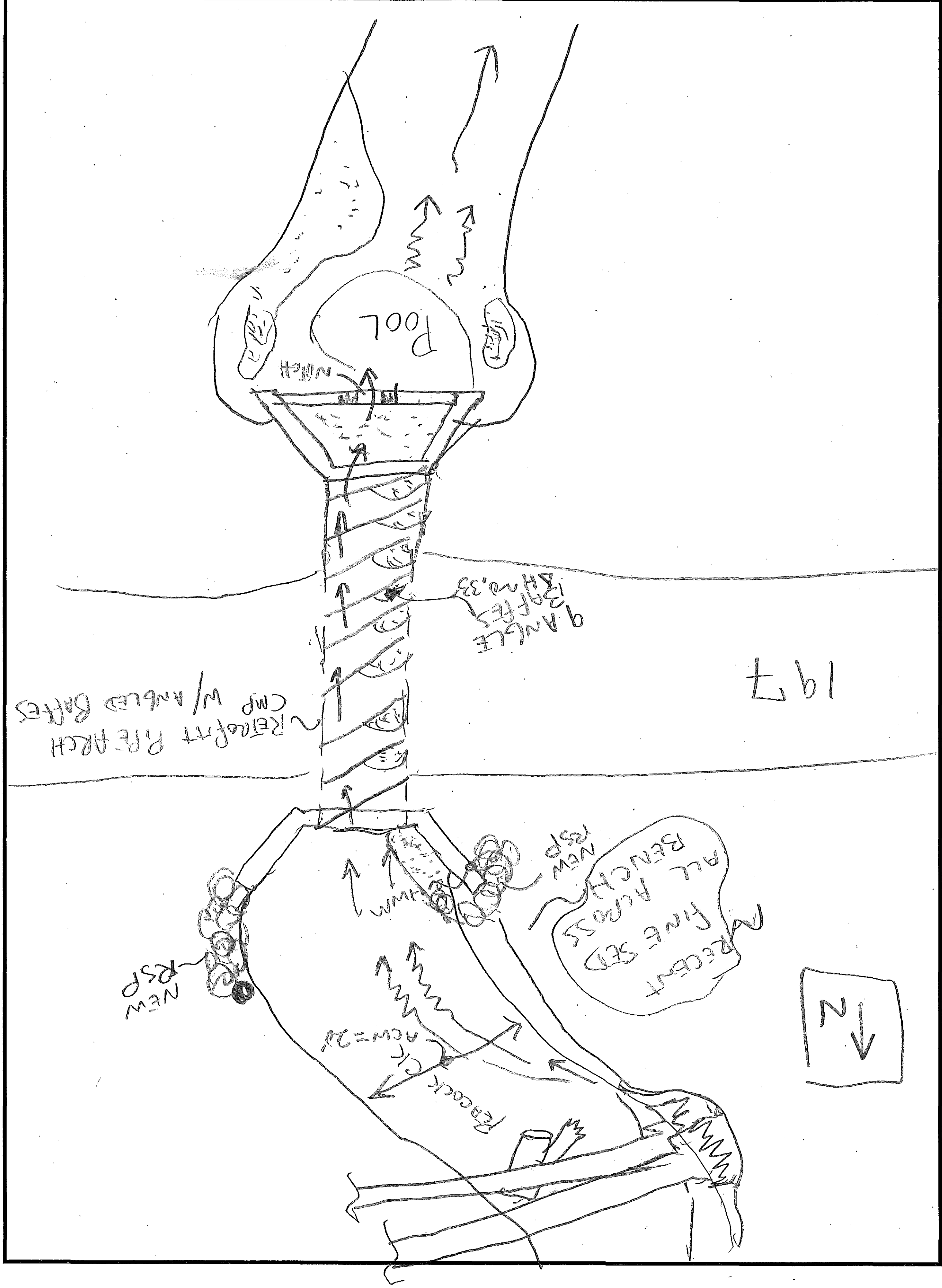
The constricted width of the culvert compared to the channel width does create a backwater upstream of the culvert as evidenced by bank deposits and high water marks on the inlet wingwalls.

Channel Measurements

Location	Active Channel Width (ft)
~50 ft downstream of outlet	19.2
~50 ft upstream of inlet	20.0
Upstream of downed logs in US channel	20.3

Site Name: __Peacock Creek_________

Site Sketch PEACOCK CREEK 197



Site Name: __Peacock Creek_________

Figure 1. Upstream channel looking upstream to show logs in channel.

Site Name: __Peacock Creek_________

Figure 2. Left inlet wingwall showing some bank erosion from backwatering during high flows.

Site Name: __Peacock Creek_________

Figure 3. Culvert barrel looking downstream from the inlet.

Site Name: __Peacock Creek_________

Figure 4. Sediment accumulation behind most baffles.

Site Name: __Peacock Creek_________

Figure 5. Concrete square-notched weir at outlet. Drop elevation is ~1 foot at low flow.

Site Name: __Peacock Creek_________

Figure 6. Downstream channel looking downstream from culvert outlet.

Site Name: __Peacock Creek_________

Figure 7. Possible reference reach upstream of project site.

Site Name: __Sultan Creek____

Location (County-Road-Postmile)	Del Norte 197, PM 5.00		
PAD ID Number:	707143	Date:	9-May-19
Stream Name:	Sultan Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		
Overall Crossing Description - Emphasize Fish Passage Design Elements	The channel below the bridge is aggrading sediment so that the height from the channel bottom to the bottom of the bridge deck is very constricted. See attached photos (Figures 1 and 2). The sediment issues here appear to be more a function of the site location and upstream conditions than a crossing design issue but it does have debris passage and flood performance consequences. There is evidence that at higher flows, water leaves the stream channel and flows down the Green Diamond access road and crosses DN 197 to the south of the bridge (see Figures 3 & 4).		

Is the crossing performing as designed?	Yes	[✓ No]			
Comments	Crossing has lost nearly half of its open area due to sediment aggradation, leading to frequent inundation of the bridge soffit and extremely limited ability to convey woody debris downstream. Wood debris accumulations will likely occur frequently and could block fish passage at times.				
Structural condition	Excellent	[✓ Good]	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	[✓ No]
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	[✓ Yes]	No
if yes, take photos and describe:	The crossing site is in a depositional zone with lots of aggradation and debris is accumulated in the channel upstream of the crossing..	

Picture name	Description
Figure 1	View of accumulated sediment looking upstream from downstream channel.
Figure 2	View of accumulated sediment looking downstream from upstream channel.

Site Name: __Sultan Creek____

What is the potential for sediment delivery from the crossing?	***Low***	Moderate	High	

Comments

The sediment is not being delivered from the crossing but accumulating at the crossing due to the shallow local channel slope and the constricted bridge cross section area.

If a project objective, was potential for future sediment delivery reduced?	Yes	No	***N/A***

Are grade control structures functioning as desired?	Yes	No	***N/A***

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable.

Were there unintended effects on the channel?	***Yes***	No

if yes, take photos and describe:

Picture name	Description
	The frequent backwatering and upstream ponding from the constricted bridge opening may be causing the stall-out of woody debris further upstream, including the formation of the upstream large wood jam that is causing out of bank flooding that flows onto SR197.
Figure 3	Location of flow leaving the channel and flowing down a Green Diamond Rd
Figure 4	Flow paths from Green Diamond Rd onto SR 197

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	***Yes***	No

This site has a high potential for blockage and debris capture due to reduced cross section area from sediment accumulation. There is also significant wood upstream that could move and be trapped on the bridge.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __Sultan Creek____

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

The reduced cross section area is likely affecting fish passage under some conditions.

Notes: Preliminary measurements and full survey planning

Channel Width measurements

	Active Channel (ft)	
US at bridge	31	
30 ft US of bridge	21	
100 ft US of bridge	25	
US of Green Diamond bridge	27	Channel is wide and shallow here with bankfull depth of 2.5 ft
US in reference reach	23.7	This location is ~800 ft US of bridge
50 ft DS of bridge	32.7	

Other Notes:

Height of bridge opening (thalweg to bottom of bridge deck) had a max of 2.25 ft upstream and 2.6 ft downstream of the bridge.

The debris jam downstream of the bridge is also likely to be influencing sediment accumulation at the bridge. The channel slope increases below the debris jam into the confluence with the Smith River.

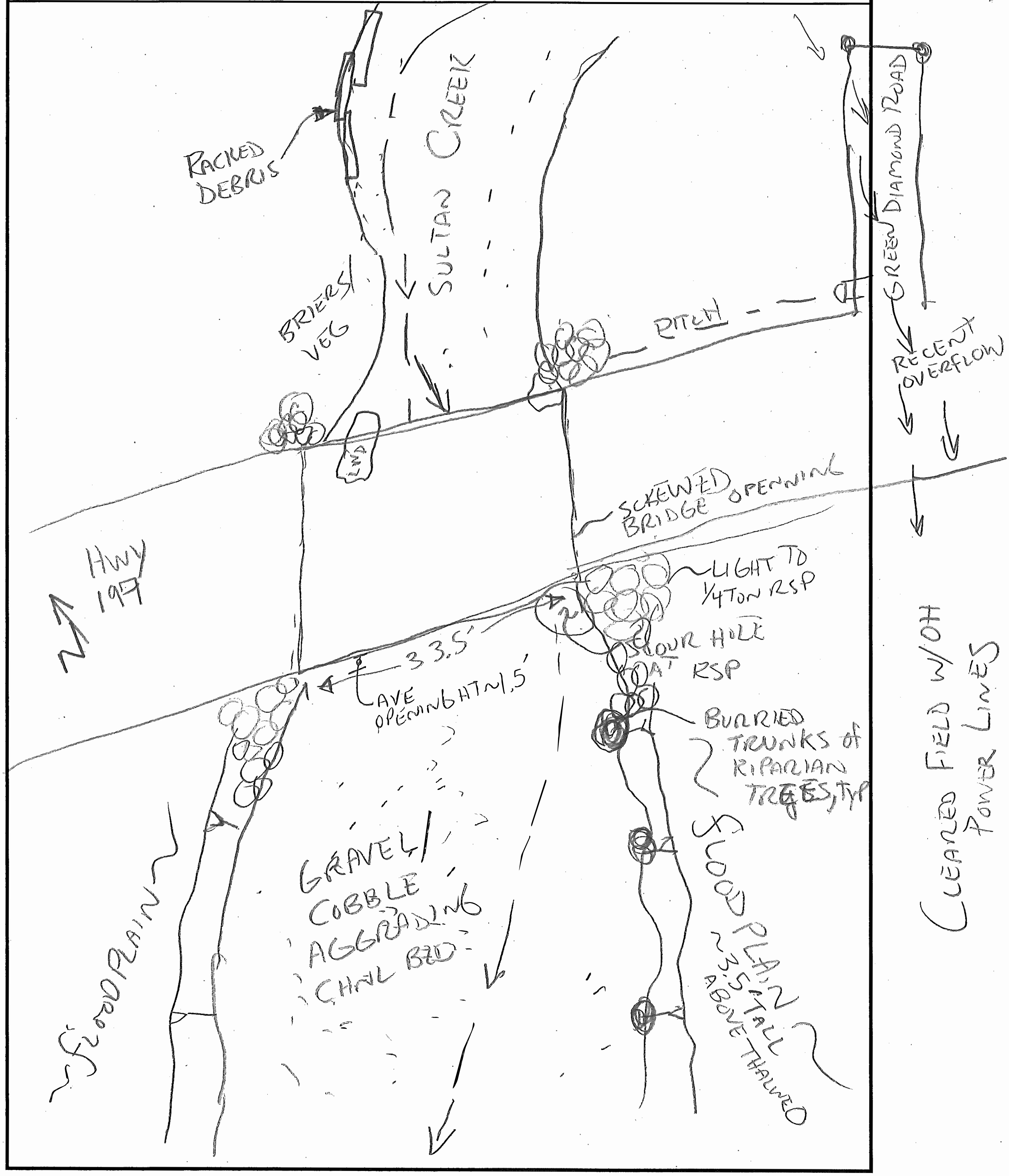
There is evidence that flow leaves the channel upstream of the bridge (influenced by LWD and a channel bend) and flows down the Green Diamond access road and across DN 197 (Figures 3 & 4)

All section of the channel appear to experience high rates of sediment transport.

Salmonids observed in an isolated pool at the downstream extent of surface water during this May visit. Channel was dry adjacent to the bridge.

Site Name: __Sultan Creek____

Site Sketch



Site Name: __Sultan Creek____

Figure 1. Sediment accumulation under the Sultan Creek bridge on Del Norte 197, postmile 5.00. View is looking upstream from the downstream channel.

Site Name: __Sultan Creek____

Figure 2. Sediment accumulation under the Sultan Creek bridge on Del Norte 197, postmile 5.00. View is looking downstream from the upstream channel.

Site Name: __Sultan Creek____

Figure 3. At high flow, water leaves the channel at this location and flows down the Green Diamond access road. There is a debris jam and channel bend at this location in the main channel.

Site Name: __Sultan Creek____

Figure 4. Intersection of Green Diamond access road and DN 197. Water along the road has deposited wood from the channel. Water that leaves the channel flows to the left on DN 197 (blue arrow); Sultan Creek is to the right (red arrow).

Site Name: ____Little Mill Ck____

Location (County-Road-Postmile)	Del Norte 197, PM 6.15		
PAD ID Number:	707142	Date:	9-May-19
Stream Name:	Little Mill Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Bed elevation under the bridge appears to have downcut approximately 1 ft. A lot of sediment has been deposited on the right bank from Smith River backwatering into the site. This was a high water year and this sediment appears very mobile, these deposits could vary a lot from year-to-year. Left bank rip rap is undercut by erosion and appears to be missing some lower layers. This erosion could compromise the bridge structure if it continues to migrate to the left. The rock weir grade control structures installed as part of the project are no longer present but their absence does not appear to compromise fish passage through the structure. Fish passage conditions are good and not impacted by changes in the bed structure or grade control in the project site.

Is the crossing performing as designed?		***No***	

Comments

Stream erosion has destroyed or removed many of the constructed channel elements, primarily rock weir grade control, but these changes are not impacting fish passage through the structure.

Structural condition		***Good***				

Comments

Only structural elements of concern are the erosion/undercutting of rip rap on the left bank. This is an outside channel bend and continued migration in this direction may eventually compromise the bridge structure.

Is there any visual evidence of damage to the structure?		***No***	

if yes, take photos and describe:

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	***Yes***	

if yes, take photos and describe: Photos are appended with captions to this document.

Picture name	Description
112232427 (Fig 1)	Wood/sediment ~100 m US of site, view looking US
112238660 (Fig 2)	Wood/sediment ~100 m DS of site, view looking US
115819449 (Fig 3)	Deposits on right bank - view looking US
115827187 (Fig 4)	Deposits on right bank - view looking US, closeup

Site Name: ____Little Mill Ck____

What is the potential for sediment delivery from the crossing?	***Low***			
Comments	Sediment is generally being transported in channel and through the structure. The exception is deposition of sediment in the project area when it is backwatered by the Smith River. This sediment is stored within the project site, primarily on the right bank (inside channel bend).			
If a project objective, was potential for future sediment delivery reduced?				***N/A***
Are grade control structures functioning as desired?			***No***	
Rock weirs were included in the project design and built through the crossing but they no longer exist.				
If there was channel incision/scour downstream of the crossing, has it stabilized?				***No***
The crossing/channel location is right at the confluence of Little Mill Ck and the Smith River. Sediment erosion and deposition in this area will be highly variable from year to year.				
Were there unintended effects on the channel?	***Yes***			

if yes, take photos and describe:	Photos are appended with captions to this document.
Picture name	Description
121559945 (Fig 5)	Left bank rip rap toe erosion under bridge
122100036 (Fig 6)	Missing rock weir grade control

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.
No. Sediment erosion and deposition through the project site does not appear to be impacting fish passage conditions.

Should this location be monitored for changes in performance?	***Yes***	
Erosion of the left bank rip rap should be monitored and rip rap improved. It appears that the rip rap was not submerged below the channel bed and is vulnerable to undercuts and mobilization. The rip rap mobility could expose the bridge structure.		

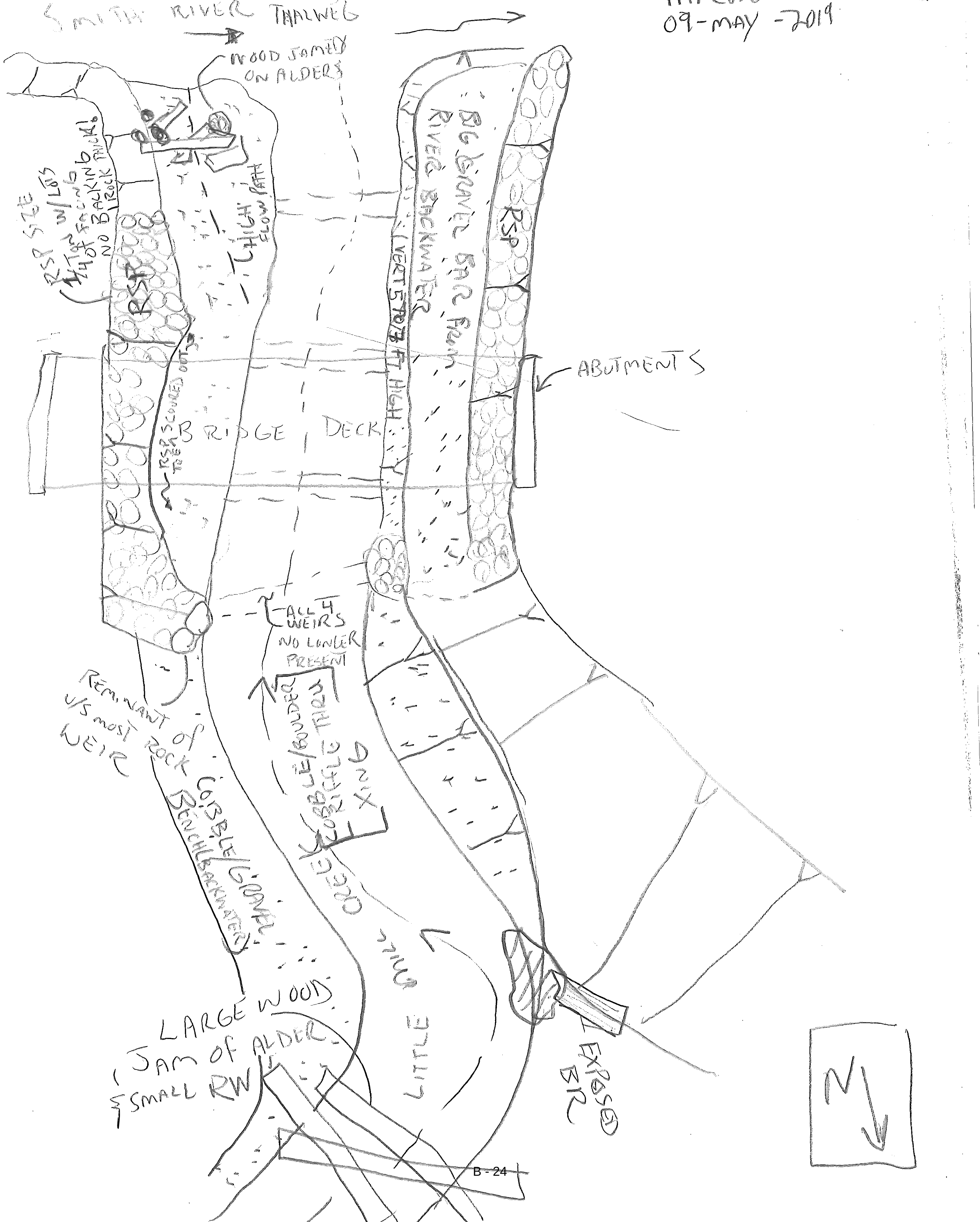
Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?
There are no immediate maintenance issues or concerns at this time.

Site Name: ____Little Mill Ck____

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
There are no immediate fish passage issues or concerns at this time.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)
There are no site access issues - easy parking off highway and paths to channel.

Site Name: ____Little Mill Ck____

M. LOVE
09-MAY-2019



Site Name: ____Little Mill Ck____

Figure 1. Wood and sediment ~100 m upstream of project site. View is looking US. This deposit would likely not be captured at the crossing.

Site Name: ____Little Mill Ck____

Figure 2. Wood and sediment ~100 m upstream of project site. View is looking DS through project site. This deposit would likely not be captured at the crossing.

Site Name: ____Little Mill Ck____

Figure 3. Right bank sediment deposit looking US through project site.

Site Name: ____Little Mill Ck____

Figure 4. Right bank sediment deposit looking US through project site – closer view.

Site Name: ____Little Mill Ck____

Figure 5. Left bank erosion of rip rap toe. Lowest rock appears to be missing.

Site Name: ____Little Mill Ck____

Figure 6. Missing/eroded rock weir grade control at upstream end of project site. Fish passage conditions are not compromised by the missing rock weirs.

Site Name: ____Little Mill Ck____

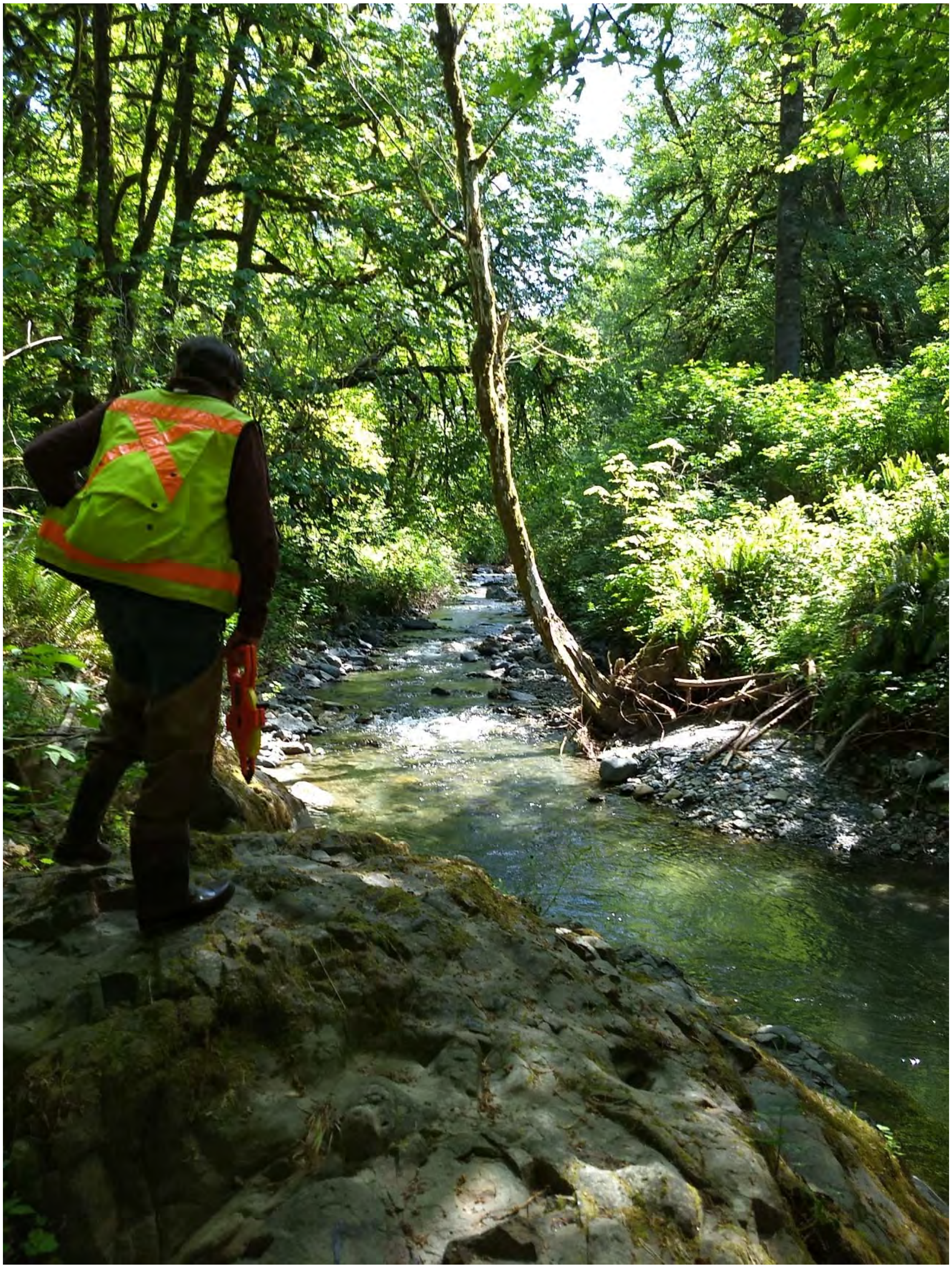


Figure 7. Possible reference reach upstream of project site.

Site Name: __Hall Creek____

Location (County-Road-Postmile)	Humboldt 299, PM 4.20		
PAD ID Number:	716742	Date:	9-Jun-20
Stream Name:	Hall Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Vortex weir fish ladder installed downstream of the Highway 299 bridge piers. The structure was installed to maintain grade and prevent scour at the bridge piers. The confluence of Hall Creek and the Mad River is just downstream of the bridge. Elevation changes and migration of the Mad River confluence have created a large elevation drop at the site (> 7 ft) and the fish ladder maintains the streambed elevation at the bridge piers while providing passage over the elevation difference.

Is the crossing performing as designed?	***Yes***	No			
Comments					
Structural condition	***Excellent***	Good	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	***No***	
if yes, take photos and describe:			

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	***No***
if yes, take photos and describe:		

Picture name	Description

Site Name: __Hall Creek____

What is the potential for sediment delivery from the crossing?	[✓ Low]	Moderate	High	
Comments				

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]

Are grade control structures functioning as desired?	[✓ Yes]	No	N/A

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Downstream of the crossing is the Mad River. The main channel of the Mad River in this reach has extensive variability and lateral migration.

Were there unintended effects on the channel?	Yes	[✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

The confluence with the Mad River approximately 100 feet downstream of the lowest fish ladder weir is highly mobile with a large variation in its elevation and geometry likely over time. The confluence is currently on a side channel far from the main channel of the river and the elevation control for this channel is a small riffle at the downstream end of a pool. This section of the channel dries out in summer and could be a potential fish stranding hazard. See attached photos.

Should this location be monitored for changes in performance?	[✓ Yes]	No

This site should be monitored regularly for debris and connectivity/elevation changes with the Mad River.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __Hall Creek____

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
The weir crests, with their abrupt edges, were not designed for passage of lamprey which typically require rounded crests. However, rounding these weir crests could cause adverse hydraulic conditions for this type of fishway. At higher flows that spread out onto the adjacent RSP, lamprey are likely able to migrate upstream along the margins of the wetted channel unrestricted.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Channel Measurements:

Under the bridge Active Channel width = 15 ft
Bankfull channel width = 22 ft (estimated from slope change and grout failure)

In channel US of bridge after the confluence of Hall Creek and the drainage ditch
Active Channel width = 12.5 ft
Bankfull channel width = 19.5 ft

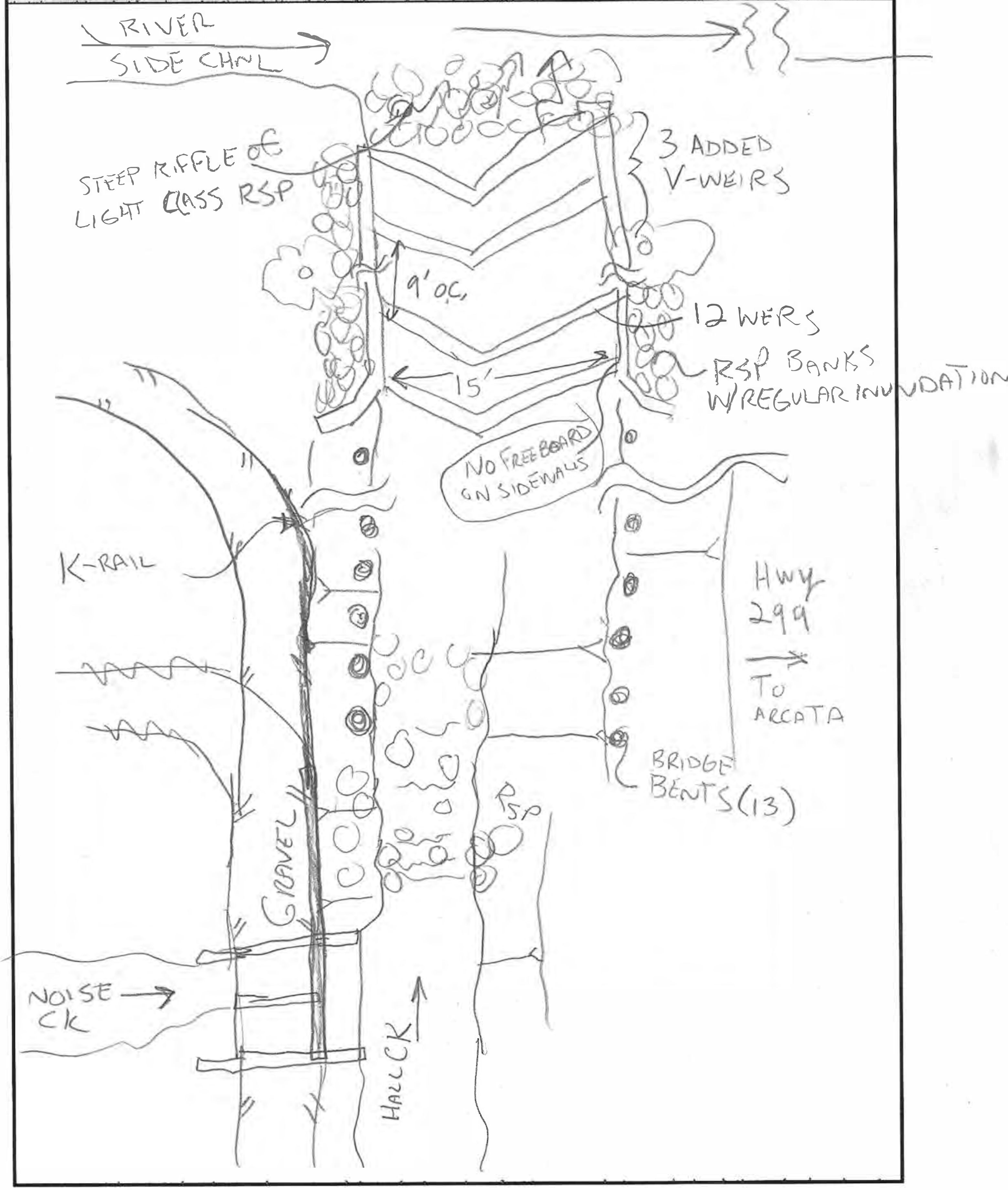
Fish Ladder Characteristics:

- Pool depth at the vortex weir edges is ~4 feet with little accumulated sediment in the pools
- Ladder has an inside width of 15 ft.
- The vortex spacing measured between the two upstream weirs is 9 feet
- Wall angle is 45 degrees
- 12 weirs total with a thickness is 3/4 ft.
- Weirs do not have rounded edges - should consider modifications for lamprey passage.

- The fish ladder side walls are coincident with each weir elevation at the weir-wall intersection. Thus, the wall top has the same slope as the fish ladder and provide no freeboard. Moderate high flows regularly exceed the wall elevation and are not contained within the ladder channel. There is not significant erosion outside of the ladder due to placement of 1-ton RSP along the ladder but there is evidence of sediment transport and some abrasion on the walls.

Site Name: HALL CK

Site Sketch



Site Name: ____ Hall Creek ________

Figure 1. Confluence of Hall Creek with the Mad River. The confluence is currently located in a backwater with the pool elevation control at the downstream riffle crest seen on the upper left of this photograph. The pool dries up and disconnects during most summers. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 2. Confluence of Hall Creek and the Mad River looking upstream. Fish ladder begins approximately 40 feet upstream of this confluence. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 3. Hall Creek fish ladder looking upstream from the downstream end and its transition to the natural channel. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 4. Hall Creek fish ladder looking upstream to the inlet transition under the HUM299 bridge. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 5. Hall Creek fish ladder looking upstream from the first weir to the natural channel bottom under the HUM 299 bridge. The ladder was installed to maintain the stream bed elevation at this upstream-most weir. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 6. HUM 299 bridge piers and upstream channel looking upstream from the Hall Creek fish ladder. Photo taken by M. Lang June 6, 2020.

Site Name: ____ Hall Creek ________

Figure 7. Upstream channel above the HUM299 Hall Creek bridge right at the confluence of Hall Creek (left) and a channel draining the ranch to the east. Photo taken by M. Lang June 6, 2020.

Site Name: _ Dunn Creek _

Location (County-Road-Postmile)	MEN 1, PM 92.83		
PAD ID Number:	706958	Date:	17-Jul-19
Stream Name:	Dunn Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Full spanning bridge replacement of a formerly culverted crossing. Eleven rock weirs were installed beneath and mostly upstream of the bridge to maintain grade control through the site.

Is the crossing performing as designed? Yes [✓ ***No***]

Comments: The downstream most weir (Weir 1) has failed due to changing elevation control downstream of the site. The failure of Weir 1 has created a large drop (1.8 ft at low flow) over the next weir upstream (Weir 2). A large scour hole is developing downstream of Weir 2 and beginning to undermine this weir. It will likely fail in the near future, migrating the problem upstream. See Figure 1.

Structural condition: [✓ ***Excellent***] Good Fair Poor Failed

Comments: The bridge structure is in excellent condition.

Is there any visual evidence of damage to the structure? Yes [✓ ***No***]

if yes, take photos and describe:

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility? Yes [✓ ***No***]

if yes, take photos and describe:

Picture name	Description

Site Name: _ Dunn Creek _

What is the potential for sediment delivery from the crossing? [✓ ***Low***] Moderate High

Comments

If a project objective, was potential for future sediment delivery reduced? Yes [✓ ***No***] N/A

Are grade control structures functioning as desired? Yes [✓ ***No***] N/A

The most downstream has failed creating a large drop at the next weir upstream. The downstream channel is incised and accounting for or correcting for the downstream elevation is needed.

If there was channel incision/scour downstream of the crossing, has it stabilized? Yes [✓ ***No***]

The incision is moving upstream and has reached the second weir and is now compromising its structure. Without intervention this issue will likely migrate upstream.

Were there unintended effects on the channel? Yes [✓ ***No***]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

The large drop at Weir 2 (1.8 ft at low flow) due to the failure of Weir 1 has altered the fish passage conditions for the site.

Should this location be monitored for changes in performance? [✓ ***Yes***] No

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

There are no immediate maintenance needs for the structure but the stability of the grade control weirs is compromised and should be addressed to prevent the problem from migrating upstream.

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

At the far downstream boundary of the project, the possible extent of the channel bottom vertical elevation change was not correctly estimated. The channel incised more than expected and the incision migrated upstream to the first grade control weir. This weir failed and now a large drop exists from the top of Weir 2 to its plunge pool - 1.8 ft at low flow. The weirs upstream of Weir 2 look stable now but if Weir 2 fails the problem will continue to migrate upstream. Some of the upstream weirs have large, deep plunge pools (see Figures 2 - 4) that should be periodically monitored to assess whether they are undermining the weir rock.

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Upstream channel has logging slash and debris and many areas of wood jams. The largest debris jam in the project vicinity had a drop height of 3.3 ft and pool depth of 2.2 ft at low flow. There were a few locations with old cable anchored restoration logs. See Figures 5 and 6.

Measurements of active and bankfull channel width upstream of the crossing:
Measurement 1: Active channel width = 9.9 ft; Bankfull channel width = 11.0 ft

Measurement 2: Active channel width = 12.0 ft; Bankfull channel width = 13.2 ft
This measurement site was identified as a good representative section for the crossing and was flagged as a cross section measurement location.

Measurements of active and bankfull channel width downstream of the crossing:
Measurement 1: Active channel width = 11.4 ft; Bankfull channel width = 12.7 ft
This location was flagged for a cross section survey. This is the channel location that is currently the elevation control (a riffle crest) downstream of the project area.

Measurement 2: Active channel width = 11.3 ft; Bankfull channel width = 12.5 ft

This location was also identified as the downstream extent of the longitudinal profile survey at a redwood fallen across the creek. Downstream of this there is a new slide from the road bank into the creek. This slide could influence the upstream channel bed elevation as it begins to trap debris and sediment in subsequent years.

Site Name: DUNN CK, HWY 1 PM

WEIR 11
2.2' POOL
1.5' ΔH

WIER 10
1.4' POOL
0.5' ΔH

WEIR 9
3.6' POOL
1.4' ΔH

WEIR 8
3.1' POOL
1.3' ΔH

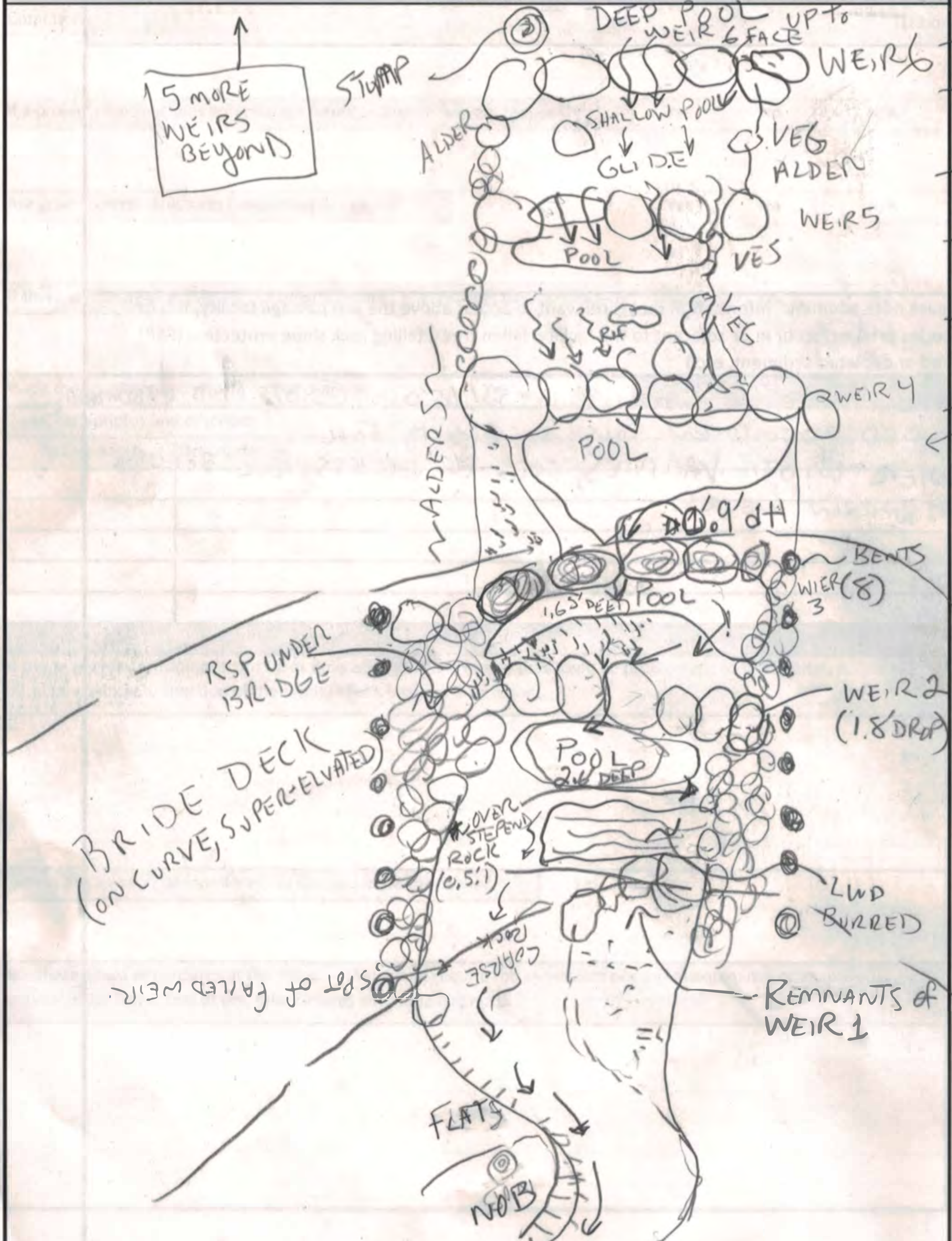
WEIR 7 (POOL W STUMP
2.8' POOL
1.5' ΔH.

WEIR 6
1.3' POOL
1.1' ΔH

WEIR 5
1.1 POOL
~0.6 ΔH

WEIR 4
1.45 POOL
ΔH=0.4

Site Sketch



DUNN CREEK

LESSON
POOL NR STUMP IS VERY DEEP, LIKELY DO TO DIGGING & REALY NARROW → DISTRUBING CHLN BED & NOT [illegible] W/ COMPACT MAT

Figure 1. Most downstream rock weir that has failed is in foreground. The next weir is currently in place but now has a 1.8 ft elevation drop at low flow. Photo by Michael Love on 7/17/2019.

Site Name: _ Dunn Creek _

Figure 2. Upstream rock weirs with deep plunge pools. Photo by Michael Love on 7/17/2019.

Figure 3. Upstream rock weir with deep plunge pool exposing foundation rock. Photo by Michael Love on 7/17/2019.

Figure 4. The two most upstream weirs in wider, lower gradient channel region and without the deep plunge pools. Photo by Michael Love on 7/17/2019.

Figure 5. Older log weirs installed upstream outside of the project reach. Photo by Michael Love on 7/17/2019.

Figure 6. Channel upstream and out of project area to be used as a reference reach. Photo by Michael Love on 7/17/2019.

Site Name: ____Upp Creek ____

Location (County-Road-Postmile)	MEN 101, PM 48.14		
PAD ID Number:	705136	Date:	12-Sep-19
Stream Name:	Upp Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Full spanning bridge with rock weirs for grade control.

Is the crossing performing as designed?	[✓ ***Yes***]	No			
Comments					
Structural condition	[✓ ***Excellent***]	Good	Fair	Poor	Failed
Comments					
Is there any visual evidence of damage to the structure?	Yes	[✓ ***No***]			
if yes, take photos and describe:					

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	[✓ ***No***]
if yes, take photos and describe:		

Picture name	Description

Site Name: ____Upp Creek ____

What is the potential for sediment delivery from the crossing?	[✓ Low]	Moderate	High	
Comments				

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]

Are grade control structures functioning as desired?		Yes	[✓ No]	N/A

The upstream most rock weir (the straight one) is gone (Figure 1). The angled weirs are intact (Figure 2). The loss of this rock weir is not impacting fish passage.

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	[✓ No]

Were there unintended effects on the channel?	[✓ Yes]	No	

if yes, take photos and describe: The headcut upstream is causing some right bank erosion approximately 100 ft US of crossing. The headcut is currently stabilized by a large tree and its roots. These effects are likely not a due to crossing.

Picture name	Description
Figure 3	US channel bank erosion and headcut
Figure 4	Tree roots currently arresting headcut and upstream bank erosion

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	Yes	[✓ No]	

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: ____Upp Creek ____

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

No issues are present that are affecting fish passage. Scour holes are developing at some of the weirs with the deepest at the most upstream of the pre-project weirs (Figure 5). The weir just downstream of, but not under the bridge, appears to be backwatered and is being buried in sediment (Figure 6).

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Channel Width Measurements

	Active (ft)	Bankfull (ft)
Channel US of project	19.5	23.8
Under bridge at downstream fenceline	27.7	45
DS in representative reach (US end)	13.1	15.5
DS in representative reach (DS end)	12.4	14.3
Older restored channel section (constructed)	37	46
Older restored channel section (adjusting)	14.3	18.8

The channel in the project area seems over widened. The downstream channel with previous restoration is a good comparison. In this reach, willows have encroached to narrow the channel width to better match the upstream channel geometry - these are the two constructed and adjusting widths given above.
The project is at a slope transition where a wider channel than the confined US channel would be expected.
See Figure 7.

Cross section surveys
At site, US and DS fencelines and middle of bridge.

In representative reach, 1) US below the tree, 2) through the pool, 3) at control DS end of pool, and 4) at the fenceline
Be sure to measure details of the adjusting cross section widths in some of these cross sections.

Longitudinal Profile
Start US at tree roots holding the headcut then proceed through project site downstream to the fenceline at cross section 4 for the representative reach.

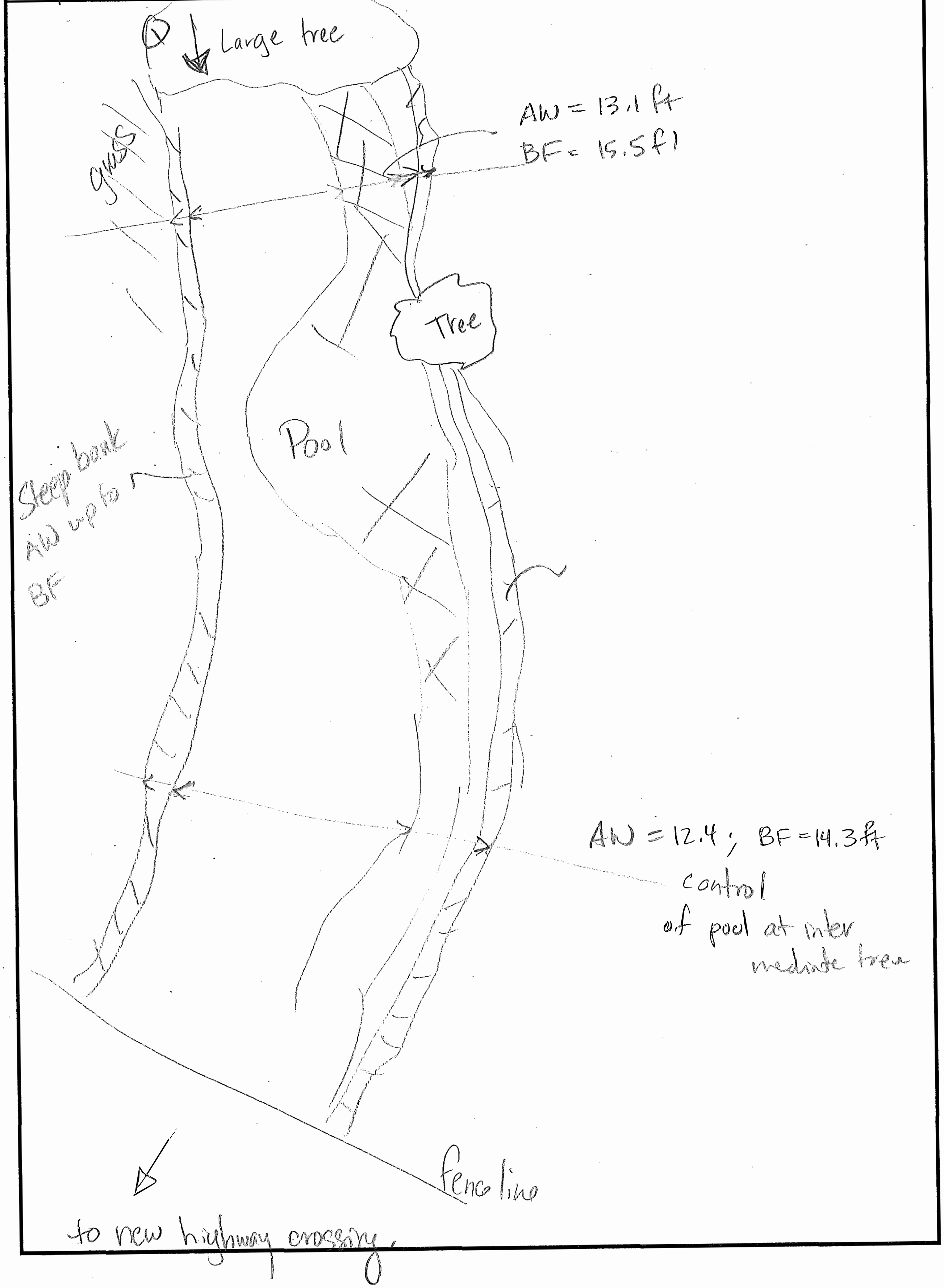
Survey all banklines and RSP placement.

Pebble counts US, in project and in representative reach.

Site Name: Upp Ck

Representative Reach

Site Sketch



Site Name: ____Upp Creek ____

Figure 1. View looking upstream from beneath the new bridge. The most upstream V-shaped rock weir is in the foreground and the straight rock weir upstream of this weir is missing. Photo by Michael Love on 9/12/2019.

Site Name: ____Upp Creek ____

Figure 2. Intact and fully functioning rock weirs viewed from downstream looking upstream at new bridge. Photo by Michael Love on 2/24/2021.

Figure 3. Upstream erosion on right bank, view is looking upstream and new bridge is downstream. Photo by Michael Love on 9/12/2019.

Figure 4. Tree roots stabilizing headcut and bank erosion upstream of the project site. Photo by Michael Love on 2/24/2021.

Figure 5. Scour maintained pool downstream of rock weirs. This is the same rock weir shown in Figure 2. Photo by Michael Love on 9/12/2019.

Site Name: ____Upp Creek ____

Figure 6. The weir just downstream of the bridge appear to be backwatered and being buried in sediment. Photo by Michael Love on 9/12/2019.

Site Name: ____Upp Creek ____

Figure 7. The older channel restoration just downstream of this project site was built at similar channel widths as the new channel under the bridge. This channel is being narrowed by encroaching willows. Photo by Michael Love on 9/12/2019.

Site Name: __North Fork Ryan Creek___

Location (County-Road-Postmile)	MEN 101, PM 52.36		
PAD ID Number:	707086	Date:	Sept. 12, 2019
Stream Name:	North Fork Ryan Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		
Overall Crossing Description - Emphasize Fish Passage Design Elements	Embedded, 12-ft wide by 11-ft high prefab reinforced concrete box culvert. The culvert height to substrate top was 6.8 ft at the inlet (embedded depth of 4.2 ft) and 7.5 ft at the outlet (embedded depth of 3.5 ft). The culvert substrate is plane bed with no real bed structures or bank lines. Streamflow went subsurface at the culvert inlet and resurfaced immediately downstream of the project. Isolated surface flow was present between weirs downstream of the culvert. This condition appears to be creating fish stranding potential. DisrupterThe rocks footing the upstream most weir are undermined and the weir appears at risk of failing. The residual drop over this weir is in excess of 1.5 feet. Rocks forming the weir near the culvert inlet have shifted and no longer function as a weir. rocks on the left side of the channel are mostly buried and not keeping the thalweg away from the left culvert wall until approximately halfway through the culvert. The downstream third of the culvert appears to have shallow, spread out flow under low flow conditions but was dry at the time of this assessment. The soil was still moist indicating recent drying out. The upstream channel had cool water temperatures, nice pools and juvenile salmonids. Pictures attached.		

Is the crossing performing as designed?	Yes	[✓ No]
Comments	The crossing is not performing as designed due to the undermined footer rocks at the upstream weir and the low flows going subsurface within the project area.	

Structural condition	[✓ Excellent]	Good	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	[✓ No]
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	[✓ No]
if yes, take photos and describe:		

Picture name	Description

Site Name: __North Fork Ryan Creek___

What is the potential for sediment delivery from the crossing?	[✓ Low]	Moderate	High	
Comments				

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]

Are grade control structures functioning as desired?	Yes	[✓ No]	N/A

The grade control structures are holding grade as intended but the high porosity of the weirs and gravel substrate around them are permitting the flow to go subsurface. The drop height and scour have undermined the rocks footing the upstream most weir such that the weir appears at risk of failing. The drop is in excessive 1.5 feet. The rocks forming the weir at the culvert inlet have shifted substantially, but continue to maintain upstream grade.

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable

Were there unintended effects on the channel?	Yes	[✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

At low flow, there is a 1.5 foot drop at the most upstream grade control weir and flow also goes under this and several other weirs at low flow.

Should this location be monitored for changes in performance?	[✓ Yes]	No

The upstream most weir is likely to fail soon so should be monitored to avoid incision and headcut into the upstream channel. Monitoring is also needed in summer to see if the bed self-seals and flows return to the surface through the crossing.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

Possibly in regards addressing stability of upstream-most rock weir. The potential upstream channel adjustments associated with failure of this weir should be evaluated to determine if action is warranted.

Site Name: __North Fork Ryan Creek___

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
Yes. The 1.5 foot drop over the upstream-most weirs and flows going surface during low-flow periods in the summer may be affecting fish passage and habitat at this site.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

The channel bed within the culvert is plane-bedded with no distinct thalweg. Larger guidance boulders appear to be present in the bed but accumulated sediment has made them ineffective. The as-built drawings show 30-inches (2.5 feet) of engineered bed as backfill but the depth at the inlet is now 4.2 feet and at the outlet 3.5 feet. This reduces the cross-sectional area of the inlet, and therefore the culvert inlet capacity, by approximately 20%.

During this asssessment visit, there was good flow and habitat conditions (pools and fish) upstream of the crossing.

Downstream of the crossing, the flow is subsurface from outlet to approximately 50 feet downstream. At the second downstream weir, the flow resurfaces just downstream. At all subsequent downstream weirs, the flow goes subsurface upstream of the weir and resurfaces downstream of the weir. Pictures included

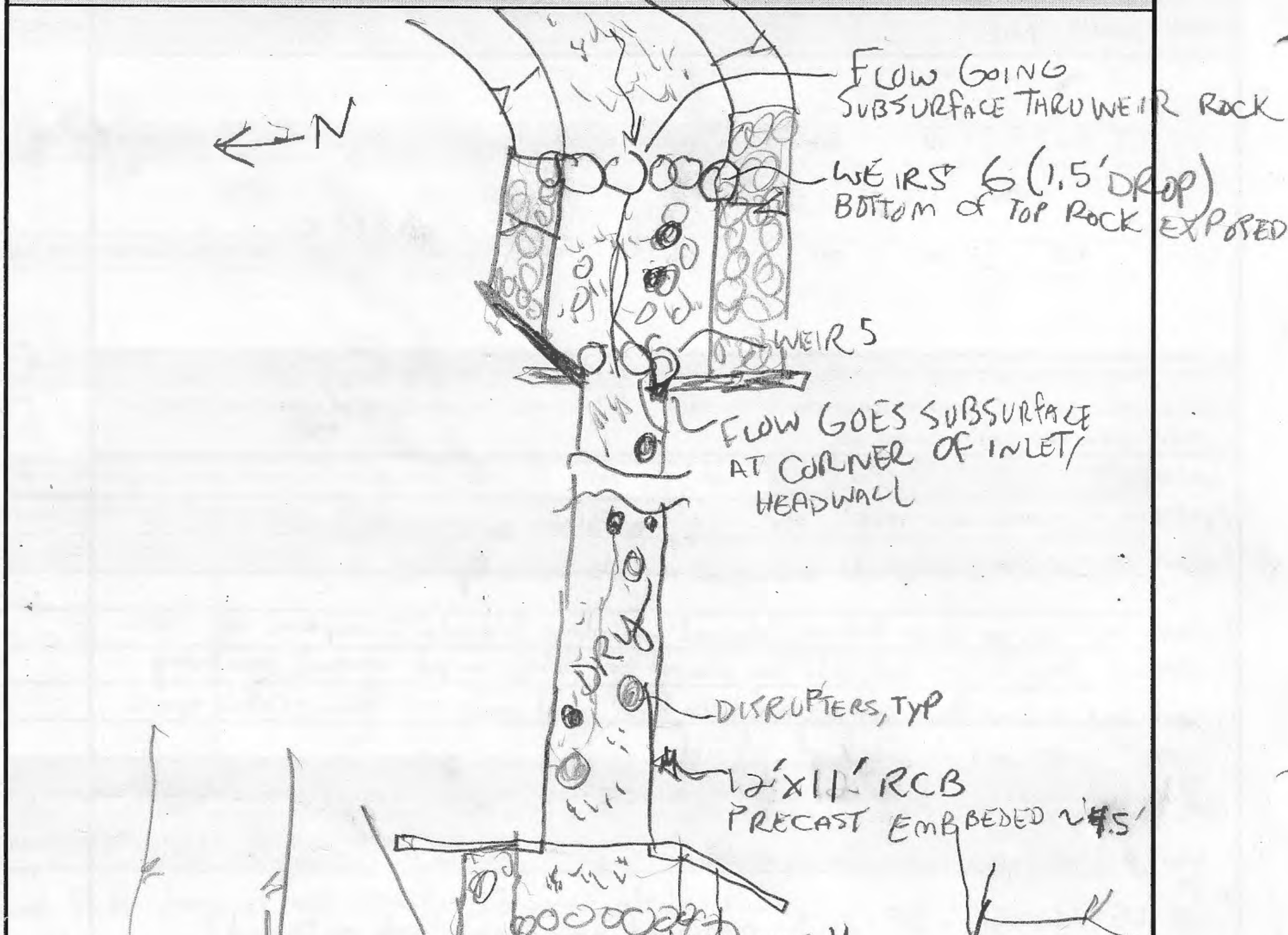
Use the channel upstream of the culvert to the fallen logs as the reference reach.

Survey the top and toe banklines from the project area upstream to the reference reach and downstream to the natural channel to assess the contour transitions.

Active and bankfull channel measurements:
In reference reach: AC = 12.5 feet; BF = 14.5 feet
Upstream of culvert: AC = 12.2 feet; BF = 20 feet - but not really a clear indicationon this rip-rap slope
Downstream of culvert: AC = 13.5 feet; BF = 21.3 feet - also not a clear indicator

Site Name: NF RYAN

Site Sketch



Site Name: __North Fork Ryan Creek___

Figure 1. View looking upstream from the North Fork Ryan Creek culvert inlet. The rock weir installed for grade control at the upstream project boundary has a low flow drop of approximately 1.5 feet. Note that flow goes subsurface at the lower right corner of the photo. Photo by Margaret Lang on 9/12/2019.

Figure 2. Close-up view of the upstream rock weir. The footing rocks are exposed in the pool increasing the potential for weir failure. Note that the low flow is going through the rocks in the weir rather than over the crest. Photo by Margaret Lang on 9/12/2019.

Site Name: __North Fork Ryan Creek___

Figure 3. Culvert inlet looking downstream from the upstream project boundary. Stream flow was low but continuous upstream of the culvert during this site visit. Photo by Margaret Lang on 9/12/2019.

Figure 4. The culvert’s invert and natural substrate bottom. The culvert substrate is almost a plain bed with the larger disruptor rocks mostly buried. At this low flow, there was no flow in the culvert, but it was very moist along the left side. Photo by Margaret Lang on 9/12/2019.

Figure 5. The culvert outlet looking upstream. The flow becomes discontinuous starting at the culvert inlet and remains. Discontinuous through the culvert and within the downstream project reach. Photo by Margaret Lang on 9/12/2019.

Figure 6. The downstream project channel looking downstream from the culvert outlet. Flow is discontinuous but surfaces behind most of the rock weirs. Photo by Margaret Lang on 9/12/2019.

Site Name: __North Fork Ryan Creek___

Figure 7. The downstream channel showing some surface flow upstream of the third rock weir. Photo by Margaret Lang on 9/12/2019.

Site Name: __ South Fork Ryan Creek __

Location (County-Road-Postmile)	Mendocino 101, PM 52.25		
PAD ID Number:	707085	Date:	12-Sep-19
Stream Name:	South Fork Ryan Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Two 10-ft diameter rammed in welded steel casings. The left barrel invert is installed at a higher elevation than the right concentrating low flows through the right barrel. Both culverts have are embedded and the left barrel's bottom substrate is much finer representing deposition during receding high flows. The left barrel open height is 6.5 ft at the inlet indicating 3.5 ft of embedded sediment. The right barrel has a 4 ft open height at the inlet indicating 6 ft of embedded sediment. The design specifies 36 inches of embedding. At the outlet, the left barrel open height is 9 ft (1-ft of embedded sediment) and the right barrel opening height is 8 ft (2-ft of embedded sediment).

Is the crossing performing as designed?	Yes	No	***Maybe***

Comments: The inlet of the lower elevation pipe has a smaller opening than intended. This is probably not impacting fish passage but could compromise high flow performance and conveyance of woody debris and sediment.

Structural condition	Excellent	***Good***	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	***No***

if yes, take photos and describe:

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	***Yes***	No

if yes, take photos and describe:

Picture name	Description
Figure	There is some sediment accumulation upstream of the lower culvert due to its small opening.

Site Name: __ South Fork Ryan Creek __

What is the potential for sediment delivery from the crossing?	Low	[✓ Moderate]	High	

Comments

Sediment transport through the site is primarily bedload. There also appears to be transport of some legacy sediment deposits from previously installed undersized culverts at this site.

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]
Are grade control structures functioning as desired?	Yes	[✓ No]	N/A

No, the 2nd rock weir from the upstream end of the project has failed and is now a jumble of large rocks. However, these rocks are holding grade in their current state.

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

N/A

Were there unintended effects on the channel?	Yes	[✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	[✓ Yes]	No

The site should be periodically monitored for sediment and debris accumulation and flow path changes due to the invert elevation differences, embedded culvert depths and possible mobilization of the upstream sediment deposits.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __ South Fork Ryan Creek __

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

No

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Longitudinal profile - start upstream at the inlet of the replaced private culvert then continue through both Caltrans culvert barrels to the downstream project transition to the natural channel conditions.

Higher elevation culvert has finer sediment upstream and coarser downstream.
The disruption and key stone rocks within the culvert are all in place and functioning as intended.
September low flows are going subsurface downstream of the culverts at the first rock weir.
The second rock weir downstream from the culverts is buried - elevations were confirmed with designs after site survey.

Use the reach between the private and Caltrans culverts for representative channel cross sections.
Measure additional cross sections downstream at the end of the wingwall, across weir 1 and another just upstream of weir 3.

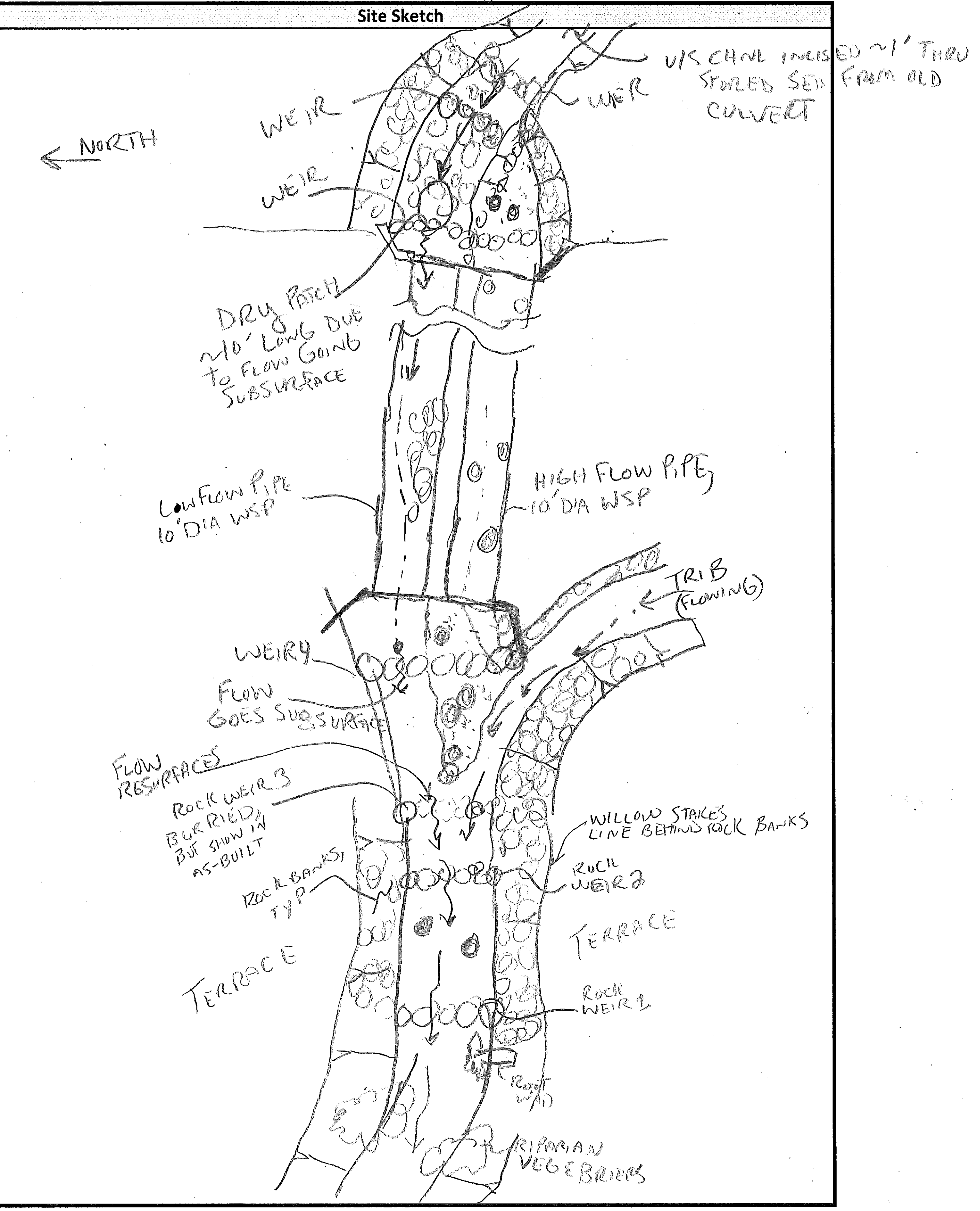
Channel Width Measurements

Location	Active Channel Width (ft)	Bankfull Width (ft)
Upstream channel	10.5	16
Downstream in project	13.9	23
Downstream channel	10.5	13.4

During this site visit, fish in the upstream channel were distinctly salmonid. Fish in the downstream channel were not.

Site Name: S.F Ryan Creek

Site Sketch



Site Name: __ South Fork Ryan Creek __

Figure 1. View looking upstream at the private culvert and upstream channel at South Fork Ryan Creek. Photo by Margaret Lang on 9/12/2019.

Site Name: __ South Fork Ryan Creek __

Figure 2. Embedded inlets of the double-barrel South Fork Ryan Creek crossing. Photo by Margaret Lang on 9/12/2019.

Figure 3. Close-up of the embedded inlets of the double-barrel South Fork Ryan Creek crossing. Photo by Margaret Lang on 9/12/2019.

Figure 4. The higher culvert’s invert and natural substrate bottom with keystone rocks looking downstream from the culvert inlet. Photo by Margaret Lang on 9/12/2019.

Figure 5. The lower culvert's invert and natural substrate bottom with keystone rocks looking downstream from the culvert inlet. Photo by Margaret Lang on 9/12/2019.

Figure 6. The lower culvert’s outlet looking upstream. At low flows, the flow goes subsurface and was discontinuous starting at the first rock weir downstream as seen in the photo’s foreground. Photo by Margaret Lang on 9/12/2019.

Figure 7. The culverts' outlets looking upstream from the downstream channel. The low flows resurface and become continuous again with the lower sections of the project and were continuous in the downstream channel. Photo by Margaret Lang on 9/12/2019.

Site Name: _Rattlesnake Creek__

Location (County-Road-Postmile)	Mendocino 101, PM 81.40		
PAD ID Number:	706986	Date:	17-Jul-19
Stream Name:	Rattlesnake Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Very large concrete arch culvert modified with three concrete outlet weirs to backwater culvert and provide grade control. The culvert not being a full span structure has had a significant impact on the channel geomorphology. Upstream, the bed is much coarser where large flows have preferentially sorted and deposited larger substrate. Downstream, the culvert outlet had directed flow at the right bank causing significant erosion. A site visit and video showing high flows on February 27, 2019 shows that the modifications have redirected this flow and mitigated this impact. Culvert is now capturing sediment and has a natural substrate bottom almost completely throughout. The invert is bare for only a short 1-ft wide and 12-ft long section along the left side at the outlet.

Is the crossing performing as designed?	***Yes***		
Comments	No issues noted and no debris trapping in new weirs.		

Structural condition	***Excellent***				
Comments	The metal plate coverings on the weir crests are performing well and a good design decision.				

Is there any visual evidence of damage to the structure?		***No***	
if yes, take photos and describe:			

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	***Yes***	
if yes, take photos and describe:	Sediment accumulation is occurring but improving performance.	

Picture name	Description
	Sediment is being deposited in the culvert to form a natural substrate bed
	Sediment is depositing in most of the outlet weir corners but good pools are being maintained below the notches.

Site Name: _Rattlesnake Creek__

What is the potential for sediment delivery from the crossing?	[✓ Low]	Moderate	High	

Comments

No concerns - sediment transport through the crossing appears to be natural transport of bed load.

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]
Are grade control structures functioning as desired?	[✓ Yes]	No	N/A

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

N/A

Were there unintended effects on the channel?	Yes	[✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	Yes	[✓ No]

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

The fishway weirs should be modified to accommodate lamprey passage. A dead adult lamprey was present in the outlet pool during the site assessment.

Site Name: _Rattlesnake Creek__

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
No current issues. Tailwater control elevation appears to be stable downstream of the outlet weirs. The tailwater elevation may also be improving (increasing) slightly because the outlet flow is now directed away from the unstable right bank of the downstream channel.

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Access is a large turnout on right when heading south on 101. Culvert outlet should be accessed by walking through the culvert and not by crossing 101 due to the blind corner.

Channel width measurements

Location	Active Channel Width (ft)	Bankfull Channel Width (ft)
US of inlet	30	35
DS at outlet tailwater	26	42
DS in natural channel	20	36

Structure bottom width is 21.5 feet

Weir Pool Characteristics

	US Pool Depth (ft)	DS Pool Depth (ft)
Weir 1 (most US)	2.2	1.7
Weir 2 (middle)	2.1	2.4
Weir 3 (most DS)	3.2	3.5

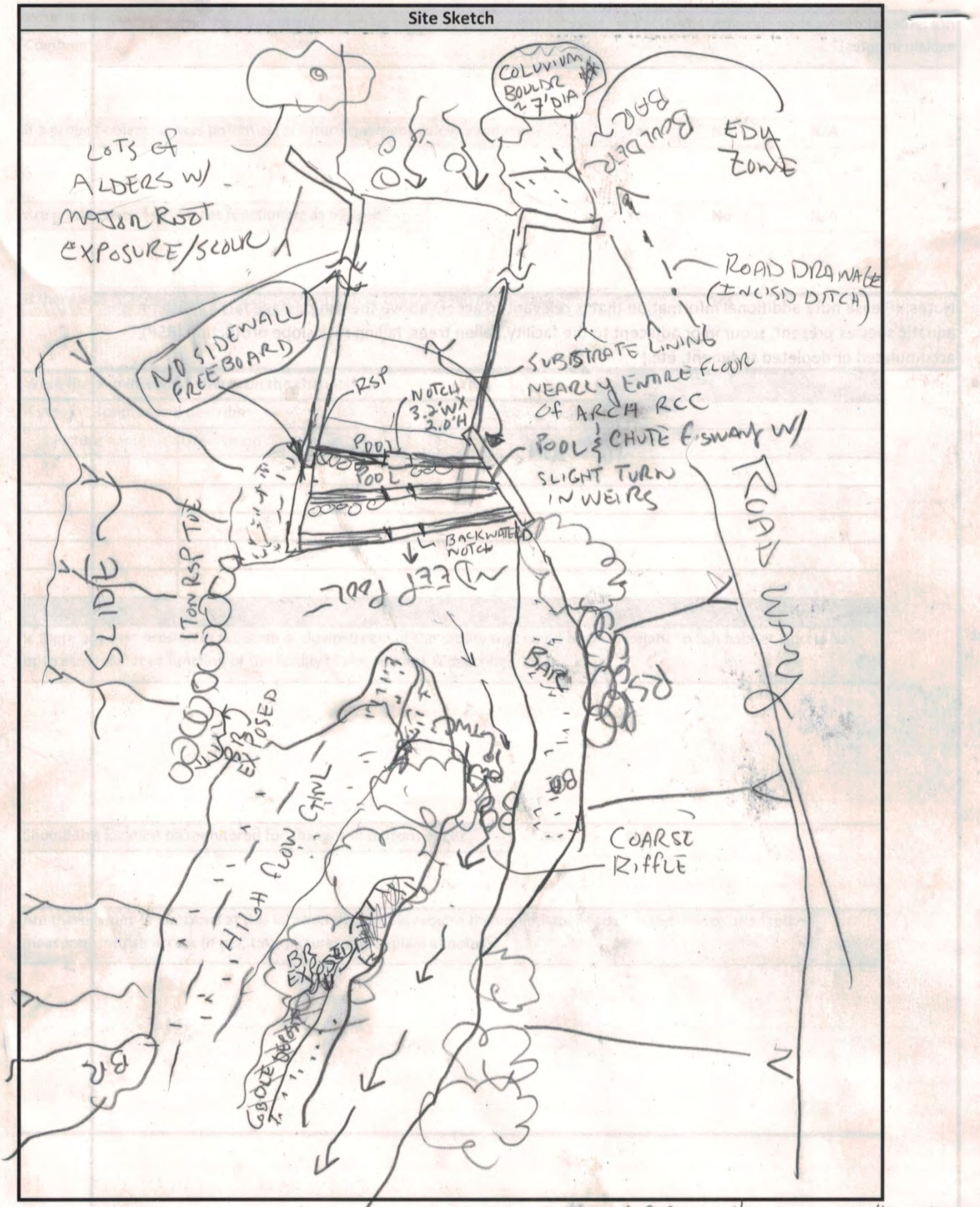
Weir Notch Characteristics

	US Notch Depth (ft)	DS Notch Depth (ft)	
Weir 1 (most US)	0.45	0.25	Note - could be fast for juveniles
Weir 2 (middle)	0.75	0.55	
Weir 3 (most DS)	0.75	0.55	

Dead adult lamprey observed in the pool at the most downstream weir.

Site Name: RATTLESNAKE CREEK

Site Sketch



TWC CAN DROP ~ 1' & STILL MEET 6" DROP CRITERIA

Site Name: _Rattlesnake Creek__

Figure 1. Looking upstream from the culvert inlet. Substrate in the channel is coarser here suggesting that the channel constriction due to a culvert width less than active channel width creates locally higher velocity than the natural channel. Photo M. Lang on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 2. Sediment accumulating to form a natural substrate channel bottom within most of the culvert, view is upstream from the culvert outlet. Photo M. Lang on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 3. Sediment trapping and pool maintenance in the outlet weirs. Photo M. Lang on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 4. The outlet pool weirs and right channel bank looking downstream from the culvert outlet. The modifications to add the weirs and reorient the outlet flow away from the right bank has reduced the erosion of the right channel bank. Photo M. Love on July 17, 2019.

Figure 5. The outlet pool weirs looking upstream from the outlet pool tailwater control. Photo M. Love on July 17, 2019.

Figure 6. The culvert outlet and most upstream weir notch looking upstream from the from outlet weirs. Photo M. Love on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 7. The outlet pool tailwater control looking downstream from the culvert outlet. Photo M. Lang on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 8. Outlet weirs looking upstream from the outlet pool tailwater control. Photo M. Love on July 17, 2019.

Site Name: _Rattlesnake Creek__

Figure 9. Downstream channel looking downstream from the outlet pool tailwater control. Photo M. Love on July 17, 2019.

Site Name: _ Cedar Creek ___

Location (County-Road-Postmile)	Mendocino 101, PM 89.04		
PAD ID Number:	706954	Date:	15-Apr-21
Stream Name:	Cedar Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Large concrete arch culvert (~22 ft wide at bottom and 21 ft high) modified for fish passage with the addition of weirs along the culvert invert and concrete pool and weir fishway at the outlet. Downstream of the fishway outlet, two rock weirs were installed and the most downstream rock weir has failed.

Is the crossing performing as designed?	[✓ ***Yes***]	No			
Comments					
Structural condition	Excellent	[✓ ***Good***]	Fair	Poor	Failed
Comments	The culvert and internal fish weirs are in excellent condition and functioning well. The concrete work on some of the outlet fishway weirs is creating minor problems as described below.				

Is there any visual evidence of damage to the structure?	Yes	[✓ ***No***]
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	[✓ ***No***]
if yes, take photos and describe:		

Picture name	Description

Site Name: _ Cedar Creek ___

What is the potential for sediment delivery from the crossing?	***Low***	Moderate	High	
Comments				

If a project objective, was potential for future sediment delivery reduced?	Yes	No	***N/A***

Are grade control structures functioning as desired?	***Yes***	No	N/A

The outlet fishway is mostly functioning as desired but some elements were not quite executed as intended. See Figures 8 and 9 for a possible impediment to lamprey passage.

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

N/A

Were there unintended effects on the channel?	Yes	***No***

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	***Yes***	No

The concrete work used to install the steel tops on the outlet fishway appears to be crumbling or vulnerable to erosion by bedload transport (see Figure 10). Suggest periodic monitoring of these weirs and installing timelapse cameras to document hydraulic conditions in the fishway and inside the culvert at higher fish passage flows.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

Possibly. Some sections of the weir tops rounded to provide lamprey passage were dewatered at the flows encountered during assessment (see Figures 8 and 9).

Site Name: _ Cedar Creek ___

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
See above and Figures 8 and 9.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Channel width measurements

Location	**Active Channel Width (ft)**	**Bankfull Channel Width (ft)**
US of inlet	37.5	45
DS at outlet tailwater	36	45

Structure bottom width is 22 feet

Drop Heights Over Weirs

	Drop Ht (ft)
Weir 1 (most DS)	1.25
Weir 2	0.5
Weir 3	0.5
Weir 4	0.5
Weir 5	0.5
Weir 6	0.5
Weir 7	0.5
Weir 8	0.8
Weir 9	0.6
Weir 10	0.8
Weir 11	0.7
Weir 12	0.6
Weir 13 (at culvert outlet)	0.5

Pool below Weir 1 was just under 5 feet deep with many juvenile salmonids.

Site Name: ____ Cedar Creek ________

Figure 1. Cedar Creek upstream channel from the culvert inlet. Photo taken by M. Lang April 15, 2021.

Site Name: ____ Cedar Creek ________

Figure 2. Cedar Creek culvert inlet. Photo taken by M. Lang April 15, 2021.

Site Name: ____ Cedar Creek ________

Figure 3. Cedar Creek culvert invert looking downstream from the inlet. The installed weirs are capturing sediment and maintaining a natural streambed near the inlet. Photo taken by M. Lang April 15, 2021.

Site Name: ____ Cedar Creek ________

Figure 4. Cedar Creek culvert looking upstream from the outlet. The internal fish weirs are functioning well. Photo taken June 3, 2021.

Site Name: ____ Cedar Creek ________

Figure 5. Cedar Creek outlet fishway looking upstream. The drop heights over the weirs under these conditions ranged from 1.25 ft (drop height at most downstream weir) to 0.4 ft; all but two drop heights were less than 0.75 ft. Photo taken June 3, 2021.

Site Name: ____ Cedar Creek ________

Figure 6. Looking upstream from the rock weir locations. In the foreground, the most downstream of the two rock weirs is somewhat intact. The most upstream rock weir is no longer present but its bank rocks are still present. The missing rock weir creates a larger drop height at the last fishway weir (~1.25 ft compared to 0.5 ft at most of the other weirs). Photo taken June 3, 2021.

Site Name: ____ Cedar Creek ________

Figure 7. Cedar Creek downstream channel looking downstream from the rock weirs. Photo taken June 3, 2021.

Site Name: ____ Cedar Creek ________

Figure 8. Cedar Creek culvert outlet weir. The concrete at this location has a small edge which was not smoothed out when the steel cover was installed. This edge creates a detached flow that does not wet the rounded section installed to assist lamprey migration. Photo taken June 3, 2021.

Site Name: ____ Cedar Creek ________

Figure 9. Cedar Creek culvert outlet weir. The concrete at this location has a small edge which was not smoothed out when the steel cover was installed. This edge creates a detached flow that does not wet the rounded section installed to assist lamprey migration. Photo taken June 3, 2021. (alternate view to supplement Figure 8)

Site Name: ____ Cedar Creek ________

Figure 10. Cedar Creek culvert outlet weirs showing some of the crumbling concrete weir edges, especially around the installed steel plate coverings. Photo taken June 3, 2021.

Site Name: __Yank (Lemm) Creek__

Location (County-Road-Postmile)	Shasta - 299 - PM 32.25		
PAD ID Number:	737295	Date:	4-Oct-19
Stream Name:	Yank (Lemm) Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		
Overall Crossing Description - Emphasize Fish Passage Design Elements	Full spanning bridge. No added elements for fish passage visible.		

Is the crossing performing as designed?	[✓ Yes]	No			
Comments					
Structural condition	[✓ Excellent]	Good	Fair	Poor	Failed
Comments	The crossing is efficiently passing all flow and likely has no fish passage issues.				

The crossing does have a high potential for scour and sedimentation problems due to the alignment and sharp, 90-degree right turn in the outlet channel. The channel appears to be reorienting to move the channel thalweg to the right and restore the historic channel alignment. In addition, the channel under the bridge is much wider and less confined than the natural channel upstream and downstream. This difference could result in insufficient depths through the crossing at lower-flows thus creating periods when the adjacent natural channel provides adequate depth but the crossing is too shallow.

Is there any visual evidence of damage to the structure?	Yes	[✓ No]
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	[✓ Yes]	No
if yes, take photos and describe:	Sediment is accumulating on the left bank and downstream of the structure as a geomorphic response to the alignment. The channel is constricted at a sharp right turn downstream of the crossing and it appears to be becoming more constricted. The left bank downstream of the crossing is currently very armored but is vulnerable to erosion. See attached figures.	

Picture name	Description
Figure 2	Sediment depositing downstream of bridge at sharp right turn into a confined channel.
Figure 3	Sediment deposit downstream of bridge, mostly on left bank as the main channel thalweg migrates to the right.

Site Name: __Yank (Lemm) Creek__

What is the potential for sediment delivery from the crossing?	Low	***Moderate***	High

Comments

It appears that most of the sediment stored upstream of the original crossing has been mobilized and transport downstream.

If a project objective, was potential for future sediment delivery reduced?	Yes	No	***N/A***
Are grade control structures functioning as desired?	Yes	No	***N/A***

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable

Were there unintended effects on the channel?	***Yes***	No

if yes, take photos and describe:

Picture name	Description
Figure 3 and 4 attached	The channel thalweg appears to by trying to develop or maintain a more skewed alignment than the crossing. The thalweg is on the far left bank and creating a scour hole near the inlet, left wingwall then crosses to the right side through the crossing. At the outlet, the channel thalweg follows the right, outlet wingwall.

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	***Yes***	No

Needs monitoring for changes in the channel location and migration of the channel thalweg.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __Yank (Lemm) Creek__

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
The constricted channel downstream of the crossing has armoring and regions of claystone bedrock chutes which may present fast velocities. These are not directly related to the crossing construction but may be exacerbated by the sediment transport conditions through the crossing.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

There were bull frogs present at the site.

The site alignment is poor with a very sharp right turn in the channel just downstream of the crossing. The outer bank of this bend is armored to prevent damage and loss of property for the adjacent ranch. The channel just downstream of the bend has claystone, bedrock controls.

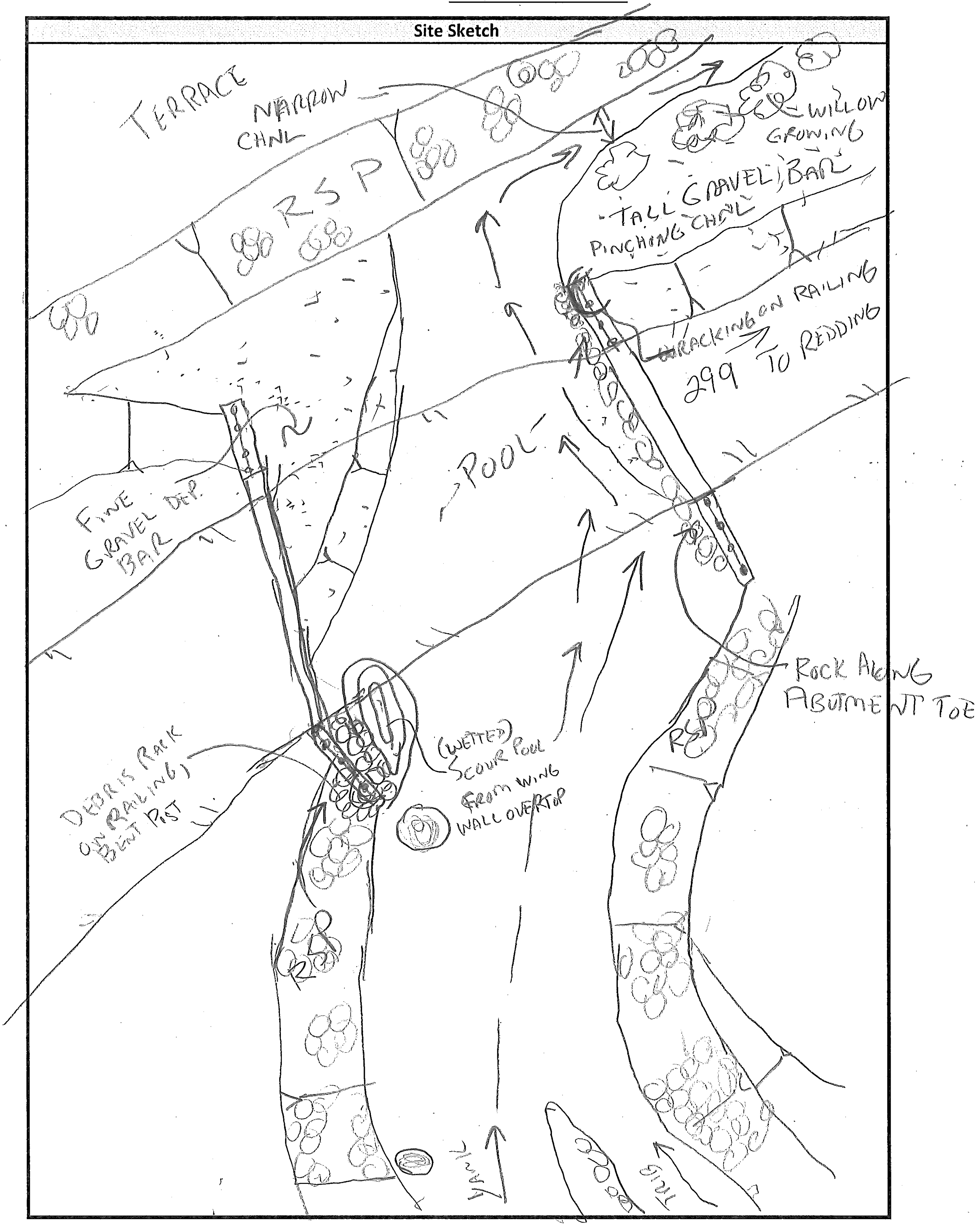
The channel upstream and downstream is adjusting to the alignment but is constricted in movement to the right by the right outlet wingwall. At high flows, water moves through the crossing at an angle as evidenced by captured flood debris on the upstream, left-bank wingwall and downstream, right bank wingwall (see included photos).

Active (AC) and bankfull (BF) channel width measurements:

AC (ft)	**BF (ft)**	**Location**
24.5	25.5	Downstream straight section after the sharp right bend
23	28	US channel away from the crossing
22.5	28	Just US of the left wingwall
38	46.5	At the bridge measured perpendicular to flow where the channel thalweg alignment crosses from left to right under the crossing.

Site Name: YANK CREEK

Site Sketch



Site Name: __Yank (Lemm) Creek__

Figure 1. Lemm/Yank Creek Highway 299 bridge looking upstream from the downstream channel. The downstream channel is a mix of claystone bedrock sections and gravel. Photo taken October 4, 2019.

Figure 2. Lemm/Yank Creek Highway 299 bridge looking downstream at the downstream channel just after the bridge. This section makes a sharp right turn along the armored embankment into a narrow, V-shaped channel for approximately 60 feet before the downstream channel widens and transitions to a natural channel shape with a mix of claystone bedrock sections and gravel. Photo taken October 4, 2019.

Figure 3. Lemm/Yank Creek Highway 299 bridge looking upstream. The creek channel is aligned with the thalweg along the left wingwall upstream, then crossing through the structure to the right wingwall downstream as shown in this picture. High flow debris was captured on the fence above the right wingwall as shown which matches debris at the same elevation as on the left wingwall fence upstream. Photo taken October 4, 2019.

Figure 4. Lemm/Yank Creek Highway 299 bridge looking downstream. The creek channel is aligned with the thalweg along the left wingwall upstream, then crossing through the structure to the right wingwall downstream. High flow debris was captured on the fence above the left wingwall as it poured over the wall creating the scour hole in the foreground. Photo taken October 4, 2019.

Figure 5. Lemm/Yank Creek channel upstream of the 299 crossing, looking downstream at the bridge. Photo taken October 4, 2019.

Figure 6. Lemm/Yank Creek channel upstream of the 299 crossing, looking upstream. Photo taken October 4, 2019.

Site Name: __Fort Goff Creek___

Location (County-Road-Postmile)	Siskiyou 96, PM 56.00		
PAD ID Number:	707168	Date:	19-Sep-19
Stream Name:	Fort Goff Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Full span bridge culvert replacement using Caltrans modular bridge design. The channel has a natural substrate bottom and appears very similar to an upstream reference reach. In further analysis review the plans to determine whether the rock placement plans.

Is the crossing performing as designed?	***Yes***	No			
Comments					
Structural condition	***Excellent***	Good	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	***No***
if yes, take photos and describe:	The structure is not damaged but the upstream, left bank footing is being exposed.	

Picture name	Description
Figures 3 - 5	Exposure and undercutting of upstream, left bank footing.

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	***No***
if yes, take photos and describe:		

Picture name	Description

Site Name: __Fort Goff Creek___

What is the potential for sediment delivery from the crossing?	[✓ Low]	Moderate	High	

Comments

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ N/A]

Are grade control structures functioning as desired?	Yes	No	[✓ N/A]

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable

Were there unintended effects on the channel?	Yes	[✓ No]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

Yes, the upstream portion of the left bank footing is exposed and starting to undercut for a length of approximately 10 feet. The bank material on the left bank just upstream of the bridge is also experiencing some scour. The channel bends to the right entering the bridge so the left outer bank likely has higher velocity. See Figures 3, 4, and 5.

Should this location be monitored for changes in performance?	[✓ Yes]	No

Periodically check the footing's exposure and competence.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __Fort Goff Creek___

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?

No

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

Upstream of the project region is a good reference reach. Survey as far upstream as possible to include the steeper upstream section. Stop at this slope change and survey a detailed cross section to act as a boundary for modeling analysis.

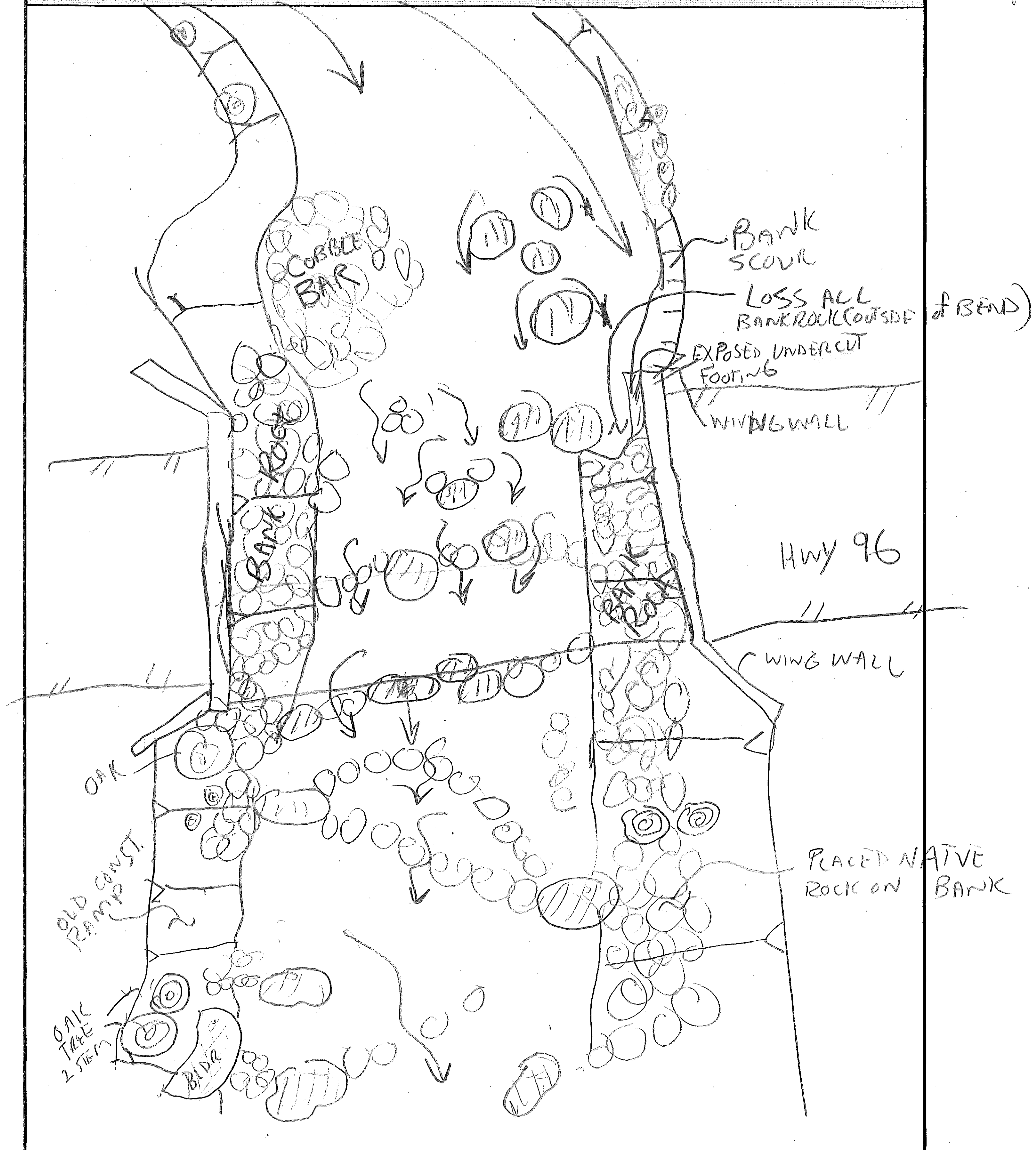
Cross section and channel survey will be fairly easy here due to good sight lines but water velocity is fast so needs to happen at low flow.

Channel width measurements

Location	**Active Channel Width (ft)**	**Bankfull Channel Width (ft)**
US in reference reach	23.0	26.5
US at channel bend	22.8	28.8
Just US of the bridge	33.0	44.5
Under the bridge	29.3	33.9
DS of bridge	23.5	27.0

Site Name: Fort Goff

Site Sketch



Site Name: __Fort Goff Creek___

Figure 1. Channel upstream and out of project area, good reference reach. Photo by M. Lang on 9/19/2019.

Site Name: __Fort Goff Creek___

Figure 2. Upstream looking downstream at bridge and project area. Photo by M. Lang on 9/19/2019.

Site Name: __Fort Goff Creek___

Figure 3. Upstream, left bank of bridge showing scoured bank protection and exposed footing. Photo by M. Lang on 9/19/2019.

Figure 4. Close-up of upstream, left bank of bridge showing scoured bank protection and exposed footing. Photo by M. Lang on 9/19/2019.

Figure 5. Upstream, left bank and bridge footing showing scoured bank protection and exposed footing. This is an outer channel bend coming into the bridge project site. Photo by M. Lang on 9/19/2019.

Site Name: __Fort Goff Creek___

Figure 6. Channel and bridge looking upstream. Photo by M. Lang on 9/19/2019.

Figure 7. Channel downstream and out of project area just above the confluence with the Klamath River. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Location (County-Road-Postmile)	Siskiyou 96, PM 65.40		
PAD ID Number:	707147	Date:	19-Sep-19
Stream Name:	O'Neill Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		

Overall Crossing Description - Emphasize Fish Passage Design Elements	Full span bridge across steep, step pool channel. No obvious crossing design elements or grade control in the channel beneath the bridge other than the bank protection and bridge foundation. The cascade/step in the channel just beneath the bridge appears to be a little steeper than the adjacent channel but it is not much different than the natural channel step geometry. The channel appears to have experienced significant bedload mobilization since the project construction.

Is the crossing performing as designed?	***Yes***	No
Comments		

Structural condition	***Excellent***	Good	Fair	Poor	Failed
Comments					

Is there any visual evidence of damage to the structure?	Yes	***No***
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	Yes	***No***
if yes, take photos and describe:		

Picture name	Description

Site Name: __O'Neil Creek___

What is the potential for sediment delivery from the crossing?	***Low***	Moderate	High	
Comments				

If a project objective, was potential for future sediment delivery reduced?	Yes	No	***N/A***

Are grade control structures functioning as desired?		Yes	No	***N/A***

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable

Were there unintended effects on the channel?	Yes	***No***	

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	Yes	***No***

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: __O'Neil Creek___

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
Probably not, but compare design plans and post project photos to existing channel conditions within the project area to confirm bed changes and bedload mobilization.

Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

The creek bed in the project area appears to be within old mine tailings and is cutting through these deposits.

Downstream of the bridge, the channel has more alluvial deposits from O'Neill Creek onto its banks from backwatering by the Klamath River confluence. There is a small diversion downstream and restoration work here is evident and was probably needed due to the deposited debris.

The channel upstream of the bridge to a large wood jam is a good representative reach and has step pool geometry similar to the channel beneath the bridge and in the downstream channel section before the water diversion and the influence of the lower debris jam. The large wood jam upstream will likely blow out in the future and has finer sediment trapped above it that will be released downstream.

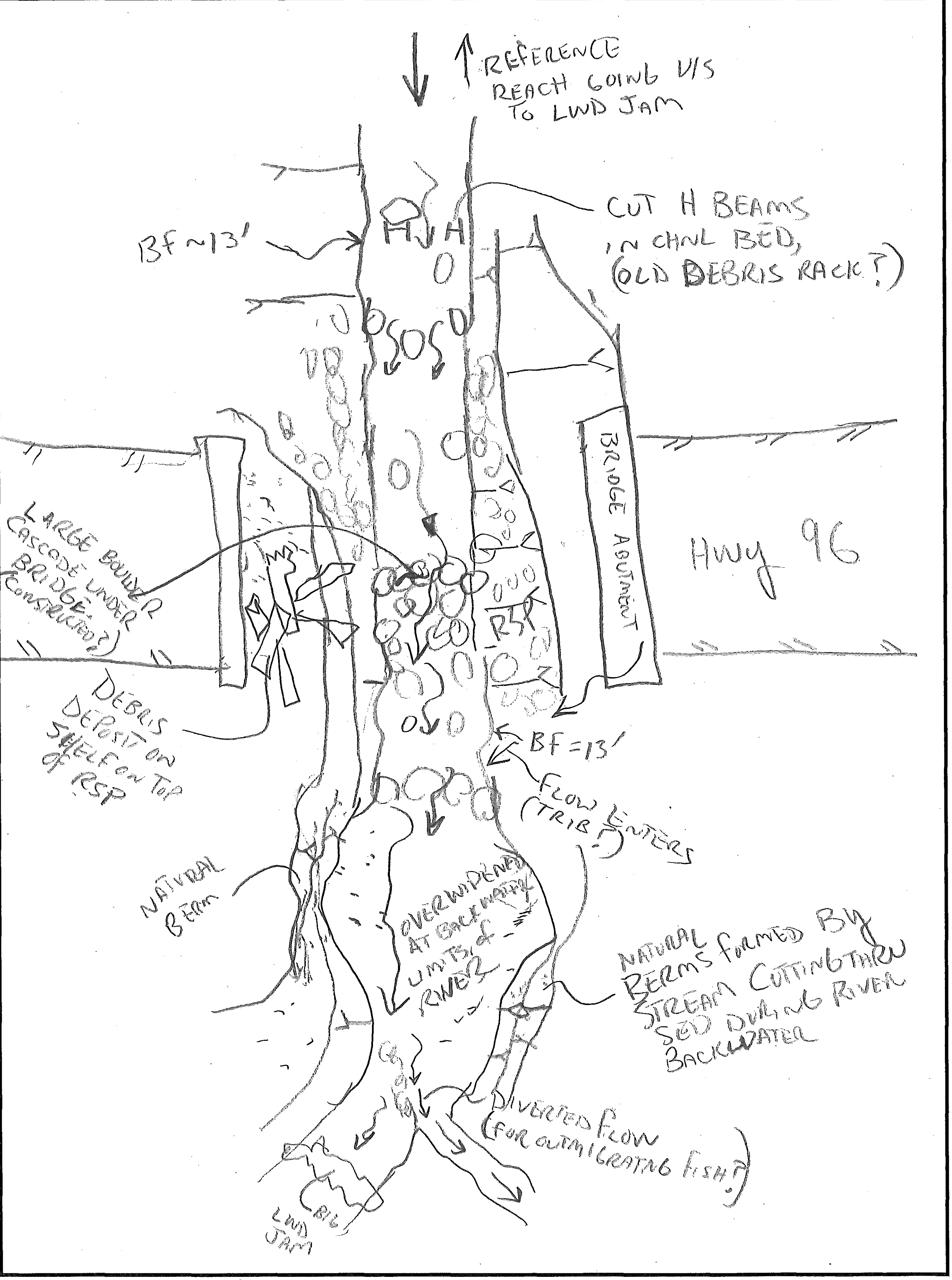
Bridge span at channel height upstream of main step under the bridge is 40.8 feet.

Channel width measurements

Location	**Active Channel Width (ft)**	**Bankfull Channel Width (ft)**
US channel above log jam	7.5	12.7
US of bridge below log jam	11.0	14.5
Just US of the main step under the bridge	8.5	14.5
Just DS of the main step under the bridge	14.4	19
DS of bridge	9.0	13

Site Name: O'NIEL CREEK SIS-96 PM 65.4

Site Sketch



Site Name: __O'Neil Creek___

Figure 1. Channel downstream of the bridge looking upstream. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Figure 2. Channel downstream of the bridge looking downstream at the section with backwater deposits. There is a water diversion on the left channel that had been reworked to maintain its flow and elevation. The main channel is on the right. Photo by M. Lang on 9/19/2019.

Figure 3. The channel bed under the bridge channel and transition into the downstream channel looking upstream. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Figure 4. The upstream channel and transition looking upstream from under the bridge. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Figure 5. Closeup of the primary low flow channel under the bridge looking upstream. Photo by M. Lang on 9/19/2019.

Figure 6. Channel under the bridge showing wood deposited at high flows onto the top of the constructed bank protection. Photo by M. Lang on 9/19/2019.

Figure 7. Upstream channel looking upstream from the bridge. The channel is narrower upstream. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Figure 8. Log jam in upstream channel looking upstream. This wood jam looks like it could mobilize at high flows with a potential to release finer sediment. Photo by M. Lang on 9/19/2019.

Figure 9. Log jam in upstream channel looking downstream. This wood jam looks like it could mobilize at high flows with a potential to release finer sediment. Photo by M. Lang on 9/19/2019.

Site Name: __O'Neil Creek___

Figure 10. Log jam in upstream channel looking downstream. The sediment in the channel and the banks in this reach are finer than downstream. This channel section looks appears to be a location of periodic deposition. Photo by M. Lang on 9/19/2019.

Site Name: _ Dibble Creek _

Location (County-Road-Postmile)	Tehama 5, PM 28.10		
PAD ID Number:	737008	Date:	4-Oct-19
Stream Name:	Dibble Creek		
Evaluator (1):	Margaret Lang		
Evaluator (2):	Michael Love		
Overall Crossing Description - Emphasize Fish Passage Design Elements	Double span bridge on Interstate 5. Modified with sheet piling grade control and constructed low flow channel with rock weir fishway on river right just downstream of the bridge crossings. The five rock weirs define a low flow channel that is 28 feet wide with the left (in channel boundary) constructed with a rock berm.		

Is the crossing performing as designed?	Yes	No	[✓ ***Probably***]
Comments			

The channel was dry when during this field site visit so confirmation of flow paths were not possible but it appears that the concentration of low flow and performance of the rock weir fishway would be approximately as intended.

Structural condition	Excellent	[✓ ***Good***]	Fair	Poor	Failed
Comments	Most rocks in the rock weirs were still in place. The pools formed by the rock weirs appear				

a little small to provide sufficient turbulence damping but this would need to be confirmed at fish passage flows. The site could have porosity and dewatering issues due to loss of material used to fill voids within the weir structural elements.

Is there any visual evidence of damage to the structure?	Yes	[✓ ***No***]
if yes, take photos and describe:		

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	[✓ ***Yes***]	No
if yes, take photos and describe:	Structure seems to be storing finer sediment upstream of crossing.	

Picture name	Description
Figure 1	View of upstream channel looking downstream at the crossing
Figure 2	Substrate in the left (high flow) channel stroed under the bridge

Site Name: _ Dibble Creek _

What is the potential for sediment delivery from the crossing?	Low	[✓ ***Moderate***]	High	

Comments	The crossing bed is mobile with a finer substrate size upstream of the structure. Only localized scour was observed around the bridge piers and rock weirs (minimal).

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ ***N/A***]

Are grade control structures functioning as desired?	[✓ ***Yes***]	No	N/A

The rock weirs are mostly intact. A few rocks have moved due to being undercut and rolling (see attached Figure 4) but the weirs are functioning as intended. The confining rock berm constructed on the left bank of the low flow channel has some locations were water can easily leave the channel confines. The structures have lost smaller substrate introduced to fill voids and much of the backfill specified on the as-builts.

If there was channel incision/scour downstream of the crossing, has it stabilized?	Yes	No

Not applicable

Were there unintended effects on the channel?	Yes	[✓ ***No***]

if yes, take photos and describe:

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	[✓ ***Yes***]	No

The site's bed mobility could compromise the rock weirs and low flow channel stability. Recommend periodic inspection following flood flows.

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

No

Site Name: _ Dibble Creek _

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
The site has significant bed mobility and scour potential. It appears to de-water rapidly which may be a concern for possible stranding issues. The pools between rock weirs are filling with sediment and may not experience routine high flows for scouring this sediment from the pools. The rock weir structures appear stable if the bed elevation remains stable. See attached Figures 4 and 5.
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)

The bridge spans are sufficiently wide and do not encroach on the channel but each has one pier in the active channel that may be subject to scour. The sheet piling installed for grade control currently provides protection from excessive scour at the piers.

Channel measurements at and near the site:
Upstream channel approximately halfway between the frontage road and I-5 crossings
Active channel width = 49 feet; Bankfull channel width = 59 feet

The span between bridge piers for both lanes of I-5 are 53 feet

The width of the rock weir fishway, low flow channel is 28 feet

Just downstream of the rock weir, the active channel width is 98 ft and the bankfull channel width is 110 ft

Downstream of the project area, the channel is very open with nice gravel substrate.
Active channel width is 87 feet; Bankfull channel width is 93 feet

Site Name: Dibble Ck

Site Sketch

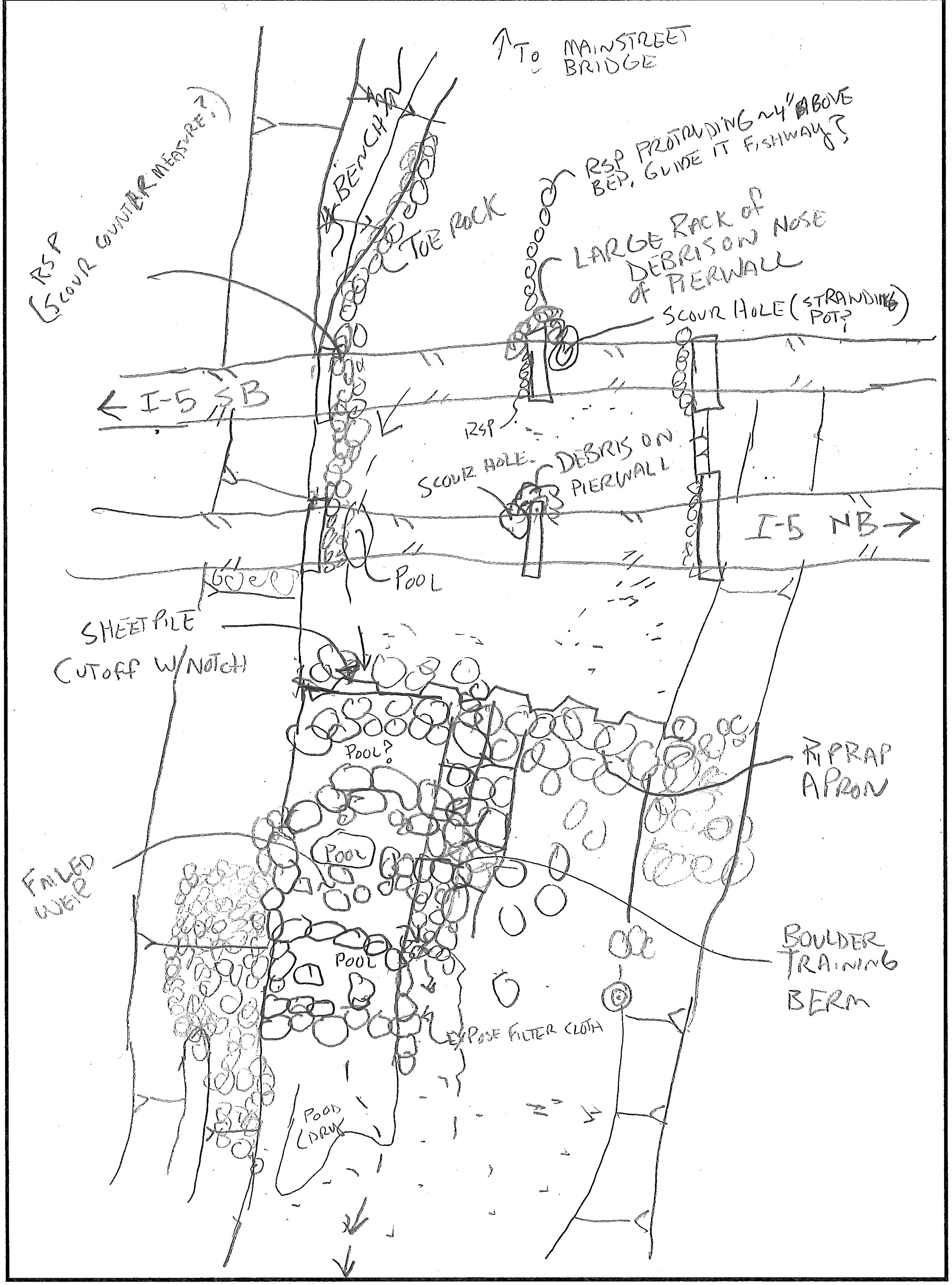


Figure 1. Dibble Creek looking downstream at the Highway 5 bridges. The main channel is on the right as indicated by the lower elevation and coarser substrate. Photo taken October 4, 2019.

Figure 2. Dibble Creek middle footing of southbound Highway 5 bridge looking upstream at the frontage road bridge. The main channel is on the left of this picture. The left channel has much finer sediment. Photo taken October 4, 2019.

Figure 3. Dibble Creek looking downstream from the bridge left span. The low flow channel is on the right. The high rock weir in the picture forefront controls water elevation in the left channel to guide water to the low flow channel on the right. The sheet piling is just visible upstream of the rocks and is present but at lower creat elevation on both sides of the channel. Photo taken October 4, 2019.

Figure 4. Dibble Creek looking upstream at the Highway 5 bridge from just downstream of the low flow channel. The low flow channel is on the left. Photo taken October 4, 2019.

Figure 5. Dibble Creek low flow channel with stored fine sediment. Photo taken October 4, 2019.

Figure 6. Dibble Creek looking downstream from the Highway 5 bridge Photo taken October 4, 2019.

Site Name: _ Craig Creek _

Location (County-Road-Postmile)	Tehama 99, PM 21.10		
PAD ID Number:	737012	Date:	4-Oct-19
Stream Name:	Craig Creek		
Evaluator (1):	Michael Love		
Evaluator (2):	Margaret Lang		
Overall Crossing Description - Emphasize Fish Passage Design Elements	Full spanning bridge with natural channel bottom. No evidence of grade control beneath or adjacent to the structure and no evidence that grade control is needed for the site. RSP under the bridge does constrict the channel compared to channel widths upstream of the crossing influence, which may increase velocity under the bridge at high flow events relative to velociteis in the adjacent channel reaches.		

Is the crossing performing as designed?	[✓ ***Yes***]	No			
Comments					
Structural condition	[✓ ***Excellent***]	Good	Fair	Poor	Failed
Comments					
Is there any visual evidence of damage to the structure?	Yes	[✓ ***No***]			
if yes, take photos and describe:					

Picture name	Description

Is there an accumulation of sediment or debris in or upstream of the facility?	[✓ ***Yes***]	No
if yes, take photos and describe:	It appears the rock protection under the bridge is constricting the channel and causing sediment deposition upstream and some local scour under the crossing. The deposited sediment is cobble/gravel and is actually creating more diverse in-channel habitat.	

Picture name	Description
Figure 1	
Figure 2	

Site Name: _ Craig Creek _

What is the potential for sediment delivery from the crossing?	[✓ ***Low***]	Moderate	High	

Comments

If a project objective, was potential for future sediment delivery reduced?	Yes	No	[✓ ***N/A***]
Are grade control structures functioning as desired?	Yes	No	[✓ ***N/A***]

If there was channel incision/scour downstream of the crossing, has it stabilized?	[✓ ***Yes***]	No

The channel incision near the crossing appears to have stabilized but the downstream channel is very incised due to regional conditions unrelated to the crossing.

Were there unintended effects on the channel?	[✓ ***Yes***]	No

if yes, take photos and describe: These effects may be positive by providing better channel substrate.

Picture name	Description

Is there any new erosion or scour up or downstream of the facility that could be problematic to fish habitat, access to upstream habitat or function of the facility? Take pictures & describe.

No

Should this location be monitored for changes in performance?	[✓ ***Yes***]	No

Some of the bank protection under the bridge has been eroded/mobilized but the structure is not currently compromised (see attached Figure ___).

Are there issues or concerns at this location that would require the immediate need of maintenance or adaptive measures, for fish access (if yes, take pictures and explain in notes)?

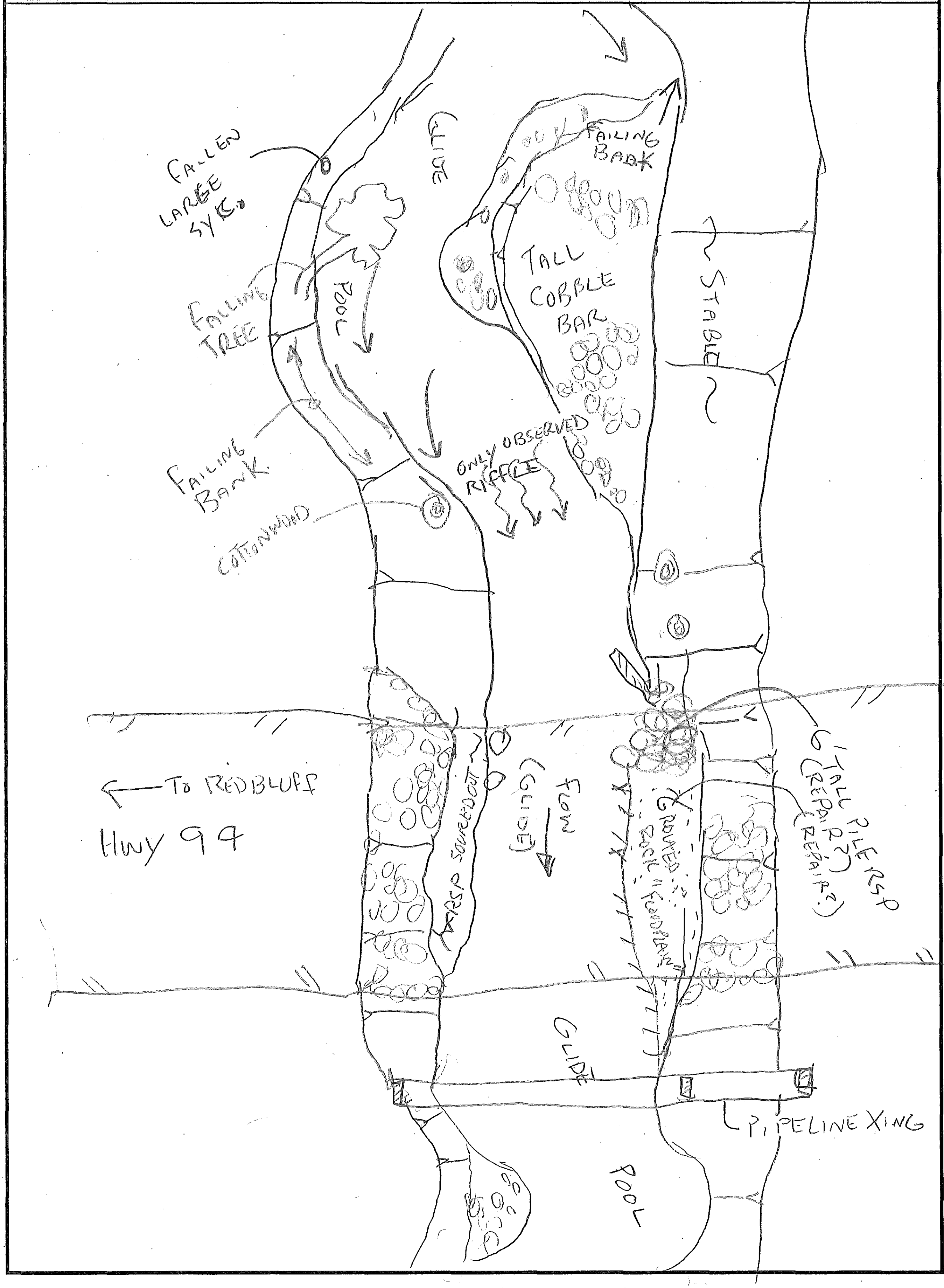
No

Site Name: _ Craig Creek _

Are issues at this location currently affecting the ability for fish to pass upstream of the facility (if yes, take pictures and explain in notes)?
No
Notes: (Please note additional information that is relevant to access above the fish passage facility, fish or aquatic species present, scour in or adjacent to the facility, fallen trees, failing rock slope protection (RSP), accumulated or depleted sediment, etc.)
None that were not addressed above.
Measurements and notes for detailed field survey
Need cross section survey at the bridge to show the downcut from the original bed (see Figure __) The longitudinal profile should extend upstream to show the the riffle and deposition zone is about at the same elevation as the bed elevation of the built crossing. Deep pools downstream - will need wetsuit and not waders to survey. Channel width measurements: Upstream of crossing influenced deposition zone: Active channel = 29 ft; Bankfull channel = 35.2 ft Upstream in deposition zone: Active channel = 40 ft; Bankfull channel = 43 ft Upstream under bridge: Active channel = 36 ft; Bankfull channel = 41 ft Middle under bridge: Active channel = 23.5 ft; Bankfull channel = 29.5 ft At this location, there is a bench and the width to the back of the bench is 45 ft (see Figure __)

Site Name: Craig Creek

Site Sketch



Site Name: _ Craig Creek _

Figure 1. Craig Creek looking upstream from the Highway 99 bridge. Photo taken October 4, 2019.

Site Name: _ Craig Creek _

Figure 2. Craig Creek looking upstream at the bridge. The substrate and gravel/cobble bar deposits in this reach provide good channel diversity. Photo taken October 4, 2019.

Figure 3. Craig Creek looking downstream from the bridge. Just downstream of the bridge, there are gravel/cobble bar deposits. Photo taken October 4, 2019.

Figure 4. Craig Creek looking downstream. The downstream channel is highly incised due to regional conditions unrelated to the crossing. Photo taken October 4, 2019.

Figure 5. Craig Creek downstrem channel showing extreme incision that is not related to the crossing but could influence conditions through the crossing. Photo taken October 4, 2019.

Figure 6. Craig Creek Right bank erosion and loss of bank protection by undercutting at the crossing. Photo taken October 4, 2019.

APPENDIX C – MONITORING METHODS

Appendix C – Monitoring Plan

Study Site Monitoring Plan for Project 65A0711: Design Guidance for Full-Span Crossings

Project Title: Fish Passage Engineering
Project Agreement Number: 65A0711

Project PI:
Dr. Margaret Lang, P.E.;
Humboldt State University
Environmental Resources Engineering
Arcata, CA 95521

Project co-PI:
Michael Love, P.E.
Michael Love & Associates, Inc.
791 8th Street, Suite R
Arcata, CA 95521

Introduction

This project was initiated through the California Department of Transportation's (Caltrans) Division of Research Innovation and System Information's (DRISI) to develop draft design guidance for remediating fish passage at road crossings. Caltrans is required by state laws, primarily SB-857 passed in 2005, to identify, prioritize and remediate structures that present a migration barrier to all life-stages of salmon and steelhead trout in systems that currently or historically support these populations (Sts&HighCode, 2006). Remediation of road crossings to improve or restore fish passage can be achieved through several design methods that are generally placed into one of two categories: hydraulic designs or geomorphic designs (CDFW, 2009). Hydraulic designs typically modify an existing structure by the addition of baffles or weirs to reduce water velocity and increase water depth and/or the installation of fish ladders or grade control structures to mitigate steep slopes. Geomorphic designs attempt to restore continuity of all natural channel processes and have as primary characteristics a width that is larger than the natural channel's bankfull or active channel width, a bed composed of natural channel substrate and a channel slope similar to the adjacent channel or a nearby reference reach (USFS, 2008).

The project objective is to develop draft design guidance for full-span road crossings. This road crossing type is the preferred design for road crossings requiring fish passage in California (CDFW, 2009; NMFS, 2001). A component of this project is field evaluation of the 19 representative Caltrans road crossing sites (Table 1) identified by the project Advisory Panel and that meet or attempted to meet full-span design conditions or other fish passage criteria. The site monitoring is intended to accomplish two objectives:

1. Evaluate whether the site is performing as expected with respect to fish passage, hydraulic performance, influences on the adjacent channel morphology, and maintenance

2. Collect data necessary for developing site hydraulic models as case studies for model application and design guidance development.

For objective 1, this assessment will be made by measuring the site's geomorphic and hydraulic conditions, biological monitoring is not included. Field measurements and observations will define how each site is interacting with or altering the hydraulic and geomorphic conditions within the site's project area and in the adjacent stream channel. Evaluation of whether or how site conditions are influencing or could compromise fish passage conditions, infrastructure and adjacent property is also included. Field site assessments will be conducted under low-flow conditions for good access and to be able to assess the structure condition and identify possible maintenance needs. Thus, they do not include assessment of performance under unique hydrologic conditions such as bankfull flow or a specified fish passage flow. Objective 2 is addressed under project Task 3, but the data necessary to develop the case studies for Task 3 will be collected primarily during the more detailed data collection site visit, as described below.

Each site will have at least two field visits to collect the data necessary for characterizing site performance. The first site visit is a short, 2- to 3-hour, qualitative assessment by the project PIs to identify fish passage performance issues and lessons that may be learned from the site, and to plan for the more detailed site surveys to be conducted by a Professional Engineer (PE) with HSU student assistants. This initial site visit, along with the availability of good site background data, will identify the best sites for case studies and develop the detailed site survey plan for obtaining the data needed for

Table 1. Caltrans field evaluation sites identified by the project Advisory Panel.

Site	District	County- Route- Post mile	PAD ID #	Stream Name	Project Name	Year Completed	Treatment Status
1	1	Del Norte- 197 PM 2.12	720982	Peacock Creek	Peacock Creek Emergency	2013	Partial
2	1	Del Norte – 197 PM 5.00	707143	Sultan Creek	Sultan Creek Bridge	2015	Full
3	1	Del Norte – 197 PM 6.15	707142	Little Mill Creek	Emergency Bridge	2016	Partial
4	1	Humboldt-299 PM 4.20	716742	Hall Creek	Mitigation Mad River Bridge	2013	Partial
5	1	Mendocino-1 PM 92.80	706958	Dunn Creek Bridge	10 Mile Bridge Mitigation	2013	Full
6	1	Mendocino –101 PM 48.14	705136	Upp Creek	Willits Bypass Mitigation	2017	Full
7	1	Mendocino –101 PM 52.25	707085	South Fork Ryan Creek	Willits Bypass Mitigation	2017	Partial
8	1	Mendocino –101 PM 52.36	707086	North Fork Ryan Creek	Willits Bypass Mitigation	2017	Partial
9	1	Mendocino- 101 PM 81.4	706986	Rattlesnake Creek	Rattlesnake Creek	2009	Partial
10	1	Mendocino-101 PM 89.04	706954	Cedar Creek	Cedar Creek	2018	Full
11	1	Mendocino - 128 PM 49.66	707219	Edwards Creek	Edwards Creek Fish Passage	2011	Partial
13	2	Shasta – 299 PM 32.2	737295	Yank /Lemm Creek Bridge	Yank Creek/Lemm Creek Bridge	2014	Full
14	2	Siskiyou - 96 PM 56.00	707168	Fort Goff Creek	Fort Goff Creek Fish Passage	2014	Full
14	2	Siskiyou - 96 PM 65.40	707147	O'Neil Creek	O'Neil Creek Fish Passage	2008	Full
15	2	Tehama – 5 PM 16.90	737006	Elder Creek	Elder Creek Scour Mitigation	2008	Partial
16	2	Tehama – 5 PM 28.10	737007	Dibble Creek	Dibble Creek Scour Mitigation	2008	Partial
17	2	Tehama - 99 PM 21.1	737012	Craig Creek	Craig Creek/ Sunset Canal Bridges	2011	Full
18	4	Napa – 121 PM 1.00	733333	Huichica Creek	Duhig Road Project	2010	Full
19	4	Napa – 122 PM 9.30	758605	Sarco Creek	Sarco Creek Bridge	2017	Partial

the case studies during the second site visit. The second site visit for field data collection is a detailed survey intended to collect data needed to fully assess site performance. At select sites, the collected data will also be used to develop design case studies and apply hydraulic and geomorphic models and analytical tools. Additional site survey data will be collected for those sites identified as good case study candidates for evaluating the usefulness of 2D hydraulic models in design and analysis. This document describes the monitoring protocols for each of these visits. The monitoring protocols used for the project are adopted from existing, accepted methods for stream channel measurements (Harrelson et al., 1994; Wolman, 1954) and those developed or proposed specifically for assessing fish passage crossings (FishPAC, 2019; Barnard et al., 2015; Klingel 2014).

Initial Site Reconnaissance

The initial site visit provides an overall assessment of the site's performance, identifies obvious problems or maintenance conditions needing attention, and is used to develop site specific plans for the more detailed second survey. Information collected on these site visits includes everything on Caltrans' Fish Passage Facility Monitoring Form, Expert Inspection (FishPAC, 2019 and attached as Appendix A). A more detailed, project-specific form has also been developed that includes all the information on the Caltrans Expert Inspection Form and both forms will be completed and submitted for each site. A copy of the project-specific form is attached as Appendix B and a completed example is included as Appendix C. The information to be collected during the initial site visit is described in more detail below.

Verification of Site Conditions

The primary purpose of the initial site visit is to document current site conditions and plan for the more detailed second site survey. New site photos, a sketch of current conditions, and the field notes described here and on the form in Appendix B will be made and collected during this site visit. The minimum photo points collected will include upstream and downstream views from crossing inlet and outlet to document the crossing and adjacent channel conditions.

This site visit will also compare current conditions to design plans or as-built surveys from available Caltrans documents. When possible, available plans will be reviewed prior to each site visit and brought to the site to compare current to previous or intended conditions. For the initial site visit, these comparisons are qualitative, with the second site survey collecting detailed measurements that might quantify changed conditions .

Specific site features and indicators that will be documented include:

- Tailwater control
- Type, frequency and drop heights at grade control structures
- Active channel and bankfull channel width measurements (3 upstream and 3 downstream when appropriate)
- Document high water marks
- Qualitatively assess the influences of the crossing on the channel including observed aggradation/degradation, widening/narrowing, headcuts
- Describe channel bed conditions and characteristics in the project area and adjacent channel – sediment size (qualitative), sediment sorting, channel forcing features controlling plan and profile (large wood, roots, bedrock, rock), and document other influences
- Identify features that may create adverse hydraulic conditions for fish passage or potentially capture debris and sediment

These will be documented with photos, sketches and notes and flagged or marked for detailed measurement during the second, more intensive survey. The PIs will also document their initial interpretation of site conditions and functionality, and potential lessons that can be learned from the site.

This initial site visit will also focus on developing site-specific instructions for the detailed data collecting site visit, including:

1. Safety
   a. Access to inlet and outlet
   b. Parking
   c. Adjacent property ownership and access
   d. Channel conditions
   e. Confined space situations that should be avoided
2. Longitudinal profile upstream and downstream extents
3. Location of a representative section or reference reach in the adjacent channel
4. Features to capture in the representative section or reference reach survey
5. Number and location of cross sections to survey
6. Where to do pebble counts
7. Note unique or additional features to measure.

Condition of the Crossing and Associated Structures

The condition of the crossing and all associated structures will be documented by photographs and any measurements needed to describe the condition that are not already included in those described above will be made. These measurements would include:

- Missing or damaged grade control elements
- Missing or compromised/under-cut bank protection
- Debris accumulation
- Structure damage from debris or other sources

Detailed Data Collection Site Visit

The 19 sites selected for field assessment, and listed in Table 1, vary in type from full span stream simulation projects with natural channel beds to full and partial spanning crossings designed to meet fish passage criteria using hydraulic design approaches. Many of the sites that employed a hydraulic design approach have concrete weirs, rock weirs, baffles, or fish ladders for grade control and to produce favorable passage hydraulics.

For all of the sites, regardless of their type, the monitoring effort will focus on confirming and evaluating that the crossing design components are intact, appear to be performing as intended and are not having adverse impacts on the stream channel, habitat, roadway, other adjacent property and infrastructure . This includes the ability of the crossing to convey the stream's flow, sediment, and debris load without adverse impacts. Important elements to capture in evaluating these conditions include:

- A longitudinal thalweg profile
- Upstream, downstream and within crossing cross sections

- Sediment aggradation, degradation or preferential sediment sorting
- Stability and condition of the crossing and, if present, grade control structures
- Verify rock sizes used for grade control structures and bank protection
- Active and bankfull channel widths in a representative section of the adjacent natural channel
- Grain sizes (pebble count) and apparent mobility/embeddedness in a representative section of the adjacent natural channel and in the crossing, if present

Sites designed as full-span stream simulation crossings, which includes a stream channel designed to match the natural channel slope and morphology, will be evaluated using additional monitoring methods, similar to those described by Barnard et al. (2015) and Klingel (2014). The selected representative section identified during the initial site reconnaissance will serve as a “reference reach” for these sites. A reference reach is a stable, natural channel section that serves as the design template for a stream simulation crossing design. The reference reach is usually located upstream of the crossing and has the same geomorphic conditions and slope as the crossing site (USFS, 2008). Geomorphic site conditions at the crossing will be then compared to those measured in the reference reach. This comparison is to evaluate the project’s success at providing channel morphology throughout the project length that is similar to adjacent natural channel morphology. The additional data collected for this comparison includes:

- Extended thalweg profile to understand context of the site within the overall channel slope and to include the reference reach in this profile
- Detailed mapping of channel forcing features at the crossing and in the selected reference reach
- Detailed mapping of the active channel margins and bankfull indicators within the reference reach that define the stream’s bank lines
- Mapping of the bank lines throughout the project site
- Pebble counts of streambed material at similar channel features (i.e. riffles) at the crossing and in the reference reach

Table 2 lists the measurements that will be taken at the two general types of crossing sites during the second, detailed site survey. The methods used for each of these measurements are described in detail below. The quantity of data and its format for these measurements varies greatly from site-to-site and most measurements will be collected using a total station survey. Thus, standardized forms will not be used for overall data collection during the second site monitoring visit, but a checklist similar to Table 2 and customized for each site based on the findings from the initial site visit will be utilized. Standard survey notes and sketches will be made, then scanned and compiled with the survey data to archive the collected data. Ideally, each site will have survey control points identified on site plans provided by Caltrans. If these are not available, surveys will be completed in a local coordinate system and transformed if benchmarks are identified or adjusted to site specific relative elevations using points on the crossing structures.

Table 2. Field data to be collected for different types of crossing sites during the detailed site survey.

	Full-Span Stream Simulation Designs		**Partial or Full-Span with Hydraulic Design/Grade Control**	
Field Data Collection	**Project Site**	**Reference Reach***	**Project Site**	**Representative Reach***
Thalweg Profile (and water surface)	Y	Y	Y	Y
Mapping Channel Forcing Features	Y	Y	Y	N
Channel Cross Sections	Y	Y	Y	Y
Pebble Counts	Y	Y	V	Y
Active Channel Widths	Y	Y	V	Y
Bankfull Channel Widths	Y	Y	V	Y
Mapping Bank Lines	Y	Y	N	N

* A *representative reach* is identified for evaluating hydraulic designs, and *reference reach* is identified for evaluating geomorphic designs
(Y) Yes, this data will be collected
(N) No, this data will not be collected
(V) Varies depending on type of site.

Longitudinal Thalweg Profile

A longitudinal survey of the thalweg profile through the project site is the primary measure used to evaluate how the project interacts with the channel slope and can potentially affect the transport of water, sediment and debris. Recommended minimum longitudinal profile lengths are 10 – 20 times the bankfull channel width upstream and downstream of the crossing (USFS, 2008; Barnard, et al., 2013). Some site conditions, such as low slope, small channel sites where the crossing impact could extend farther upstream, may require longer distances. The profile must be sufficient in length to identify the overall stable channel slope outside of the crossing influence. Another reason to extend a longitudinal profile is to measure a section of channel outside of the influence of the crossing that is a good reference reach for stream simulation sites.

For this project, the thalweg profile will be surveyed using a total station and recording the water depth at each measurement location if water is present. The upstream and downstream extent of the surveys will be the riffle crest or grade control feature that meets the length of longitudinal profile required to measure beyond the extent of influence of the crossing structure. Longitudinal profiles meeting these length criteria will be completed where practical and where adjacent parcel access permissions allow.

Within the project reach, and within the reference reach for those sites that have them, the features controlling the channel profile will be included and noted during the survey, as well as sketched in the field book. For project sites without a reference reach, the same features will be measured along a profile meeting the length criteria described above. Natural control or forcing features will be noted and surveyed. These are typically large rock, bedrock, large wood, and roots that interact with the channel bed and bank. At some of the project sites, these also include constructed boulder weirs, concrete weirs or sills, and fish baffles installed within or adjacent to the crossing.

Channel and Crossing Cross Sections

Where possible a minimum of four channel cross sections will be measured at each project site: one upstream of the structure, two within the structure and one downstream of the structure. The two cross sections outside the structure will be located at the first hydraulic control (i.e. riffle crest) just upstream or downstream of the structure, respectively. Cross sections will extend from above bankfull elevation and cross the channel perpendicular to the thalweg.

An additional four cross sections will be measured within the adjacent stream channel beyond the influence of the crossing to allow comparison between the internal channel geometry at the crossing and the natural channel. For sites where a reasonable reference reach exists, these cross sections will be measured within the reference reach. The reference reach upstream and downstream cross sections will be located at hydraulic controls (i.e. riffle crests) with longitudinal spacing similar to the cross sections measured for the structure. The other cross sections will be located at the same spacing as those measured within the structure. Geomorphic features will be noted and measured for each crossing section, including the edges of wetted, active and bankfull channel; substrate size and type; vegetation size and type and elevation of high-water marks.

Sediment Aggradation, Degradation or Preferential Sorting at Crossing Sites

Accumulation, scour or preferential sorting of sediment in and around crossing structures is often an indicator of hydraulic performance. At all sites, assessment of these conditions will be made and documented with photographs and the site survey data. When possible, survey results will be compared to as-built surveys to identify changes in the site topography since construction.

At the representative section or reference reach, the natural stream substrate will be characterized using a pebble count approach, as described by Wolman (1954). The pebble count will be taken at specific morphological units, such as riffles or plane-bed sections. At full-span stream simulation crossings, pebble counts will be done within the project reach at similar morphological units to compare to the reference reach. In other types of crossings that have sections of natural channel substrate, pebble counts will be completed of this material. At sites where preferential sorting appears to have occurred, the surface pebble counts will be used to quantify the difference in bed material size at different locations within the structure and in the adjacent channel. These results will be summarized as differences between D_{50} and D_{84} and in distribution plots of sediment sizes measured at the different locations. Local coarsening of the bed surface material or a coarser bed material in the structure compared to the adjacent channel is an indication of areas of higher average velocity.

Scour around foundations, grade control structures and other locations will be documented by survey measurements and photographs. The survey measurements and site design documents or as-built surveys will be used to estimate scour volumes.

Active and Bankfull Channel Widths and Bank Lines

Active and bankfull channel widths beyond the influence of the crossing are measured using a cloth tape at select locations during the initial site reconnaissance visit. They are also measured as part of the surveyed cross sections.

For full-span stream simulation crossings and crossings selected for 2D modeling case studies, the active and bankfull channel margins will be mapped throughout the length of the project and reference reach using a total station. These measurements define the bank lines of the channel. Similarly, the bank lines through the project site will also be mapped using a total station, extending at least one bankfull width upstream and downstream of the project extents. The bank line mapping will be used to evaluate the continuity of the stream banks through the project reach and their connectivity with the adjacent natural channel.

The average width and variability in the channel widths in the project reach can be compared to that of the reference reach to evaluate similarity. Klingel (2014) evaluated a monitoring protocol for the USFS stream simulation crossings that used 20 – 25 equally spaced measurements of active channel and bankfull channel widths in both the crossing and reference reach. The statistics of these measurements (average, standard deviation and variance) were computed and non-parametric methods used to quantify the similarity between the crossing and reference reach values. This data collection protocol relied on measurements made using a tape. Using total station survey data, the same analysis can be completed more efficiently using the surveyed bank line toes and tops for the active channel and bankfull widths.

Measure Rock Sizes of Grade Control and Bank Protection

The as-built rock size used for all crossing design elements will be measured in the field and compared to available design plans. Both under-sized and over-sized rock can contribute to poor crossing conditions or failure to maintain fish passage conditions over the range of flows necessary. Where potential fish passage or channel stability issues exist due to placed or shifting rock (i.e. undermining of rock grade control), the issue will be noted, measured and photographed.

Case Study Sites

Two or three sites will be selected as case study sites for two-dimensional modeling using SMS-SRH-2D (Lai, 2008). Preference for these sites will be sites that fully span the bankfull channel width, and suitability as a case study will be confirmed during the first site monitoring visit. Input from the project Advisory Board will also be used to identify these sites. All the measurements described above for the second site monitoring visit will be completed at the case study sites, but these sites will require additional survey data. The additional data needed include continuous break lines along the active and bankfull channel elevations and detailed cross section surveys at the model boundaries.

References

Barnard, R., Johnson, J., Brooks, P., Bates, K., Heiner, B., Klavas, J., . . . Powers, P. (2013). *Water Crossings Design Guidelines.* Olympia, WA: Washington Department of Fish and Wildlife. Retrieved from http://wdfw.wa.gov/hab/ahg/culverts.htm

Barnard, R., Yokers, S., Nagygyor, A., & Quinn, T. (2015). An Evaluation of the Stream Simulation Culvert Design Method in Washington State. *River Research and Applications* , 1376–1387.

CDFW. (2009). *California Salmonid Stream Habitat Restoration Manual. Part XII - Fish Passage Design and Implementation.* California Department of Fish and Wildlife.

FishPAC. (2019). *California Fish Passage Advisory Committee (FishPAC) Expert Inspection Form.* Retrieved from https://www.cafishpac.org/science-data

Harrelson CC, R. C. (1994). *Stream Channel Reference Sites: An Illustrated Guide to Field Technique.* Fort Collins, CO: .S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Klingel, H. (2014). *Developing a Physical Effectiveness Monitoring Program for Aquatic Organism Passage Restoration at Road-Stream Crossings.* Fort Collins, Colorado: Department of Geosciences, Colorado State University.

Lai, Y. G. (2008). *SRH-2D version 2: Theory and User's Manual.* Denver, CO: U.S. Department of the Interior, Bureau of Reclamation.

NMFS. (2001). *Guidelines for Salmonid Passage at Stream Crossings.* Santa Rosa, CA: National Marine Fisheries Service, Southwest Region.

Sts&HighCode. (2006). *California Code, Streets and Highways Code - SHC § 156.1.* Sacramento: State of California.

USFS. (2008). *Stream Simulation: An Ecological Approach To Providing Passage for Aquatic Organisms at Road-Stream Crossings.* San Dimas, CA: USFS National Technology and Development Program.

Wolman, M. (1954). A Method of Sampling Coarse River-bed Material. *Transactions, American Geophysical Union, 35*(6), 951-956.

APPENDIX D – MODELING CASE STUDIES

APPENDIX D - MODELING CASE STUDIES

Modeling case studies were completed to illustrate the additional information obtained from 2D hydrodynamic models compared to the historically applied 1D analyses typically used for Caltrans stream crossing designs. Two case study sites were selected from the project's 15 full-span stream crossing sites. The designs for these sites used a 1D hydrodynamic model (HEC-RAS) for design and analysis. The results from the 2D analysis are used to identify possible benefits to the design and the understanding of the crossing performance gained from using 2D analysis. Included in the discussion of modeling results are additional data needs and the advantages and disadvantages of options available for representing crossings within 2D models. The case study sites are the Fort Goff Creek full-span bridge replacement (State Route 96, PM 56.00 in Siskiyou County) and the North Fork Ryan Creek embedded box culvert replacement (State Route 101, PM 52.36 in Mendocino County). A full description and history of these sites is provided in Appendix A.

Two-dimensional site models were developed for all case studies using the Sedimentation and River Hydraulics 2D (SRH-2D) model (Lai, 2008) within the Surface-water Modeling System (SMS) software developed by Aquaveo, LLC. This software was selected because it is currently being supported by Federal Highway Administration (FHWA) for use by state departments of transportation. The FHWA support includes development of numerous transportation infrastructure specific modeling features and protocols as well as integration with standard FHWA analysis tools such as the HY-8 culvert hydraulics software (FHWA, 2021). Modeling methods varied slightly between the sites to illustrate differences between approaches and these details are described with the individual case studies. Where available, the case studies include comparison between results obtained from SRH-2D and the 1D HEC-RAS analysis conducted for site design.

An advantage of 2D models is that they better predict local velocity magnitudes and directions in hydraulic features such as eddies and better define velocity variations around bends and obstructions in the channel. Features like eddies may cause the main flow to be concentrated over a narrower width than the full submerged channel width at a given flow rate, leading to locally higher velocities that would not be defined by the cross-sectional average velocity provided by a 1D hydraulic model. Spatially varying velocities from a 2D model can also be extracted for specific locations, providing greater hydraulic detail along the banks, at stabilizing structures such as rock weirs, and at interfaces between structures and the natural channel.

The case study models were developed using each site's current conditions as measured by topographic survey data collected for this project. The topographic data was then used to create a model surface in SRH-2D. The topographic data was collected using a Trimble S-7 Robotic Total Station and a Topcon GTS 226 Total Station. The topographic surveys included the crossing reach, including the stream channels directly upstream and downstream of the crossing and within the crossing, and upstream reference reaches. Survey data collected includes longitudinal thalweg profile; wetted channel boundary; active channel boundary; slope breaks; and boundaries defining different surface roughness such as the streambed, banks, floodplain and rock slope protection (RSP). Cross sections were surveyed upstream and downstream of the crossings as well as in the upstream reference reach. Channel bed surface roughness was measured by pebble counts conducted in the reference and stream crossing reaches using the Wolman pebble count method (Wolman, 1954). Additional tools used to process this data and estimate model parameters, such as the USFS XStream software (underdevelopment, beta version 1.0 provided by USFS for review), are described within the relevant case study.

1 FORT GOFF CREEK

Fort Goff Creek is a tributary to the Klamath River near Orleans, California. The Highway 96 crossing over Fort Goff Creek (SIS 96 - PM 56.00) was selected as a modeling case study to illustrate application of 2D hydrodynamic model evaluation for bridge crossings. The site and field data collection are described in detail in Appendix A – Site Summaries. This site used a prefabricated bridge element system (PBES) design, and the crossing is performing well and meeting all project objectives with the exception of some bank erosion and minor undermining of the bridge abutment footing on the upstream left bank, positioned on an outside channel bend (Figure 12-4, Appendix A). A primary model case study objective was to evaluate whether a 2D hydrodynamic model (SRH-2D) would better characterize local velocity conditions at this footing location.

The hydrologic characteristics assumed for the site were all taken from the Caltrans' Final Hydrology and Hydraulics Report for the crossing design (Caltrans, 2013). The Fort Goff Creek crossing of State Route 96 (PM 56.00) is located approximately 250 feet upstream of the confluence with the Klamath River and has an upstream drainage area of 12.95 square miles. The discharge estimates reported in Caltrans' report were obtained from gage data for Indian Creek (USGS STN ID: 11521500) and scaled to Fort Goff Creek using a 13-year overlapping record when both sites had USGS gages. The lowest discharge simulated, 60 cfs, was the estimated discharge during the field site survey on March 30, 2020 and this value was also estimated using the Indian Creek gage data.

The site was modeled using four different approaches for evaluating streambed roughness as part of evaluating model sensitivity and resolution of the results. This involved using constant verses depth dependent roughness value for the Manning's coefficient applied to the channel as well as testing the influence of including large boulders in the model mesh. The four model scenarios were:

1. A constant streambed roughness value set based on each simulation’s discharge, and using a model mesh that did not define large boulders as part of the topography (Simulation Name: Cons n)
2. A depth-dependent roughness that varies the value based on depth of flow in each model cell, and with a model mesh that did not define large boulders as part of the topography (Simulation Name: Depth Var n)
3. A constant streambed roughness value and using a model mesh that defined large boulders as part of the topography
   (Simulation Name: Boulders, Cons n)
4. A depth-dependent roughness using a model mesh that defined large boulders as part of the topography (Simulation Name: Boulders, Depth Var n)

Active channel roughness values for both the constant bed roughness and depth-varying roughness scenarios were calculated using the measured surface pebble count data and the surveyed cross sections. This data was input into the USFS XStream Version 1.0 software (described above) to calculate the roughness parameters. Multiple empirical relationships are available to estimate roughness from field data both in XStream and elsewhere. The Jarrett method (Jarrett, 1984) was chosen for use at the Fort Goff site because of its applicability to small, steep streams. The Jarret estimates of Mannings’ roughness coefficient (n) were reduced by 32% as suggested by Marcus et al. (1992) for application in channels with characteristics similar to Fort Goff Creek. Figure 1 shows the calculated n values as a function of depth for the corrected Jarret n values and the Mussetter method n values (Mussetter, 1989) used by Caltrans in developing the 1D HEC-RAS design models (Caltrans, 2013). The results from all three measured cross sections are shown for the Jarrett method and are quite similar. The average of the n-values from Jarrett was used for simulations. The Mussetter and Jarrett method estimated roughness become quite similar at deeper water depths, and appear interchangeable for application to stream channels similar to Fort Goff Creek when modeling extreme flood events. However, the lower n values estimated at shallower depths using the Jarrett method may be more conservative for simulating hydraulic conditions for fish passage flows because lower roughness values predict faster velocities and lower depths in the channel.

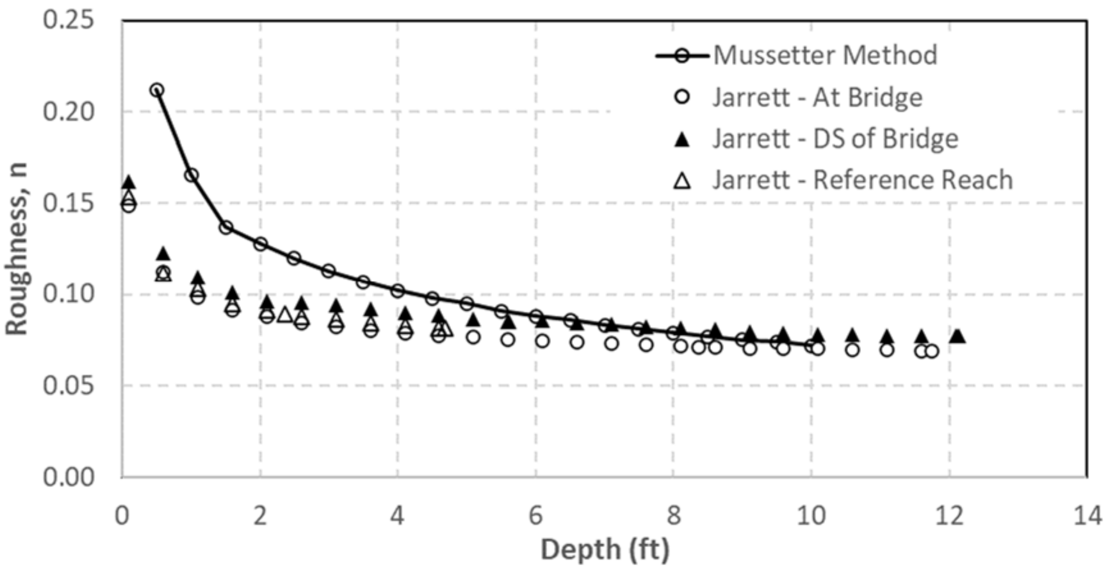


FIGURE 1. DEPTH DEPENDENT ROUGHNESS VALUES FOR THE JARRETT AND MUSSETTER METHODS.

Defining large boulders as part of the channel topography versus accounting for them with the selection of the roughness coefficient has tradeoffs and depends on the analysis objectives. For simulating high flows where in-channel boulders are fully submerged, accounting for the boulders' influence using an appropriate (high) roughness value is generally sufficient. At lower flows, when boulders or similar large objects, such as bedrock features, are not submerged including them in the topography/model mesh produces more accurate predictions of local depths and velocities.

Including large boulders, wood or similar objects in a model requires extra effort in both the field data collection and in developing the models. For the Fort Goff models, the top elevation of all exposed boulders 2 ft in diameter and larger was surveyed. The diameters of each of these boulders was measured in two dimensions using a tape and averaged. Another method commonly used to capture a boulder's size is to survey four to six points around the outside in addition to the boulder's top elevation. With this field data collected, the boulders are located within a preliminary model mesh and then the mesh is edited at each boulder location to account for the boulder size and height. Obtaining an accurate representation for these types of channel features usually requires a finer mesh scale; thus, more mesh elements and computation time.

The various model simulations were run in SRH-2D for flow rates of 60 cfs (winter base flow and the flow rate during the channel survey), 419 cfs (50% of $Q_{2\text{-year}}$) and 4,433 cfs ($Q_{100\text{-year}}$) used in the Caltrans HEC-RAS 1D analysis for flood flows. The lowest flow rate, 60 cfs, was the only flow where the boulders were not fully submerged. Figure 2 shows the depth averaged velocity through the bridge region of the model domain at 60 cfs for both the mesh that does (right) and does not (left) explicitly define the large boulders as part of the channel bed topography. The exposed boulders are visible as the white polygons within the wetted channel area. At the two higher flows analyzed, the majority of the boulders were completely submerged.

To compare predictions of water surface elevation and velocity between the four different bed roughness scenarios, values were extracted along a cross section just upstream of the bridge and along the channel thalweg through the project region (Figure 3). Figure 4 shows the predicted water surface elevations along the thalweg profile for all four simulation scenarios at 60 cfs (winter base flow), 419 cfs (50% of $Q_{2\text{-year}}$) and 4,433 cfs ($Q_{100\text{-year}}$). The depth varying n simulations predict consistently greater water depths while the models that explicitly include the large boulder topography captures the locally elevated water surface as flow moves over and around individual boulders.

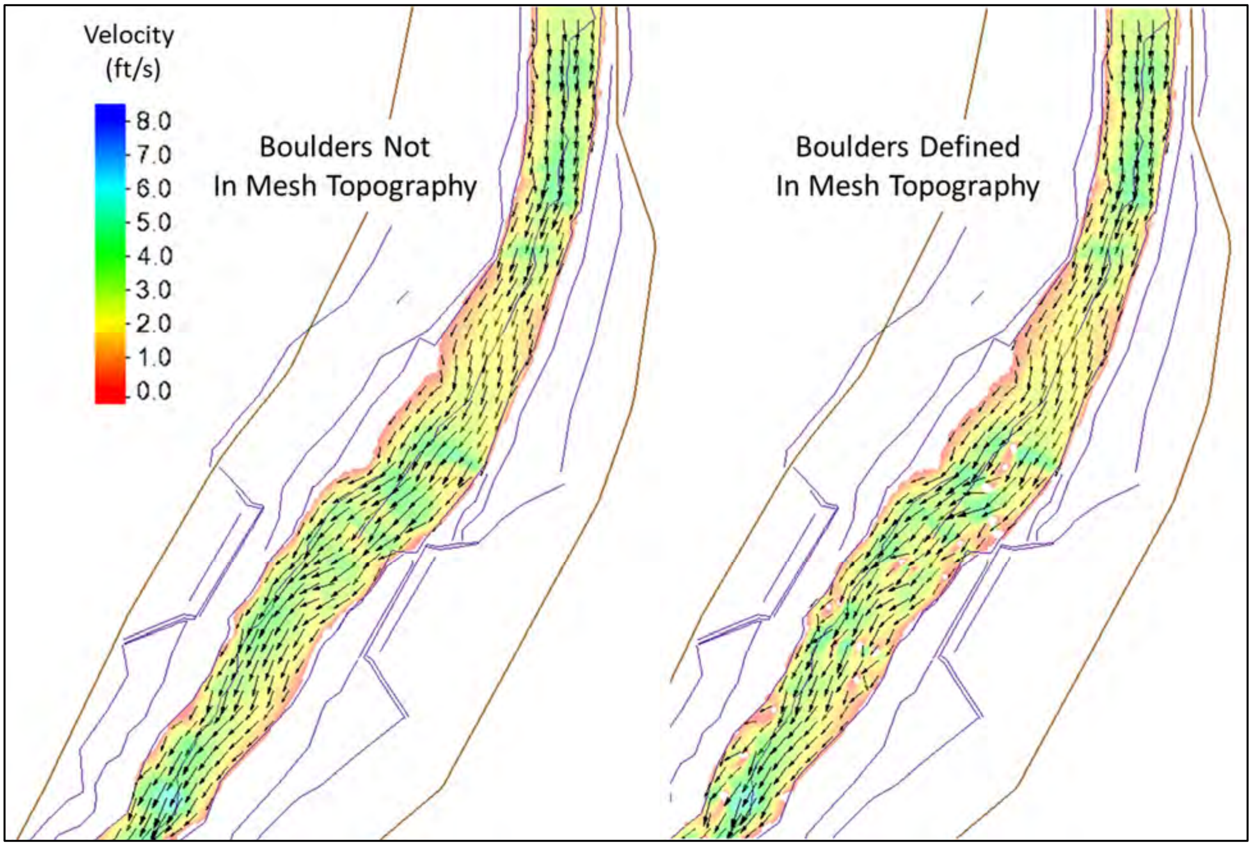


FIGURE 2. COMPARISON OF A SIMULATION AT 60 CFS (WINTER BASEFLOW) WITHOUT (LEFT) AND WITH (RIGHT) THE LARGE BOULDERS DEFINED WITHIN THE MODEL MESH. EXPOSED BOULDERS APPEAR AS WHITE POLYGONS IN THE RIGHT IMAGE. BOTH OF THESE SIMULATIONS USED THE CONSTANT N-VALUE ROUGHNESS ASSUMPTION.

Figure 5 shows the distribution of depth-average velocity extracted from the simulation results along the cross section spanning the channel from right bank to left bank just upstream of the bridge (Figure 3) for the three different simulation flows. For all simulations, higher velocities are predicted along the left bank entering the bridge opening. This is expected because the left bank is an outer bend in the channel and the 2D simulations clearly show its effect on the velocity patterns. At the winter baseflow of 60 cfs (Figure 5a), the two constant n simulations predict velocities approximately 1.5 times higher than the depth-varying n simulations. The simulations defining the large boulders as part of the mesh also predict higher and more concentration of velocities near the left bank as a result of flows being directed around individual boulders near this location. These boulders may have been placed to try to protect the bridge footing but instead are causing local concentration of flows and higher velocities against the bank, exacerbating the observed scour of the bridge footing in this location.

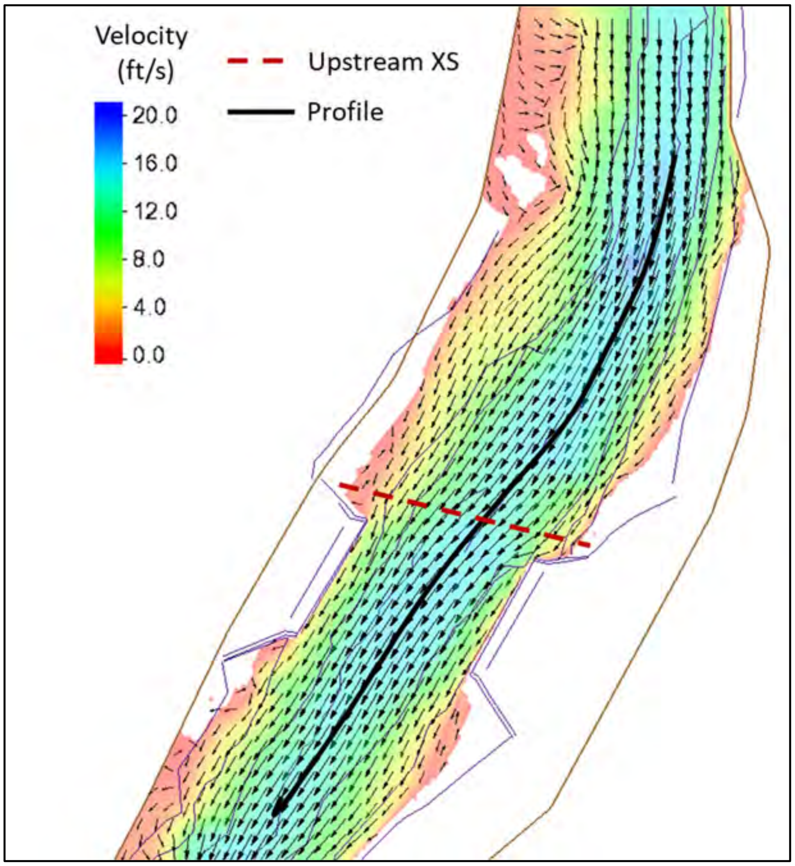


FIGURE 3. LOCATIONS OF VELOCITY CROSS SECTION UPSTREAM OF THE BRIDGE OPENING AND THE PROFILE LINE USED TO COMPARE PREDICTED WATER SURFACE ELEVATION FOR THE MODEL SIMULATIONS. THESE LOCATIONS ARE USED TO COMPARE THE WATER SURFACE ELEVATIONS IN FIGURE 4 AND DEPTH-AVERAGED VELOCITIES IN FIGURE 5.

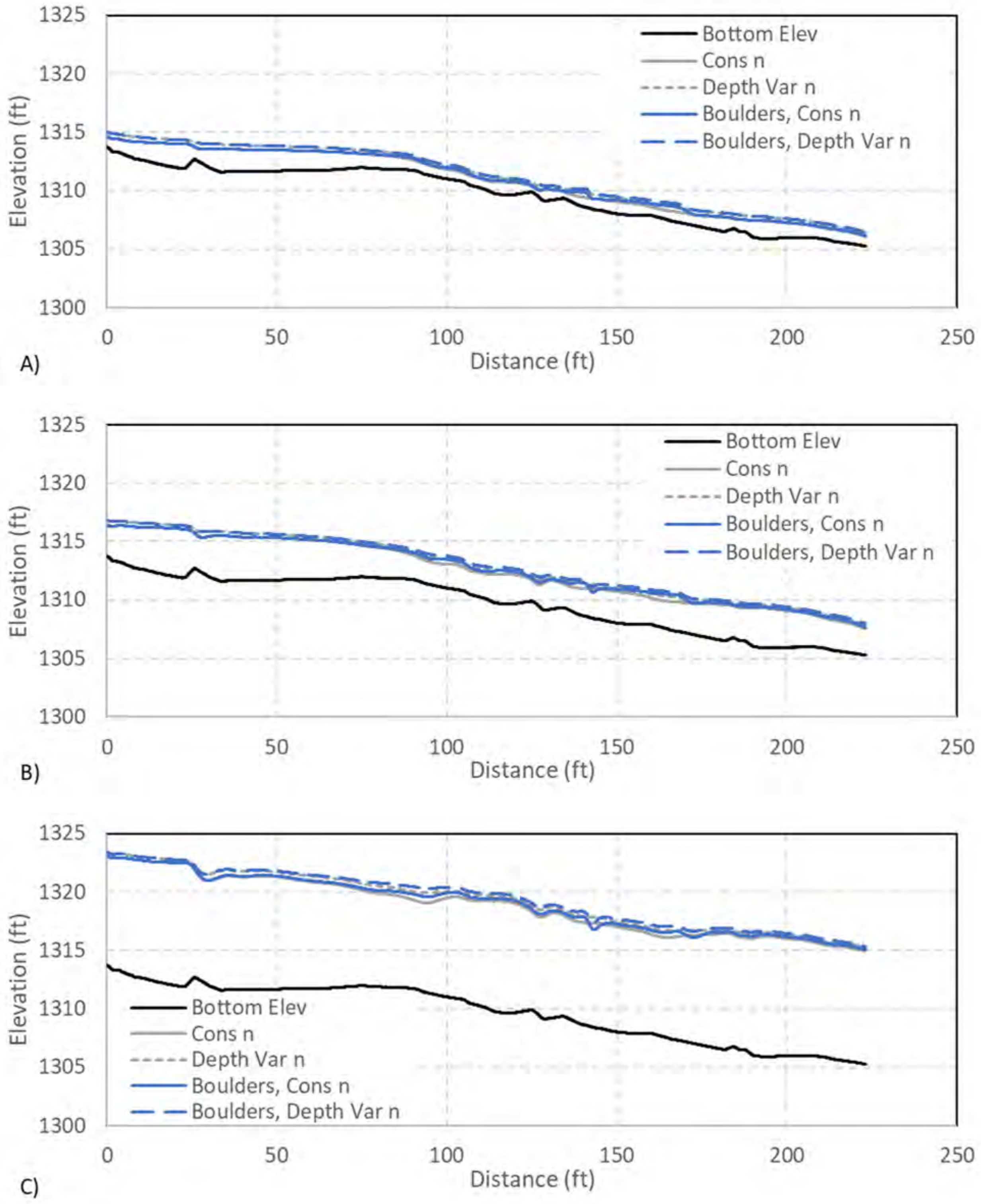


FIGURE 4. WATER SURFACE ELEVATIONS THROUGH THE PROJECT REACH FOR (A) 60 CFS WINTER BASE FLOW, (B) 419 CFS 50% OF $Q_{2\text{-YEAR}}$, AND (C) 4,433 CFS $Q_{100\text{-YEAR}}$.

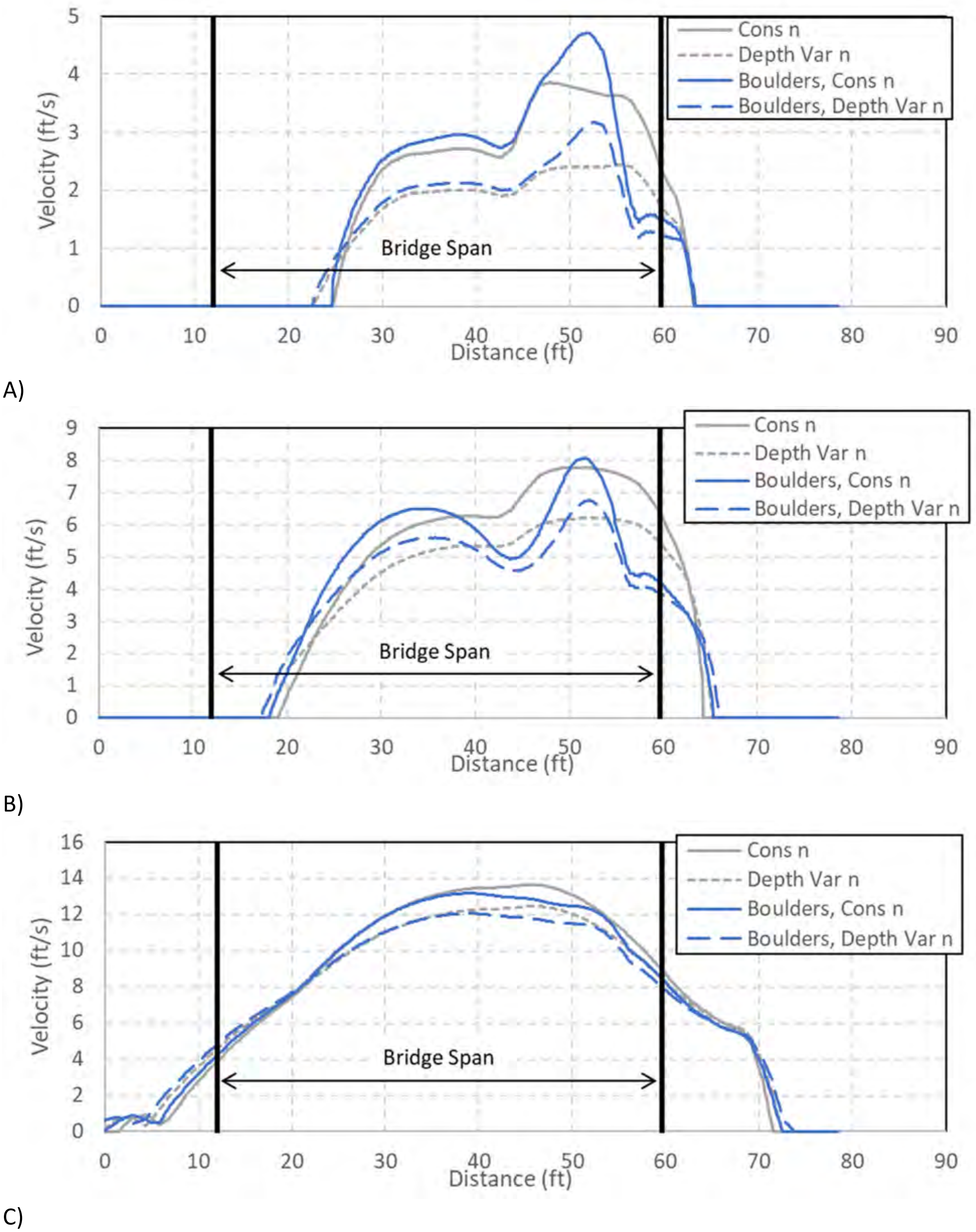


FIGURE 5. DEPTH-AVERAGED VELOCITY ACROSS THE UPSTREAM BRIDGE OPENING (A) 60 CFS WINTER BASE FLOW, (B) 419 CFS 50% OF $Q_{2\text{-YEAR}}$, AND (C) 4,433 CFS $Q_{100\text{-YEAR}}$.

Figure 5b shows a similar velocity pattern estimated for 419 cfs, 50% of $Q_{2\text{-year}}$, a moderate winter storm flow. The difference in velocity magnitude between simulation assumptions is less, ranging from 6.2 to 8.1 ft/s, and the boulder defining mesh simulations show more concentrated, greater velocities near the left bank. At the $Q_{100\text{-year}}$ flow of 4,433 cfs, the difference between simulation assumptions is diminished because the water depths within the channel are almost all large enough that the n values approach the minimum n-values in Figure 1 and become near constant (Figure 5c). At this flow, the boulders are also fully submerged and velocity patterns are no longer influenced by flow around individual boulders. Predicted velocities still show a distinct skew to the left side of the channel and bridge opening where scour has been occurring.

Figure 6 compares the SRH-2D simulation results to the 1D HEC-RAS water surface elevations from the hydrology and hydraulics analysis conducted by Caltrans for the site design (Caltrans, 2013). These comparisons are from the 1D and 2D simulations that do not include a backwater effect from the Klamath River. The 1D predicted water surface elevations are slightly higher upstream of the bridge and very similar to the 2D water surface elevations just downstream of the bridge.

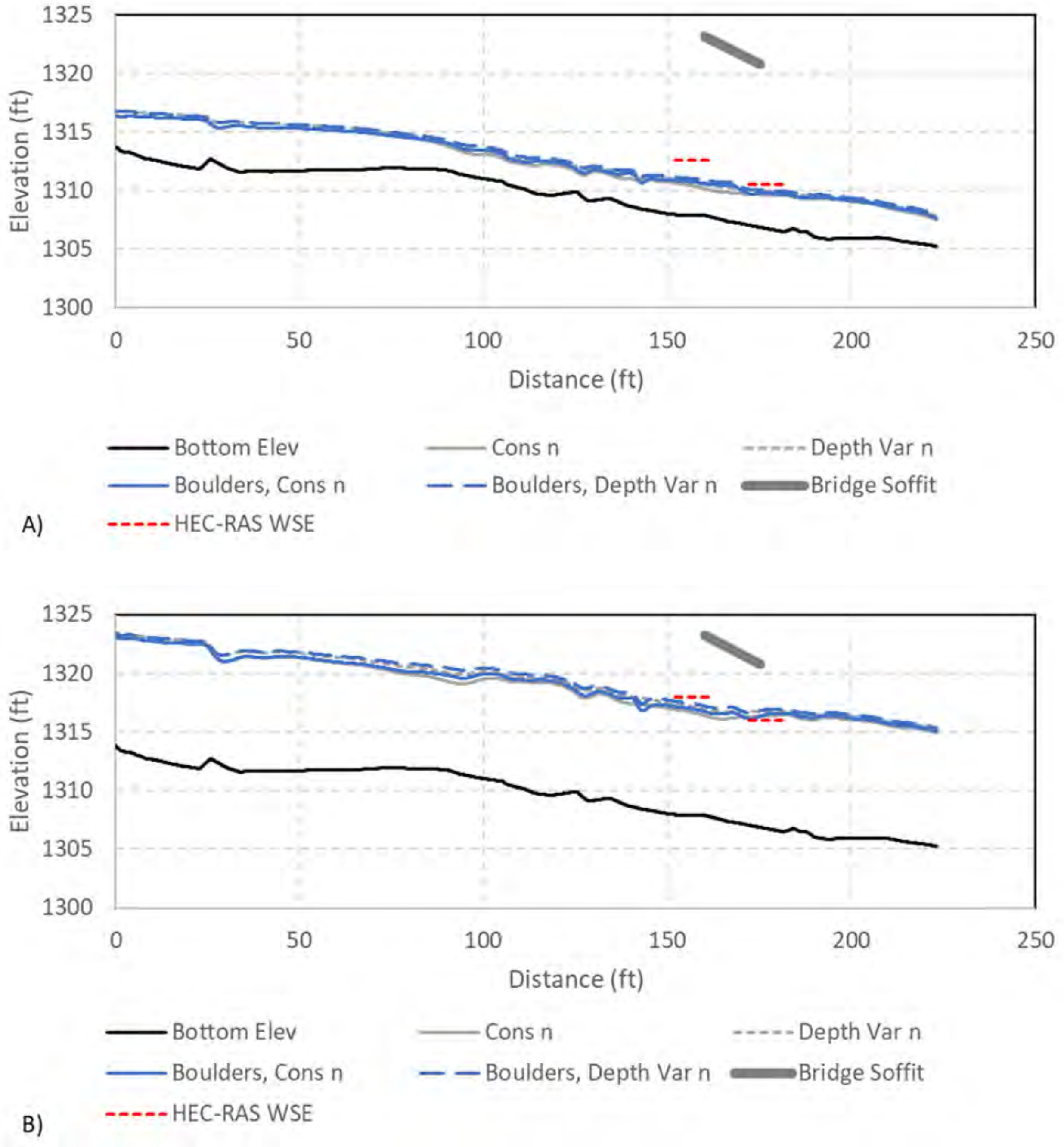


FIGURE 6. COMPARISON OF SRH-2D SIMULATION RESULTS TO THE 1D HEC-RAS SIMULATIONS COMPLETED FOR THE FORT GOFF PROJECT ANALYSIS FOR THE HIGH FISH PASSAGE FLOW (A) AND THE 100-YEAR RETURN PERIOD FLOW (B).

2 NORTH FORK RYAN CREEK

North Fork Ryan Creek is a tributary to Ryan Creek which flows to Outlet Creek, which then discharges to the upper mainstem Eel River. The Highway 101 crossing at North Fork Ryan Creek (MEN 101 – PM52.36) was selected as a modeling case study to:

1. Compare the 1D HEC-RAS AECOM (2014) design model results to analyses using SRH 2D for the existing site conditions
2. Illustrate differences in SRH-2D between two different methods for incorporating the culvert into the model analyses
3. Conduct sensitivity analysis on the hydrology, primarily different methods for estimating the design flows

Items 2 and 3 used the initial design site plans rather than the surveyed existing site conditions to illustrate application of 2D models for design development and analysis.

The North Fork Ryan Creek crossing was replaced to restore fish passage as part of mitigation for the Willits Bypass Project which constructed a new freeway alignment of US 101 to the east of and around Willits, CA (AECOM, 2014). The previous culvert, a 5-foot diameter corrugated metal pipe (CMP), had a perched outlet which prevented fish passage for all species and life stages (Lang, 2005). The CMP was replaced with a 12-ft span x 11-ft rise reinforced concrete box (RCB) countersunk 48 inches below the design streambed. The as-built drawings (Seyoum, 2017, p. D-2a) show there were two upstream and four downstream rock weirs installed for grade control and this matches site observations (see Appendix A).

The AECOM site assessment prepared for the crossing design states that the reference reach active channel width was 7-ft (84 inches) wide and used this value to select the design width of the crossing at approximately 1.5 times the active channel width (AECOM, 2014). HSU field assessment of the upstream reference reach in 2019 estimated the bankfull and active channel width as 14.5 ft and 12.5 ft, respectively. An earlier site assessment conducted by Prunuske Chatham, Inc. for the Five Counties Salmonid Conservation Program reports the reference reach bankfull width as 12 – 15 ft and developed a preliminary replacement design for the crossing as a 20.6-ft wide by 13.2-ft high structural steel plate arch compared to the 12-ft wide box culvert that was installed (Prunuske Chatham, Inc., 2007). Assuming that a 2-year return period discharge is approximately the bankfull discharge, the modeling results show the existing crossing does not appear to meet the width criteria for a full-span crossing.

2.1 Comparison of HEC-RAS 1D and SRH 2D Analyses

This section compares 1D (HEC-RAS) and 2D (SRH-2D) model simulations of the North Fork Ryan Creek crossing. The 2D results are taken from Alyssa Virgil's MS thesis (Virgil, 2020). The original intent of her research was to run the 1D and 2D simulations in parallel. However, the Caltrans 1D HEC-RAS model could not be obtained so the limited simulation results available from the AECOM final project report were used as the basis for comparison (AECOM 2014). The water depth and average velocity from the 1D HEC-RAS simulations are compared to the SRH 2D simulation results for both the 100-year flow of 263 cfs and the high fish passage flow of 16 cfs (50 percent of $Q_{2\text{-year}}$) used in the AECOM analysis (AECOM 2014).

The SRH 2D simulations presented in this section used a mesh developed for the existing site conditions. The topographic data was collected 01/14/2020 and 3/16/2020 using a Topcon GTS 226 Total Station. The survey covered the stream crossing reach, including the stream channel directly upstream, downstream and within the crossing, and the upstream reference reach. The survey included a longitudinal thalweg profile; 19 channel cross sections; wetted, active and bankfull channel breaklines; slope breaks; boundaries defining different surface roughness polygons; the stream crossing structures and the flood plain terrace. There were 54,277 mesh elements in the site model, and element size ranged from just under 0.3 ft^2 in the channel to 1.5 ft^2 on the flood plain terrace. All simulations were steady flow. For this analysis the culvert was defined as a rectangular, open channel because the inlet remained unsubmerged for all flows simulated. The inlet boundary condition was a constant flow distributed across the inlet channel by conveyance capacity. The outlet boundary condition was a constant water surface elevation determined from the normal depth through the outlet cross section as calculated using the calculation tool provided in SMS.

The initial simulations used the mesh described above at the $Q_{100\text{-yr}}$ (263 cfs) and 50% of the $Q_{2\text{-yr}}$ (16 cfs) flows, as reported by AECOM and used for their 1D HEC-RAS simulations. These simulations allowed direct comparison between the 1D and 2D model results. Figure 7 shows a plan map of depth-averaged velocity at 263 cfs. Eddies form along the bank downstream of the rock weir. The eddy formed on the right bank is 4.8 feet wide and the eddy formed on the left bank is 3.2 feet wide, while the wetted channel width is 20.2 feet. The primary flow width between the eddies is 12.2 feet compared to the flow width of 18.0 ft upstream of the weir. The maximum velocity in the primary channel downstream of the rock weir is 6.9 ft/s and the velocity over the top of the rock weir is 13.4 ft/s. The 6.9 ft/s velocity is the same as the maximum average velocity predicted by AECOM's 1D HEC-RES for simulations for this flow rate. The location of this velocity is described only as "near the proposed rock weirs" in the AECOM report so it is not known whether the location of maximum velocity is the same for the 1D and 2D models.

The average velocity across the inlet opening is 5.8 ft/s and eddies are predicted to form on both the right and left banks. Hydraulic conditions predicted at the culvert outlet are similar to the inlet with two pronounced eddies adjacent to the left and right banks. The velocities at the culvert outlet are predicted to be 8.6 ft/s at the right edge of the culvert, 9.6 ft/s in the middle of the outlet opening, and 8.3 ft/s at the left culvert wall. All of these velocities exceed the 6.9 ft/s average velocity predicted at the culvert outlet by the 1D HEC-RAS simulation for this flow rate. Inlet velocities for the 1D results were not available.

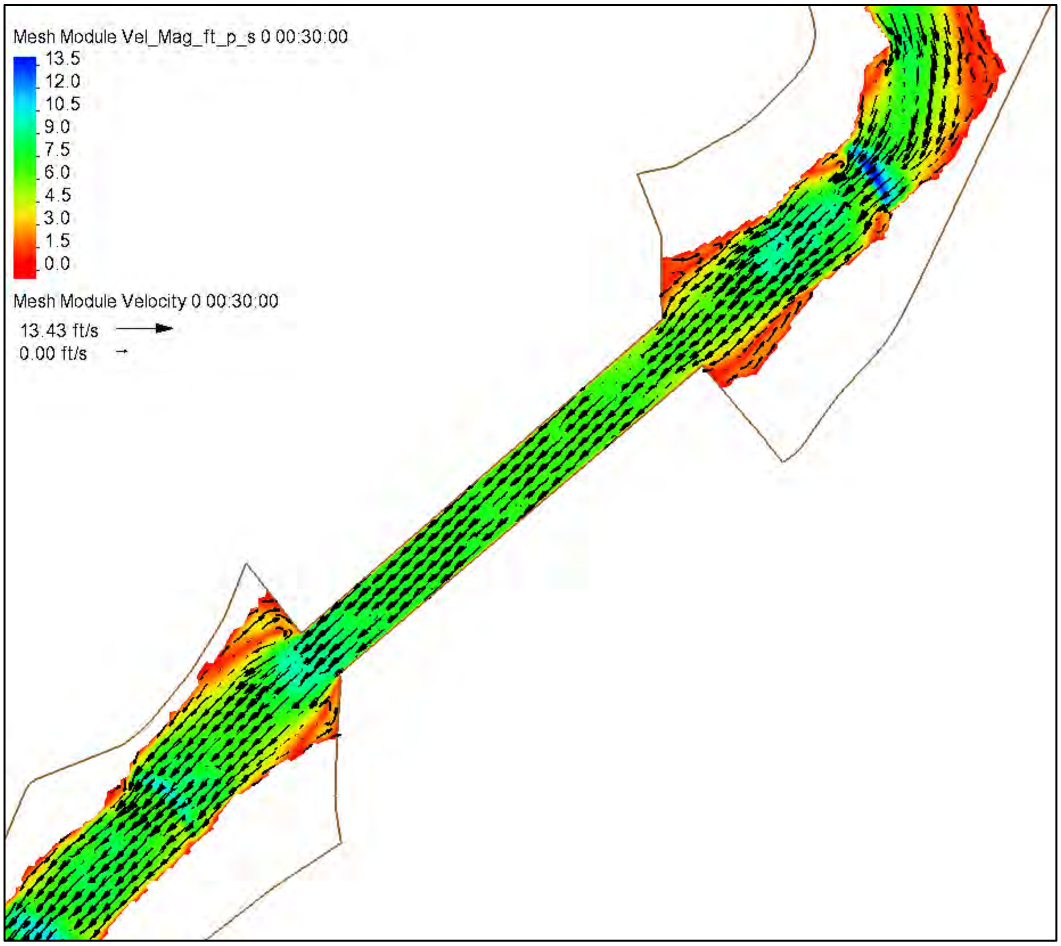


FIGURE 7. VELOCITY FOR $Q_{100\text{-YEAR}}$ = 263 CFS. MAXIMUM VELOCITY OCCURS OVER THE UPSTREAM ROCK WEIR SHOWN HERE AS A BLUE PATCH IN THE UPSTREAM CHANNEL SECTION.

Figure 8 shows the predicted water surface elevations through the culvert for the two simulation flow rates. The plot also includes the water surface elevations reported from the 1D analysis for $Q_{100\text{-year}}$ in the AECOM design report (AECOM, 2014). At all locations, the 1D model predicted greater depths than the 2D model. Thus, the 1D model would provide conservative estimates of inundation depths but underestimate velocities.

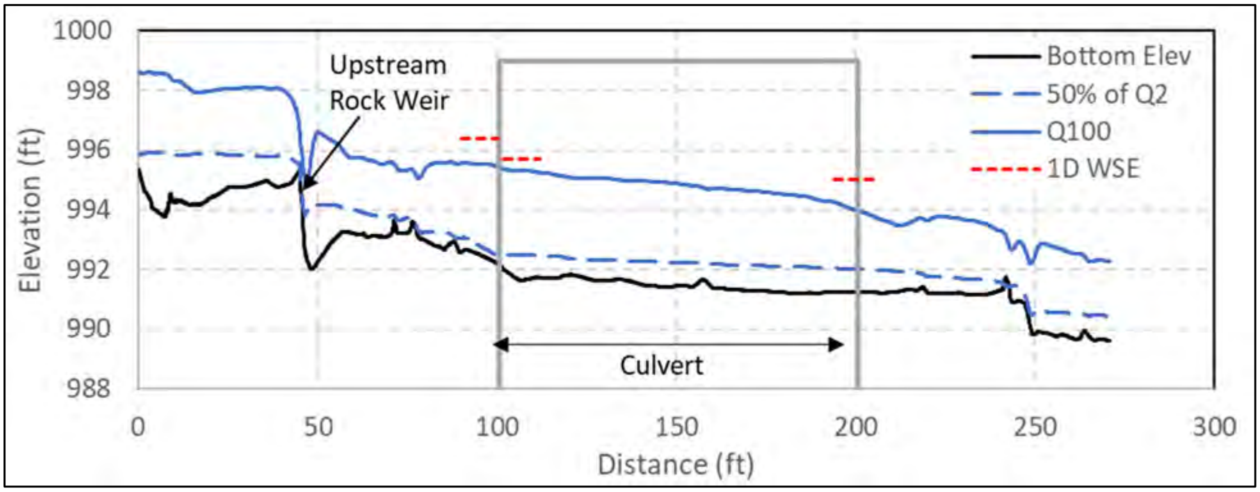


FIGURE 8. PROFILE PLOT OF WATER SURFACE ELEVATION (WSE) FOR $Q_{100\text{-YEAR}}$ (263 CFS) AND THE ADULT HIGH FISH PASSAGE FLOW (50% OF $Q_{2\text{-YEAR}}$ = 16 CFS) FOR THE 2D MODEL RESULTS. THE RED, SHORT DASHED LINES INDICATE THE 1D MODEL PREDICTED DEPTHS AT THOSE LOCATIONS. THE WATER SURFACE-TO-WATER SURFACE DROP AT THE UPSTREAM ROCK WEIR IS PREDICTED TO BE 1.6 FT AT 50% OF $Q_{2\text{-YEAR}}$.

2.2 SRH 2D Analysis of the Design Surface

SRH 2D simulations using the design plan topography were also completed to illustrate how 2D hydraulic modeling analysis could be conducted as part of the design development. The design site surface was extracted a PDF of the Caltrans design drawings for the site (Seyoum, 2017, pages G-3 and G-4) and imported into SRH 2D as a point cloud and breaklines to develop the SRH 2D model mesh for the design topography. This surface clearly defines the culvert, including the headwall, wingwalls, engineered channel and the nine rock weirs included in the original design drawing. The active channel and embedded culvert bed material roughness was assumed to be 0.035 and the channel bank roughness was set to 0.070 for all simulations. Larger, exposed diversion rocks and rock weirs in the design drawings were included as part of the bed topography by editing the mesh at those locations. Simulations assumed steady flow, and for all simulations, the upstream boundary condition was a constant flow rate distributed across the channel width by channel conveyance capacity. The downstream boundary condition was a constant depth calculated assuming uniform flow for the channel cross section at this location. The uniform depth and water surface elevation at the downstream boundary was determined using the built-in tools within SRH 2D as implemented in Aquaveo's Surface-water Modeling System (SMS) 13.0.

Using SMS, SRH 2D can account for culvert hydraulics in two different ways: embedding a 1D HY-8 culvert analysis into the 2D SRH hydraulics or modeling the culvert as part of the channel to maintain 2D analysis through the structure. For the first method, SMS merges the 1D solutions from the FWHA HY-8 software into an SRH 2D simulation. HY-8 results are integrated within an SRH 2D simulation as internal, constant water surface elevation boundary conditions at the culvert inlet and outlet. When using this model option, an HY-8 simulation is completed first using the SRH 2D mesh to determine the culvert inlet and outlet water surface elevations for a discharge of interest. Then, these culvert inlet and outlet water surface elevations are set as internal boundary conditions at the defined inlet and outlet locations in the model mesh and used in the subsequent SRH 2D simulations. This approach assumes that the approach velocity into the culvert is zero for calculating headloss and headwater elevation at the inlet. This assumption is more conservative than a 1-D HEC-RAS model or simulating the 2D hydraulics using SRH-2D.

The second method defines the crossing geometry within the SRH 2D model mesh; e.g., a concrete box culvert is represented as a rectangular cross section open channel. Simulations using this approach are fully 2D; however, they cannot be used for crossing geometries that cannot be defined within a model mesh such as circular culverts over 50-percent full or to analyze flow magnitudes that create pressurized culverts conditions. Aquaveo recommends using this second approach where applicable because of its ability to provide more detailed hydraulic analysis. This approach is also preferred for evaluation of lower flows such as those needed to assess fish passage or habitat conditions.

To illustrate differences between the two methods, Figure 9 and Figure 10 show the velocity magnitudes and vector fields predicted using HY-8 versus modeling the culvert as a rectangular, open channel using AECOM (2014) flow estimates for $Q_{2\text{-year}}$ (33 cfs) and $Q_{100\text{-year}}$ (263 cfs), respectively. The NF Ryan Creek inlet is not submerged at 263 cfs or any of the other simulated flows, so modeling the culvert as a channel is valid and recommended Maximum velocities occurred at the crest of the most upstream rock weir.

Overall velocity patterns, velocity magnitudes and water depths are similar throughout the model domain with the exception of the culvert outlet region. Velocity vectors at the culvert outlet for the 1D HY-8 results place them unidirectionally perpendicular to the headwall, which is skewed to the channel. In contrast, the 2D vectors are more parallel with the overall direction of flow, as would be expected. The differences in velocity direction at the outlet result in differences in the location and magnitude of eddies downstream of the outlet, especially for the eddy predicted to form on the right bank. This limitation should be accounted for when using the 1D HY-8 method for modeling culverts. As expected, the upstream simulation results are nearly identical.

Table 1 and Table 2 compare the local predictions of water depth and velocity more closely. These average values were calculated by extracting point values along a cross section at three different locations: the crest of the most upstream rock weir, the culvert inlet and the culvert outlet. The values predicted for $Q_{2\text{-year}}$ (33 cfs) agree well for all locations. The values predicted at the higher $Q_{100\text{-year}}$ (263 cfs) are similar for the two upstream locations but are substantially different at the outlet. Simulating the culvert as a 2D open channel predicts shallower, supercritical flow at the culvert outlet with a depth, 2.6 ft, that is 1 foot lower than that calculated using the embedded HY-8 simulation. The result is a much faster velocity of 9.8 ft/s for the fully 2D SRH simulation compared to 5.2 ft/s using the HY-8 method. It is difficult to confirm which hydraulic condition is the correct one without field measurements but the difference in predicted local velocity could impact design calculations for sizing rock weirs and specifying engineered bed material.

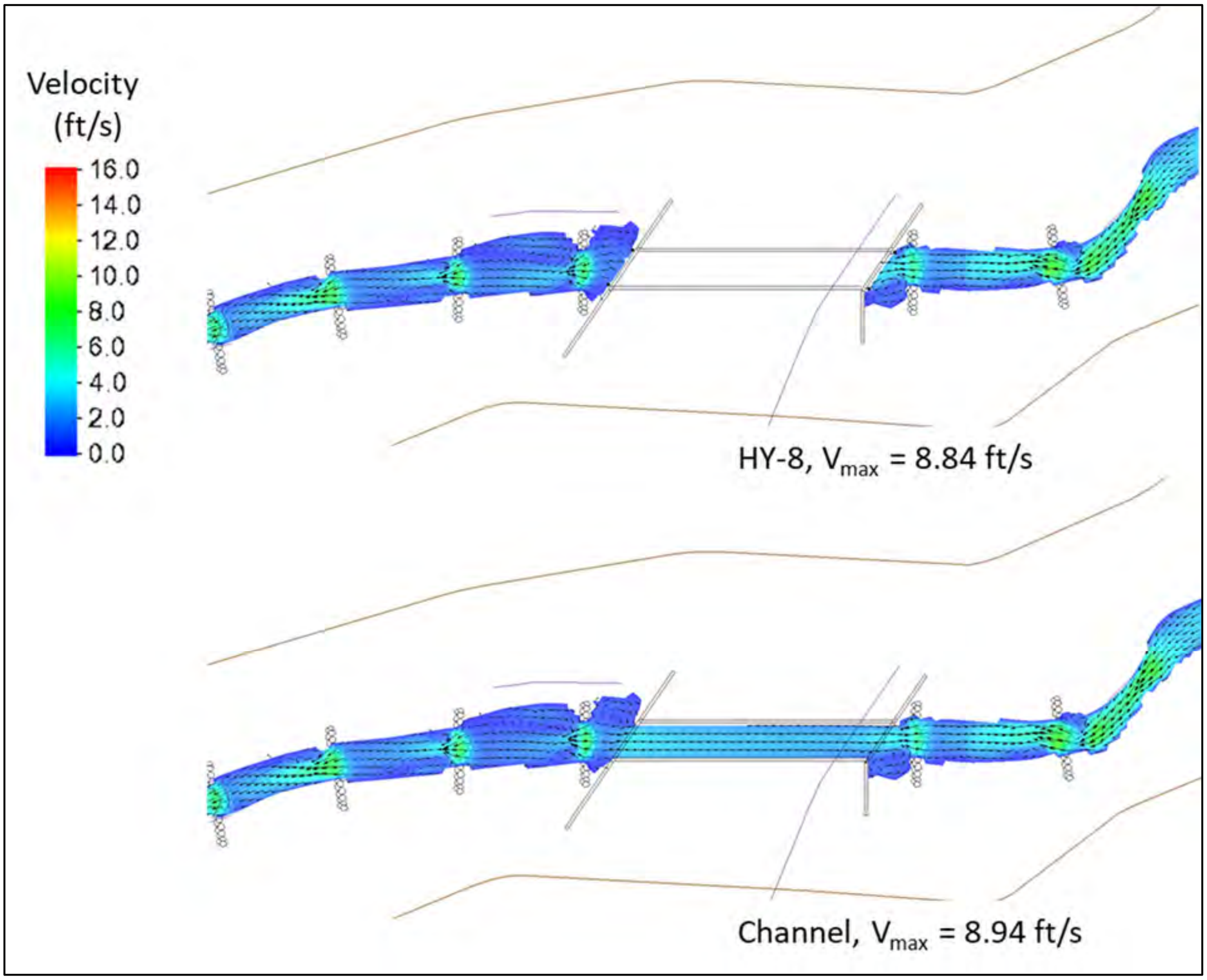


FIGURE 9. SRH 2D SIMULATION OF NF RYAN CREEK AT Q = 33 CFS USING EMBEDDED HY-8, 1D CULVERT HYDRAULICS (UPPER FIGURE) AND TREATING THE CULVERT AS A CHANNEL SEGMENT (LOWER FIGURE).

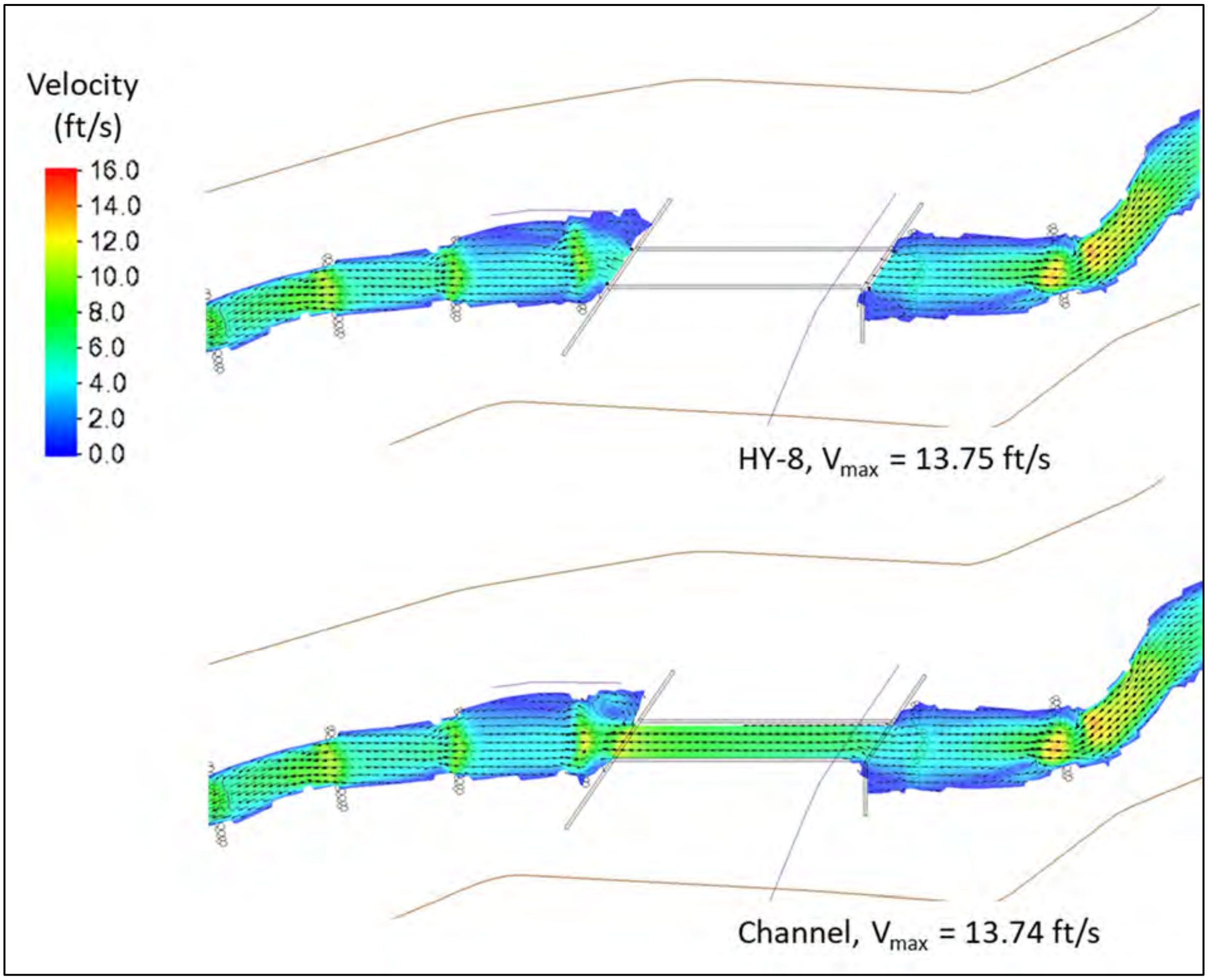


FIGURE 10. SRH 2D SIMULATION OF NF RYAN CREEK AT Q = 263 CFS USING EMBEDDED HY-8, 1D CULVERT HYDRAULICS (UPPER FIGURE) AND TREATING THE CULVERT AS A CHANNEL SEGMENT (LOWER FIGURE).

TABLE 1. COMPARISON OF CROSS-SECTIONAL AVERAGE WATER DEPTH (FT) AT THREE LOCATIONS FOR THE SHR-2D MODEL OF THE CULVERT AS A 1D ELEMENT IN HY-8 AND AS A 2-D OPEN CHANNEL.

	$Q_{2\text{-year}}$		$Q_{100\text{-year}}$	
Location	**HY-8**	**Open Channel**	**HY-8**	**Open Channel**
Upstream rock weir	0.31	0.39	1.82	1.81
Culvert inlet	1.27	1.26	4.41	4.31
Culvert outlet	2.00	1.95	3.66	2.64

TABLE 2. COMPARISON OF AVERAGE VELOCITY (FT/S) OVER THE CROSS SECTION AT THREE LOCATIONS FOR THE SRH-2D MODEL OF THE CULVERT AS A 1D ELEMENT IN HY-8 AND AS A 2-D OPEN CHANNEL.

	$Q_{2\text{-year}}$		$Q_{100\text{-year}}$	
Location	**HY-8**	**Open Channel**	**HY-8**	**Open Channel**
Upstream rock weir	6.64	6.70	11.72	11.81
Culvert inlet	2.97	3.11	4.19	4.60
Culvert outlet	1.23	2.01	5.25	9.82

2.3 Sensitivity Analysis of Design Flow Estimation Methods

The evaluation of a crossing's hydraulic performance is always subject to uncertainties related to estimating return period flows. For the North Fork Ryan Creek site, three estimates of return period flows have been made by independent entities: Prunuske Chatham, Inc. (PCI), AECOM and Humboldt State University (HSU). This section compares results from SRH 2D simulations completed for these different flow rates for models using embedded HY-8 1D culvert analysis and modeling the culvert as an open channel segment (see Section 2.2). The purpose is to compare differences in predicted crossing conditions and identify possible implications for design decisions resulting from this uncertainty.

Table 3 summarizes the values for adult high fish passage flow (50% of $Q_{2\text{-year}}$), $Q_{2\text{-year}}$ and $Q_{100\text{-year}}$ determined by the three different sources and the method used for each estimation. All methods used to estimate $Q_{2\text{-year}}$ and $Q_{100\text{-year}}$ require the upstream drainage area and a mean annual precipitation. The drainage area upstream of the North Fork Ryan Creek stream crossing is 0.67 square miles and this value was used for all calculations. A mean annual precipitation of 51 inches was used by AECOM to calculate relevant return period discharges using TR-55 (AECOM, 2014). The source of this precipitation value is not cited in the AECOM report. The mean annual precipitation from USGS StreamStats is 56.1 inches (USGS, 2020) and this value was used with the updated California regional regression equations (Gotvald et al., 2012) to calculate the HSU values in Table 3. PCI values were reported as provided by Caltrans and are believed to be from calculations using an older version of the California regional regression equations (Waananen & Crippen, 1977).

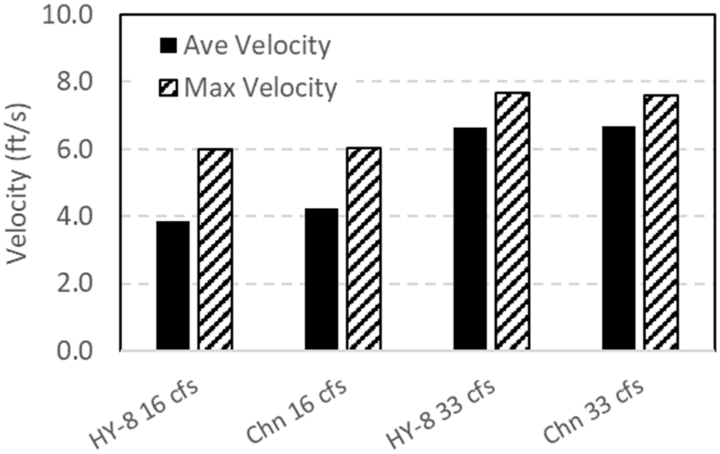
TABLE 3. METHODS AND ASSUMPTIONS USED FOR DIFFERENT ESTIMATES OF PERFORMANCE RELEVANT FLOW RATES.

Flow Description	Value (cfs)	Source	Method
50% of $Q_{2\text{-year}}$ Adult High Fish Passage Flow	16	AECOM	AECOM TR55 calculations
50% of $Q_{2\text{-year}}$ Adult High Fish Passage Flow	33	PCI, HSU	CA 2012 and 1977 Regional Regression Eqns
$Q_{2\text{-year}}$	33	AECOM	AECOM TR55 calculations
$Q_{2\text{-year}}$	66	PCI, HSU	CA 2012 and 1977 Regional Regression Eqns
$Q_{100\text{-year}}$	263	AECOM	AECOM TR55 calculations
$Q_{100\text{-year}}$	322	HSU	CA 2012 Regional Regression Eqns
$Q_{100\text{-year}}$	455	PCI	CA 1977 Regional Regression Eqns

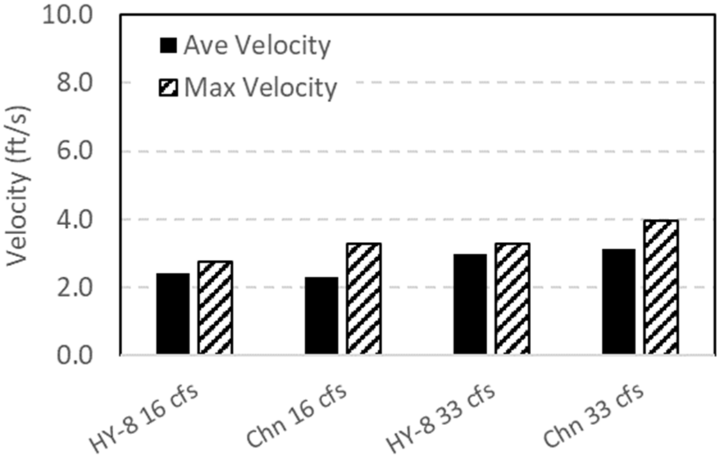
Figure 11 through Figure 13 show the average and maximum velocities predicted across cross sections at the three most sensitive locations within the model domain. For the adult high fish passage flow estimates of 16 and 33 cfs, all simulations predict average velocities that meet the fish passage threshold for adult salmonids of 5 ft/s for culvert lengths greater than 50 ft (NMFS 2001) at the crossing inlet and outlet. Average velocities at the upstream rock weir crest are predicted as 6.6 – 6.7 ft/s for the higher PCI and HSU adult passage flow estimate of 33 cfs. These values just exceed maximum average velocity for culvert barrel passage criteria but they are localized velocities along the rock weir crest and, while potentially challenging for passage, would not hinder passage of adult salmonids using burst swim speeds over this short distance. Velocity predictions for the two models are similar throughout the model domain except at the culvert outlet; simulating the culvert as a rectangular open channel predicts velocity magnitudes at the culvert outlet that are approximately twice those determined using the embedded HY-8 simulation.

Predictions are also similar for the other two cases presented. Figure 12 shows the range of velocity conditions at the same three locations for the two estimates of $Q_{2\text{-year}}$ and Figure 13 presents those for the $Q_{100\text{-year}}$ simulations. Even as flow magnitude changes, the predicted velocities remain fairly constant over the rock weir and at the culvert inlet. This agreement is expected because estimation of the hydraulic conditions at these locations is not strongly influenced by the culvert assumptions or representation. The culvert outlet hydraulic conditions are much more sensitive to flow rate and how the culvert is defined in the simulations. For the same flow rate, the simulations defining the culvert as a rectangular, open channel consistently predict supercritical flow and, consequently, higher velocities at the outlet than the HY-8 based simulations.

a) Upstream Rock Weir



b) Culvert Inlet



c) Culvert Outlet

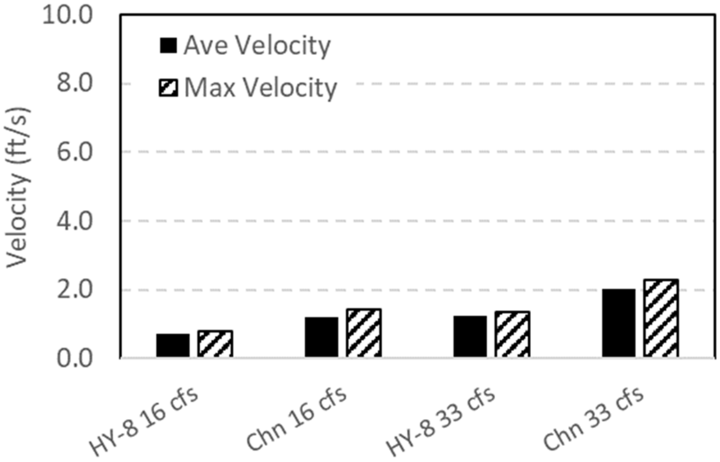
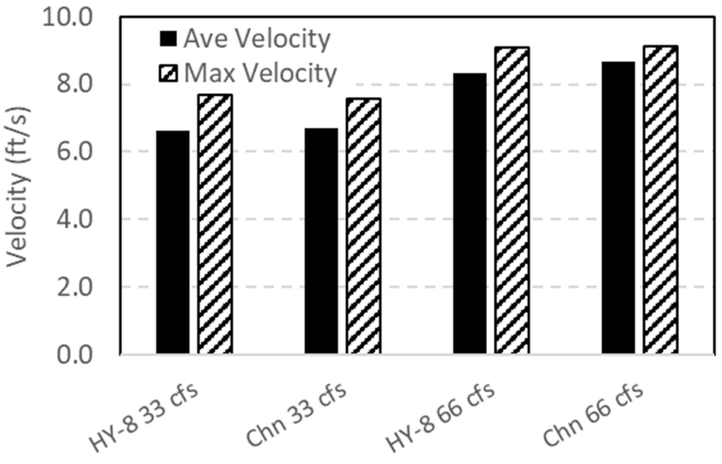
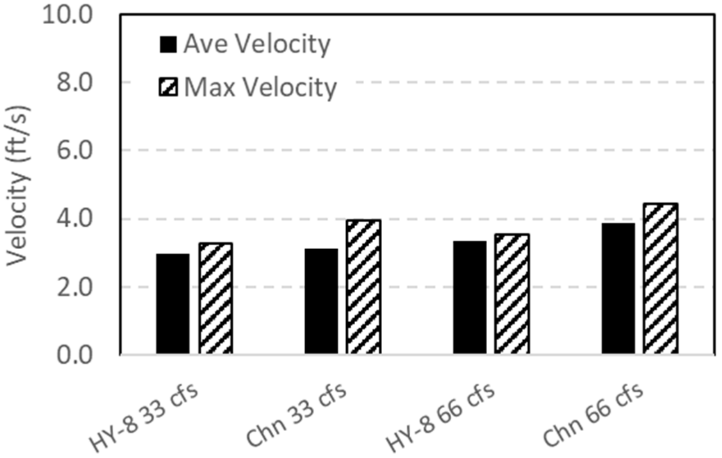


FIGURE 11. COMPARISON OF AVERAGE AND MAXIMUM VELOCITIES AT CROSS SECTIONS ACROSS THE ROCK WEIR, INLET AND OUTLET FOR THE TWO ESTIMATES OF THE ADULT HIGH FISH PASSAGE FLOW (16 CFS – AECOM; 33 CFS – HSU & PCI).

a) Upstream Rock Weir



b) Culvert Inlet



c) Culvert Outlet

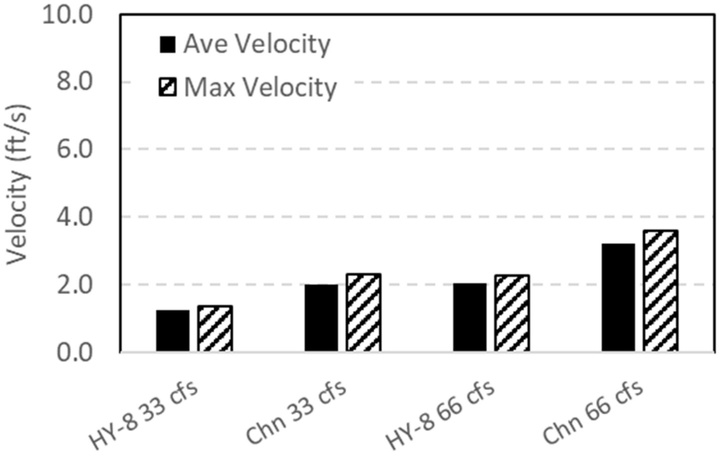
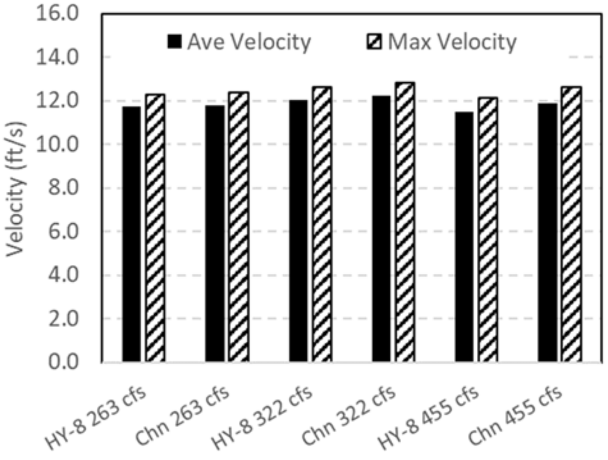
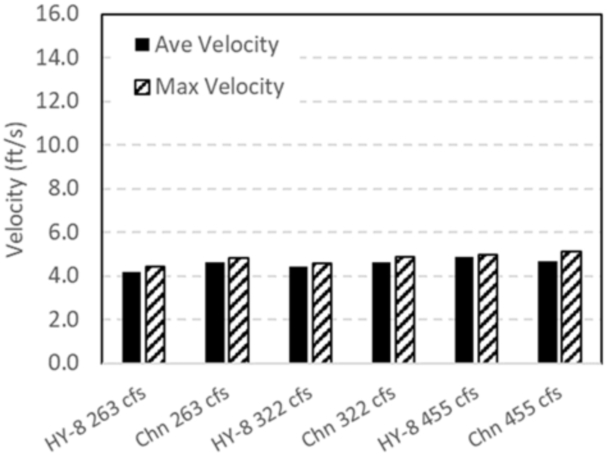


FIGURE 12. COMPARISON OF AVERAGE AND MAXIMUM VELOCITIES AT CROSS SECTIONS ACROSS THE ROCK WEIR, INLET AND OUTLET FOR THE TWO ESTIMATES OF THE $Q_{2\text{-YEAR}}$ (33 CFS – AECOM; 66 CFS – HSU & PCI).

a) Upstream Rock Weir



b) Culvert Inlet



c) Culvert Outlet

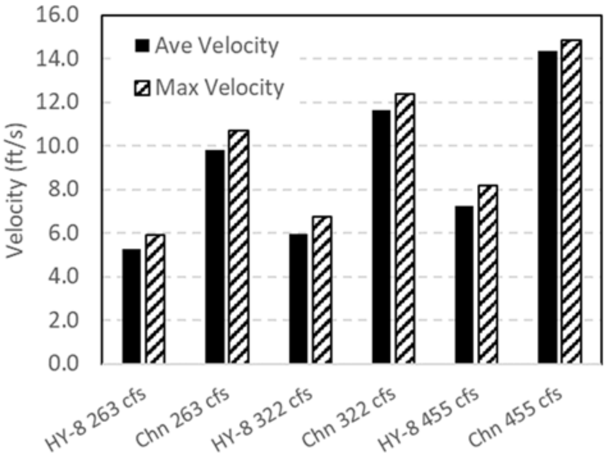


FIGURE 13. COMPARISON OF AVERAGE AND MAXIMUM VELOCITIES AT CROSS SECTIONS ACROSS THE ROCK WEIR, INLET AND OUTLET FOR THE THREE ESTIMATES OF THE $Q_{100\text{-YEAR}}$ (263 CFS – AECOM; 322 CFS – HSU & 455 CFS – PCI).

3 SUMMARY AND RECOMMENDATIONS

In the past, 1D models have been the primary design tool for fish passage and larger road-stream crossings. These models are quite good at predicting water depths at design flows of interest so are sufficient if their primary use is designing for flood capacity. Another argument for their use is that they need less field data, specifically detailed topographic data, and are computationally more efficient. One dimensional models, however, do not provide good predictions for water velocity or in regions of complex channel geometry.

Two dimensional models are now the industry standard in most agencies and engineering consulting firms for the design of large road crossings with or without fish passage concerns. Their ease of use and the tools available to assist in site model development are now very user friendly, and computational efficiency is generally not a factor with current computer processor speeds. Developing a 2D site model does require additional field work and survey data collected by a survey crew knowledgeable in the data needed to develop a 2D model. This often means that a hydraulic engineer should accompany the survey crew when the data is being collected. However, recent advances in survey technology and wide-spread availability of high-quality LiDAR data are reducing the complexity and, possibly, the need for this initial survey effort. As an example, if a site has high-quality LiDAR data available, then merging the site design plans with the LiDAR data to develop a digital elevation model (DEM) for the 2D model would allow iterative design performance analysis without the need for a detailed field survey. New survey technologies such as drone-based or ground-based LiDAR surveying tools are also available to collect high-quality, site-specific topographic data without the need to pinpoint specific data collection details such as slope breaks, top of banks, etc., allowing a survey crew to collect the necessary data quickly and efficiently.

The FHWA's support of SRH-2D within Aquaveo's SMS software platform, continued development of DOT specific analysis tools, and the availability of training for DOT hydraulic engineers makes a transition to 2D model analysis reasonable. Engineers experienced with HEC-RAS 1D could also transition to HEC-RAS 2D due to its similar platform. The US Army Corps of Engineers and others have also developed many training tools and examples for users new to HEC-RAS 2D and new model versions with added features are regularly released. Caltrans Structures Hydraulics and Hydrology division routinely develops 2D models for bridge and other complex sites. Expanded training and extending these capabilities into Caltrans District hydraulic engineers would benefit road crossing design throughout the state.

4 REFERENCES

AECOM. (2014). *Ryan Creek Culvert Replacement Project.* Prepared for Caltrans Design Branch M-5.

Caltrans. (2013). *Final Hydrology and Hydraulics Report, Fort Goff Creek Fish Passage Restoration.* Caltrans North Region-Redding, Hydraulics Design Branch.

FHWA. (2021). *HY-8 Culvert Hydraulic Analysis Program*. Retrieved from https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/

Gotvald, A., Barth, N., V. A., & and Parrett, C. (2012). *Methods for determining magnitude and frequency of floods in California, based on data through water year 2006.* USGS. Retrieved from http://pubs.usgs.gov/sir/2012/5113/

Jarrett. (1984). Hydraulics of high gradient streams. *Journal of Hydraulic Engineering, 110*(11).

Lai, Y. G. (2008). *SRH-2D version 2: Theory and User's Manual.* Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation.

Lang. (2005). *California Department of Transportation (Caltrans) District 1 Pilot Fish Passage Assessment Study: Volume 1 – Overall Results.* U.S. Department of Transportation, Federal Highway Administration.

Marcus, R. H. (1992). An Evaluation of Methods for Estimating Manning's n in Small Mountain Streams. *Mountain Research and Development, 12*(3), 227-239.

Mussetter, R. A. (1989). *Dynamics of mountain streams.* PhD dissertation, Colorado State University, Fort Collins, CO.

NMFS. (2001). *Guidelines for Salmonid Passage at Stream Crossings.* Santa Rosa, CA: National Marine Fisheries Service, Southwest Region.

Prunuske Chatham, Inc. (2007). *NORTH AND SOUTH FORK RYAN CREEK FISH PASSAGE IMPROVEMENT PROJECTS, Draft Scoping Report.* Occidental, CA: Prunuske Chatham, Inc.

Seyoum, K. (2017). North Fork Ryan Creek As Built drawings. Caltrans.

USGS. (n.d.). *USGS Streamstats*. Retrieved from https://streamstats.usgs.gov/ss/

Virgil, A. (2020). Evaluation of 1-D and 2-D hydraulic models for designing and assessing fullspan stream crossings. *MS Environmental Systems*. Humboldt State University.

Waananen, A. C. (1977). *Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21.* US Geological Society.

Wolman, M. (1954). A Method of Sampling Coarse River-bed Material. *Transactions, American Geophysical Union, 35*(6), 951-956.

APPENDIX E – LITERATURE REVIEW

Review of the Design and Performance of Fish Passage Stream Crossings

Introduction

This literature review summarizes the current knowledge and practices for design and performance of fish passage stream crossings. To meet fish passage objectives, the preferred crossing design is generally a structure that fully spans the bankfull channel width. These full-span crossings (FSCs) often have a natural substrate bottom and also provide unimpeded conveyance of water, sediment and debris at flows up to, and often higher than, the bankfull flow, which typically has a return period of approximately the 1.2- to 2-year discharge (Wolman & Leopold, 1957). The primary characteristic of FSCs is that they span the stream channel width usually defined as bankfull width with some factor of safety. The crossing design types that meet these performance criteria generally create hydraulic conditions similar to those in the adjacent natural channel. Thus, they provide continuity in hydraulic conditions, and often habitat quality, through the crossing and at transitions between the crossing and adjacent natural channel.

A brief introduction to fish passage stream crossing types, their performance and the benefits of installing stream crossings meeting these criteria compared to other designs is included here, followed by a summary of current design criteria and methods. The performance of fish passage and full-span stream crossings is summarized from existing studies that developed the monitoring procedures needed to assess their performance, then evaluated post-implementation performance with respect to hydraulic or biological criteria. The design criteria presented highlight those used in the Pacific Northwest because of its geomorphic and hydrologic similarity to much of coastal California and the species of concern are similar across these states. Methodologies and resources for designing fish passage stream crossings for site-specific conditions are summarized, and the most common software design tools are described.

Fish passage stream crossings are typically classified as either hydraulic or geomorphic designs. Hydraulic designs are those that meet specified hydraulic conditions such as water depth and velocity over a range of fish passage flows such that the target fish species can successfully swim through the crossing. The criteria for the hydraulic conditions are intended to be very conservative so that even the weakest swimming individual of the target species and life-stage can pass successfully. Geomorphic designs are intended to create hydraulic and habitat conditions within the crossing that mimic those of the adjacent or a nearby reference reach within the natural channel (USFS, Stream Simulation: An Ecological Approach To Providing Passage for Aquatic Organisms at Road-Stream Crossings, 2008). The assumption for performance of a geomorphic design is that the crossing provides passage conditions similar to the natural stream channel over the full range of fish passage flows. The variety of available fish passage engineering design approaches encompass these two classifications along a continuum (Figure 1).

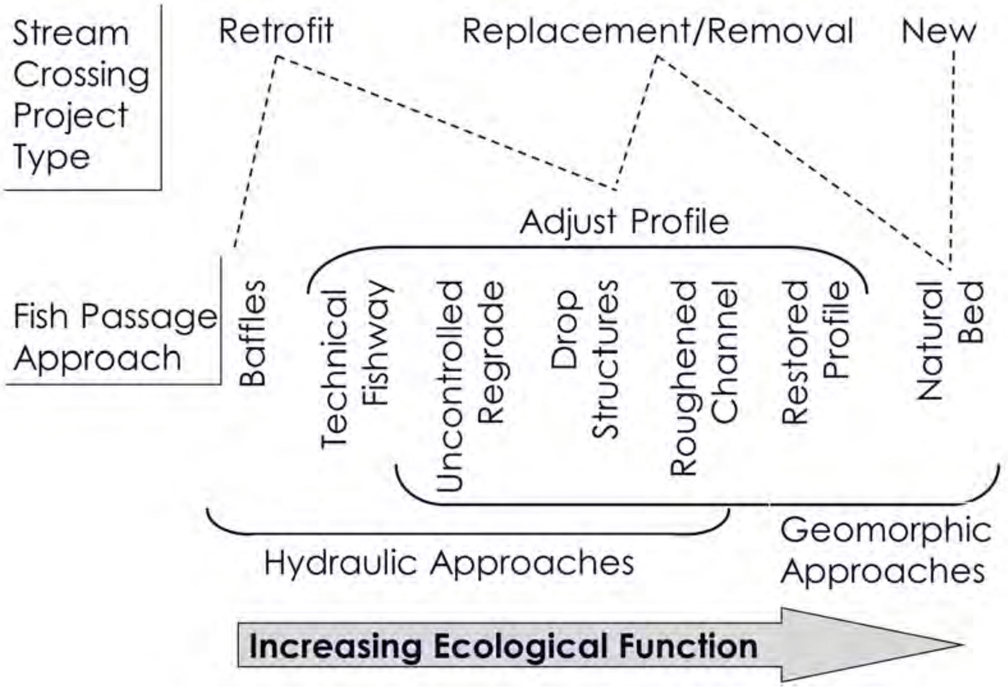


Figure 1. Hierarchy of fish passage solution approaches. Adapted from CDFG, 2009.

Fish passage is best achieved using full-span stream crossings, with bridges as the preferred FSC when feasible. Table 1 summarizes the priority of preferred crossing types identified in applicable state and federal agency fish passage design guidelines. State and federal design guidelines recommend limiting traditional hydraulic designs, which aim to satisfy hydraulic criteria for a target fish species and age class (CDFG, 2002; NOAA, 2001; Barnard et al., 2013). Full-span crossings can be designed and constructed to have mobile or immobile beds, be standard crossing installations with no substrate or incorporate grade control structures such as concrete or rock weirs to maintain bed elevations and meet fish passage criteria. FSC, with or without substrate, on streams without fish passage requirements can still provide substantial hydraulic performance and maintenance benefits in terms of greater resilience to flood damage and other impacts associated with debris clogging (TRB, 2017; Furniss et al., 1998).

Stream simulation crossings are the preferred geomorphic design and were developed to promote full continuity in stream channel processes and passage for all aquatic organisms. The concept of stream simulation crossings was introduced in the 1999 version of the Washington Department of Wildlife's Fish Passage Design Guidelines (WDFW, 1999). The design of stream simulation crossings has been further developed by the US Forest Service (USFS) and is presented in their detailed design manual, *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings* (USFS, 2008). Both full span and stream simulation crossing types have widths equal to or greater than bankfull channel width. However, the design of a stream simulation crossing also requires a reference reach within the adjacent stream channel and the crossing width, slope and substrate are matched to those within this reference reach (WDFW, 1999; USFS, 2008).

Table 1. Prioritized stream crossing design approaches for US west coast state and federal agencies.

State	Agency	Design Approach in Order of Preference	Source
CA	Caltrans	(1) Bridge; (2) stream simulation; (3) active channel/low-slope culvert; (4) hydraulic design (new hydraulic designs are not allowed in anadromous salmonid spawning habitat); (5) retrofit existing culvert	Caltrans, 2007
	CDFW	(1) Bridge; (2) stream simulation; (3) low-slope culvert; (4) hydraulic design	CDFG, 2009
OR	ODFW	(1) Bridge; (2) streambed simulation with open or closed bottom structures. Dept may approve alternate structures with justification and hydraulic analysis showing structure meets fish passage criteria	ODFW, 2020
WA	WDFW	(1) Bridge; (2) no slope culverts, only for simple installations on low-gradient streams and bankfull width less than 10 feet; (3) stream simulation, applicable for complex installation at any stream gradient.	Barnard et al., 2013
Federal			
	NMFS	(1) Road abandonment (2) bridge; (3) stream simulation; (4) hydraulic design (0 to 1% slope); (5) baffled culvert or fishway structure – for steeper slopes	NOAA, 2001
	USFS	(1) Span valley with bridge or viaduct; (2) stream simulation with floodplain connectivity; (3) stream simulation; (4) hydraulic design for fish passage; (5) hydraulic design for flood capacity	USFS, 2008
	FHWA	(0) No impedance, (1) geomorphic simulation, category 1; (2) hydraulic simulation, category 2; (3) hydraulic design, category 3	Kilgore et al., 2010

Designing all full-span crossings based on a reference reach may not be appropriate at all locations due to site specific constraints. For example, some full-span crossings require channel grade control to protect upstream infrastructure and habitat from channel incision (Castro & Beavers, 2016). In situations where stream simulation designs are not possible, a stable crossing bed, typically constructed of immobile rock in the form of a geomorphically-based roughened channel or boulder weirs, is preferred for passage of fish and other aquatic organisms and conveyance of debris and sediment. Designs with these features have been adopted by the Federal Highways Administration (FHWA) among others and are described in their HEC-26 design manual, *Culvert Design for Aquatic Organism Passage* (Kilgore et al., 2010).

The main challenge faced by full-span stream crossing projects is the initial capital cost because the crossings span a larger width and require extra design features, like deep foundations. A 2012 assessment comparing life-cycle costs of fish- and wildlife-friendly crossings to conventional designs was conducted by CTC and Associates for Caltrans (CTC and Associates, 2012). At that time, no formal data or analysis was available but many agencies surveyed reported qualitative evidence that the higher initial cost of wider span culverts were offset by reduced maintenance and stream protection costs. Several studies have been completed since that time. A Wisconsin study, discussed below, completed a fiscal and social cost-benefit analysis. A study in Vermont following Hurricane Irene assessed performance under extreme hydrologic conditions and is discussed in a later section (*Flood Flow and Debris Passage*).

Benefits of Full Span Crossings

Full-span crossings are often implemented to achieve multiple design objectives including fish and other aquatic organism passage (AOP); continuity of natural hydraulics; effective transport of flood flows, sediment and debris; habitat continuity and improved water quality. Each of these possible benefits and literature evaluating the performance of FSCs for these objectives is summarized below.

Fish and Animal Passage at Stream Crossings

The primary driver of most stream crossing replacements or modifications for organisms has been maintaining or restoring passage for threatened or endangered fish species. However, many crossing designs that benefit fish will also improve movement opportunities for other aquatic and many terrestrial animals. Stream and riparian corridors are important movement pathways and provide connectivity for many species (e.g.: Beier, 2012; CTC & Associates, 2017; Peterson & McAllister, 2014; Ward et al., 2008; USFS, 2008). One of the primary differences between FSCs and standard stream crossing designs is the crossing width. Crossing widths smaller than the natural channel width tend to create unfavorable passage conditions, including (USFS, 2008; CDFG 2009):

- constriction of flow resulting in high inlet velocities;
- localized scour that creates perched outlets, forming leap barriers;
- lack of diverse stream bed substrate or roughened surfaces in the crossing, thus producing shallow depths and higher velocities over a greater range of flow than the natural channel;
- addition of hydraulic elements (e.g., baffles or weirs) to dissipate energy that create excess turbulence or leap heights that block passage
- accumulation of debris lodged across the crossing inlet and block aquatic organism passage

- slowing approaching flow that causes in-channel deposition, resulting in bank erosion and shallow flow conditions upstream of the crossing

The conditions listed above can create total barriers to fish migration within streams leading to the extirpation of a species upstream of the crossing. They may also create partial barriers that can lead to a reduction or alteration in the species diversity or composition. If a crossing presents a partial barrier, some fish may eventually succeed in passing though the crossing but adult fish could expend excess energy that may result in their death prior to spawning or reductions in the viability of eggs and offspring. Migrating fish concentrated in pools and stream reaches below stream crossings are also more vulnerable to predation by a variety of avian and mammalian species, as well as poaching by humans (USFS, 2008).

Instream movements of juvenile and non-anadromous salmonids are highly variable and still poorly understood. Limiting these fish to shorter or isolated stream reaches may increase competition for food and shelter; cut off over-wintering habitat in tributaries; increase predation in pools; or prevent summer migration from thermally-stressed mainstem channels to cool-water refugia in smaller tributaries. Juvenile coho salmon spend approximately one year in freshwater before migrating to the ocean, and juvenile steelhead may rear in freshwater for up to four years before out-migration; one to two years is common in California (Sandercock, 1991). Because much of their life history is spent in freshwater, juveniles of both species are highly dependent on instream habitat. Juvenile salmonids may migrate upstream to find more suitable overwintering habitat, away from higher flows and potentially higher turbidity levels found in mainstem channels (Skeesick 1970; Cederholm and Scarlett 1981; Tschaplinski and Hartman 1983; Scarlett and Cederholm 1984; Sandercock 1991; Nickelson et al. 1992). During summer months in western Washington State, juvenile salmonids that moved upstream grew faster than both non-moving and downstream moving juveniles, demonstrating that this behavior may play an important role in the overall health of the population (Kahler and Quinn 1998).

Mitigating these conditions to facilitate fish passage is a major reason for implementing full-span stream crossings. Crossings that do not restrict the cross-sectional area of flow at smaller discharges than design floods, such as the 2-year return period discharge and lower, can maintain water depths and velocities that are similar to those in the adjacent natural channel assuming that channel slopes and substrate sizes are similar. Most fish and other aquatic organism volitional movements occur predominately during flows below the 2-year return period discharge. The movement of organisms is important for the mixing of traits in the species' gene pool, making regional populations more resistant to local habitat or population losses (USFS 2008). Full span structures with banklines exposed at lower flows are known to provide passage corridors for both semi-aquatic and terrestrial species and monitoring FSCs for non-fish passage is now part of Caltrans' assessment of full span crossing performance (Caltrans, 2020; Molinar & Walth, 2020).

Flood Flow and Debris Passage

The ability to pass flood flows and debris without damage can significantly extend the design life of road-stream crossings. A 2017 Transportation Research Board Webinar on *Fundamentals of Resilient and Sustainable Buried Structures* identified road-stream crossings designed to pass the 100-year return period flood flow and spanning the full stream width as resilient structures (TRB, 2017). Resiliency is broadly described as the ability to recover and can specifically be applied to stream crossings as the ability to withstand extreme events. Full-span crossings have been documented to withstand extreme events when compared to smaller spans. Gillespie et al. (2014) compared the performance of stream simulation culverts in the upper White River in the Green Mountain National Forest (GMNF) of Vermont to crossings in nearby municipalities following

Hurricane Irene in August 2011. The flooding caused in this region by Hurricane Irene was estimated to be a 500-year event. The GMNF stream simulation culverts sustained no damage compared to over 70 crossings damaged or completely lost in the five adjacent towns. Stream crossings within the GMNF with widths less than the stream bankfull width did experience significant damage (Gillespie et al., 2014).

Current fish passage guidance generally includes conveying the 100-year return period flow with the headwater depth not exceeding the crossing height (NOAA, 2001), but for many locations the water flow itself does not cause the majority of stream crossing failures. This is especially true in many Pacific Northwest and coastal California watersheds which have forested and steep topography. Debris and sediment carried by high flows can accumulate at crossing inlets and are often the driving force for crossing damage or failure at flows lower than the design flood flows (Cafferata et al., 2017). In the upper White River watershed, 70 percent of costs from the damage of GMNF stream crossings by Hurricane Irene conditions was estimated to have occurred because of debris plugging (Gillespie et al., 2014). Of the damaged stream crossings, three of four that failed were hydraulic designs with crossing width less than 52 percent of bankfull width (Gillespie et al., 2014). The added width of full-span stream crossings significantly improves passage of debris. Maintaining a stream crossing alignment nearly perpendicular to the stream channel's approach angle is also important to reduce the hazard of collecting woody debris at the stream crossing inlet (Caltrans, 2007). Dynamic channel beds and banks can also provide unimpeded passage of water and sediment during a greater variety of flow conditions (Gillespie et al., 2014). The resiliency of stream crossings is greatly enhanced if the crossing efficiently passes debris by reducing the forces placed on the structure and the potential for backwatering effects of increased water depths and erosive turbulence at the crossing inlet (Furniss et al., 1998).

Hydraulics and Sediment Transport

Even at flows much lower than flood flows, the transition conditions from the natural channel into and out of the crossing can be an important design consideration for conveying delivered flow and sediment. Hydraulic capacity has historically guided stream crossing design, but more recently stream crossing design analysis has grown to include in-channel hydraulics, sediment transport and understanding the geomorphic setting (USFS, 2008; Barnard et al., 2013). Full-span crossings focus on hydraulics in terms of water depth and velocity, while also addressing concerns about scour and destabilization. Subsets of full-span designs, like stream simulation, rely on the duplication within the crossing of adjacent natural channel reach geometry, substrate, and bedforms to create similar hydraulics and sediment transport characteristics. Specific to stream simulation full-span crossings, the bed material within the crossing that may be mobilized and transported during flood events is expected to be replenished by sediment transport from upstream (Barnard et al., 2013; USFS, 2008). Other full-span designs attempt to place controls on the hydraulics, by manipulating geometry and substrate to create diverse hydraulic conditions similar to natural channels. In this way, even crossings without substrate can be full-span designs, that provide additional hydraulic performance and maintenance benefits (Furniss et al., 1998; TRB, 2017).

Direct observations of streams can provide insight into channel hydraulics and sediment transport. Differences in sediment particle size distribution on the bed are assumed to indicate differences in hydraulic conditions. Timm et al. (2017) observed that stream simulation crossings transported sediment downstream more effectively than other fish passage designs. These observations were in low gradient systems that could be influenced by slight variations in bed slope. Barnard et al. (2015) observed that sediment size and gradation were similar between stream simulation culverts and reference reaches in Washington State indicating that both locations experienced similar hydraulic and sediment transport characteristics. The average channel velocities modeled at the 2-year return period flow, approximately bankfull flow, were also found to be comparable in the stream simulation culvert and the reference reach.

Some full-span crossings require channel grade control, steepening the channel in and around the crossing in comparison to the adjacent channel, to protect upstream infrastructure and habitat from channel incision (Castro & Beavers, 2016). In this case, a stable crossing bed, typically constructed of immobile rock in the form of a geomorphically-based roughened channel or boulder weirs, is preferred for passage of fish and aquatic organisms and conveyance of debris and sediment (Kilgore et al., 2010; USFS, 2008).

Fiscal and Social Benefits

An analysis of 495 culverts in the Green Bay tributaries of Wisconsin by Christiansen et al. (2014) evaluated the cost-benefit relationship of replacing a conventional culvert with a stream simulation design. On average, a net negative fiscal benefit of $4,500 and net positive social benefit of $7,800 was found for installation of a stream simulation crossing. Approximately 44 percent of crossing replacements yielded net positive fiscal benefits and 77 percent yielded net positive social benefits (Christiansen et al., 2014). Additionally, the cost of replacing a crossing that is a barrier to fish passage often exceeds the higher initial cost of installing a full-span stream crossing that meets all fish passage criteria (Barnard et al., 2013). Thus, if a crossing requires or may require modification or replacement to ensure fish passage, then it is worth the higher initial cost to install a more robust structure that provides additional benefits and longer design life.

Climate Change

The projected changes in overall precipitation in California due to climate change are uncertain, with some studies predicting an increase (Duffy et al., 2006; Kim, 2005; Maurer, 2007; Mote & Salathé, 2010; Pierce et al., 2013) and some a decrease (Cayan et al., 2008; Hayhoe et al., 2004). The uncertainty comes from complex topography and the location of California between mid-to-high latitude regions where increases in overall precipitation are expected and subtropic regions where decreases in precipitation are expected (Neelin et al., 2013). The conclusion agreed upon about California precipitation patterns into the future, is that California will experience more extreme seasonal variation in precipitation, with wetter winter months and drier spring and summer months (Cayan et al., 2008; Gershunov et al., 2019; Kim, 2005; Mote & Salathé, 2010; Pierce et al., 2013). Thus, designing and implementing new stream crossings that maximize resiliency to increasingly larger flow events will be important.

Atmospheric rivers will play a significant role in the increase and intensification of extreme precipitation events. An atmospheric river is a long, narrow band of moist air moving through the atmosphere and those experienced in the U.S. typically form over the northern Pacific Ocean (NOAA, 2020). Atmospheric rivers deliver intense bursts of water vapor along the West Coast: roughly 30 to 50% of annual precipitation in west coast states is delivered in a few atmospheric river events per year (NOAA, 2020). A study by Gershunov et al. (2019) tested sixteen global climate models for accuracy in modeling historic atmospheric river behavior and the contribution of daily precipitation events to annual precipitation in Western North America. The five most accurate models produced consistent changes in future behavior of atmospheric rivers, showing reliability in predictions for the Western North America region. The model projections predict increasing year-to-year variability in annual precipitation, particularly over California, where predictions of change in annual precipitation are uncertain. The study found that in three representative river basins along the West Coast, increases in extreme precipitation events was predicted to be almost entirely an effect of atmospheric rivers (Gershunov et al., 2019). An additional study found that significant precipitation increases along the California coast are associated with an eastward extension of the region impacted by the Pacific jet stream, which forms atmospheric rivers (Neelin et al., 2013). A study by Dettinger (2011) using a seven-model ensemble predicted that extremes in atmospheric rivers change significantly, while average statistics do not. The number of years with many atmospheric river events increase (but average number of atmospheric river storms per year remains about the same), the maximum storm intensities of atmospheric rivers increase (but average intensity remains about the same), and atmospheric river storm temperatures increase. Additionally, the peak season for atmospheric river events is projected to lengthen. The patterns found in this study identify the potential for more frequent and more intense extreme flow events in California under projected climate change (Dettinger, 2011). A study by Ralph et al. (2013) of California's Russian River predicted that atmospheric river storms combined with high antecedent soil moisture conditions produce up to six times greater peak streamflow and more than seven times the storm-total runoff. The study highlights the importance of monitoring for both atmospheric river and pre-storm soil moisture conditions in forecasting streamflows and runoff (Ralph et al., 2013).

With the potential for extreme events to occur more often than their current recurrence interval might suggest, stream crossing designs may need to be increasingly 'oversized' to improve their resiliency. In terms of full-span crossings, oversized would mean designs based on a wider bankfull width and greater flow rates. Washington State Department of Fish and Wildlife recently evaluated the possible changes in bankfull stream widths given projected changes to stream flow during two time periods, 2030-2059 and 2070-2099 (Wilhere et al., 2016). It was found that about 80% of the area studied is projected to experience an increase in discharge at recurrence intervals of 1-2 years over both time periods. The magnitude of the 1–2-year interval flow is considered to be the primary geomorphic control for shaping the bankfull channel. Thus, an increase of the magnitude of these flows would be expected to increase bankfull channel widths over time. This study recommended using channel evolution and climate projection models to estimate projected bankfull and 100-year flows over a crossing's complete design life. This information could then be used to conduct a cost-benefit analysis of designing crossings to accommodate the bankfull width for current versus future projected flows (Wilhere et al., 2016). This study did not address other possible geomorphic responses to increasing flow magnitude or frequency such as incision or sediment transport rates.

Design of Fish Passage Crossings

The design process for stream crossings differs with the design approach and the site location. As described above, fish passage crossing designs are typically classified as either geomorphic or hydraulic designs, and each requires a different design approach. Geomorphic designs are intended to create hydraulic and habitat conditions through the crossing matching those of the adjacent stream channel or a nearby reference reach. Hydraulic designs are those that meet hydraulic criteria needed for passage of the target fish species and life-stages. Full-span stream crossings can incorporate elements of both design types depending on the site conditions and constraints. Most full-span stream crossings will have geomorphic design features, such as a natural streambed substrate bottom. However, some FSC designs may also require structural elements to maintain a stable streambed and steeper channel gradient to provide for fish passage while limiting the migration of channel incision and protecting upstream property and infrastructure. The following section summarizes the literature describing the design process for each of these design types beginning with the standard design features and their criteria, and presents methods and tools used in the design process.

Geomorphic Site Assessments

Design of stream crossings for fish and aquatic organism passage (AOP), whether for a FSC or partial span crossing, requires a thorough understanding of the stream channel's geomorphic stability, stream type, and channel dimensions. Characterizing the stream channel should occur at the beginning of the project, as the findings guide the selection of the design approach and crossing size and layout (CDFG, 2009; USFS, 2008)

An important consideration is the channel's history of incision and its stage within the channel evolution model (CEM), as described by Schumm et al. (1984). If the channel downstream of the crossing is geomorphically unstable and may continue to incise or widen, this may limit the design approach used for the crossing. If the existing crossing structure is serving as a knickpoint, preventing the incision from migrating upstream, the project may require construction through the crossing of an immobile streambed steeper than the natural channel slope to connect the upstream and downstream channel while preventing incision from migrating upstream (Castro & Beavers, 2016). Other geomorphic considerations include understanding the proportion of flow conveyed on the floodplain, and the potential for lateral migration of the stream in the project reach.

The USFS (2008) provides a comprehensive guide to conducting the field assessments and data analysis for design of stream crossings. Through the site assessment process, the channel profile is analyzed to determine the features in the natural channel controlling the profile (i.e., wood and roots, planform forced rifles and pools, bedrock), the local scour depths associated with controlling features, the appropriate design slope through the crossing, and the range in elevations the channel bed may aggrade or degrade through the service life of the crossing. The latter is referred to as the vertical adjustment potential (VAP) of the channel bed (USFS, 2008). Among other things, the low VAP estimate is used in setting the bottom elevation of a culvert or the bottom of a culvert or bridge foundation. The high VAP is used to check that the crossing has adequate hydraulic capacity in the event that the channel aggrades to this elevation. The findings from the field assessments will then help guide the selection of the design approach.

If selecting the stream simulation design approach, it requires identifying and characterizing a reference reach upstream or downstream of the project that is used as a template for design of the crossing structure and the channel built within it (USFS, 2008). The reference reach should generally have a slope similar to the design slope in the project reach. The reference reach channel type is often characterized based on Montgomery & Buffington (1993) which focuses on classifying bed morphology and channel forcing features. The measured reference reach channel dimensions, streambed morphology, and forcing features are documented in the field for use in design development.

For projects intending to use a FSC but where the stream simulation approach is not appropriate, a geomorphic site assessment is still required to determine the channel dimensions that ensure the crossing structure spans the bankfull channel width. Regardless of the crossing type, FSC or partial-span crossing, a geomorphic site assessment is needed to establish the low and high VAP to ensure that the transition from the project to the downstream channel reach remains suitable for fish passage and that the crossing will provide adequate hydraulic capacity across all of the potential streambed elevations (CDFG, 2009).

Stream Crossing Design

Many state and federal agencies have developed detailed design guidance and methods to ensure their road-stream crossings meet fish and aquatic organism passage (AOP) requirements. In California, design of stream crossings for fish passage must meet California Department of Fish and Wildlife (CDFW) and NOAA's National Marine Fisheries Service (NMFS) performance criteria (CDFG, 2002; NMFS 2001). Along the Pacific coast, NMFS is an important regulatory agency due to the presence of anadromous species and has typically worked with state agencies to develop design guidelines that align with NFMS criteria. NMFS criteria are specific to passage of anadromous fish species, whereas CDFW criteria are broader, applying to all aquatic species. Caltrans' design manual, *Fish Passage Design for Road Crossings*, was developed to meet CDFW and NMFS criteria (Caltrans, 2007). In addition to the Caltrans design manual, CDFW has also developed crossing design and assessment guidance as part of their *California Salmonid Stream Habitat Restoration Manual* (CDFG, 2010). Design of fish passage crossings is in *Part XII - Fish Passage Design and Implementation* (CDFG, 2009).

Other state DOTs with conditions and criteria most similar and applicable to California are Oregon and Washington because of their similar stream characteristics, hydrology and species of concern. Oregon does not have a detailed design manual but the Washington Department of Fish and Wildlife (WDFW) was one of the first states to publish a comprehensive fish passage design manual and has been a leader in design of full span and stream simulation crossings. WDFW's current design manual is the 3rd edition, *Water Crossing Design Guidelines*, published in 2013 (Barnard, et al., 2013). Also relevant in California are those guidelines developed by the FHWA and the USFS. Other state DOTs have also developed detailed fish passage design guidelines but they are not included here because of their different setting or because their design guidance documents are based directly on those that are summarized here (e.g., Hernick et al., 2019; MDOT, 2016; Bates & Kirn, 2009; University of New Hampshire, 2009). Table 2 lists the current versions of the relevant state and federal design documents and highlights their importance or unique content.

In all of these design guidance documents, full span solutions are the primary approach but the definitions and criteria for a full span design vary. The minimum design standard for a full-span stream crossing is a crossing width greater than or equal to bankfull width. Many guidelines also include a factor of safety, such as the crossing width must be 1.2 times the bankfull width. The full-span crossing designs range from width criteria of 1 to 1.25 times the bankfull width or some function of the active channel width, as defined below. Table 3 summarizes the various crossing width criteria. Some design criteria also include limits on the crossing slope, the stream channel slope where a particular design type can be considered, or the crossing length; these are also noted in Table 3.

Full-span designs rely on an accurate measurement of bankfull width and there are multiple sources to guide measuring bankfull width (e.g., Harrelson et al., 1994; USFS, 2008; CDFG, 2010; Barnard, et al., 2013). Bankfull width, as defined by CDFW, is the width when the "*channel flows full and a further increase in depth results in a rapid increase in width as flow spreads across the floodplain*." In Barnard et al. (2013), bankfull width is the "*stage when water just begins to overflow into the active floodplain*" or for streams with no floodplain, "*it is the width of a stream or river at the dominant channel forming flow with a recurrence interval in the 1-to-2-year range*."

Some designs reference the 'active channel width', or the "*portion of channel receiving sufficient and frequent enough flows to maintain cleanly scoured substrate*", which is different, and generally narrower, than bankfull width in most cases (CDFG, 2009). Active channel width for Washington design guidelines, is defined as the "*geomorphic expression describing a stream's recent discharges*" that have been actively working on the channel, and are often identified by slope changes along the stream banks or changes in vegetation (Barnard et al., 2013).

In addition to the width criteria, full-span stream crossings are generally required to provide hydraulic capacity and passage of debris during the 100-year recurrence interval design flow without submerging the culvert inlet soffit or lower bridge cord. To accommodate the passage of debris, USFS (2008) recommends a maximum headwater depth at the 100-year flow no greater than 80% the height from the channel bed to the culvert soffit or low bride cord. This headwater depth design criteria allows sufficient space between the soffit and the 100-year flood water level to accommodate both flow of water and debris (Gillespie et al. 2014). Despite differences in state and agency design guidelines, the general consensus is that guidelines are presented not as a strict step-by-step design procedure but rather as a guide for identifying a solution that addresses each stream crossing location's unique characteristics (e.g., Barnard et al., 2013; Bates & Kirn, 2009; University of New Hampshire, 2009).

Crossing Streambed Design

There are two design concepts for sizing streambed material: designing for a mobile bed that is replenished by sediment transport from upstream or designing for a stable bed by sizing bed material to resist transport (Caltrans, 2007; Kilgore et al., 2010; CDFG, 2009). Mobile bed design relies on similarity with a nearby reference reach and immobile bed design follows the design approach for roughened channels. Table 4 lists the general design criteria for the crossing substrate associated with the different crossing design approaches described by state and federal agencies.

Mobile Streambed Design

Naturally occurring streambed mobility generally changes with channel type (Caltrans, 2007), so it is helpful to study a reference reach when designing for streambed mobility. The substrate for the stream crossing bed material can be made from a combination of grain sizes to produce an equivalent substrate to a reference reach streambed. Alluvial (mobile) elements should be designed to mimic the reference reach. If the reference reach streambed material is relatively mobile and transported during a bankfull flow event, then the streambed material in the culvert will be mobile during the same flow event and replenished from material delivered from upstream. Sediment entrainment calculations (unit discharge, average shear stress, or critical velocity) at incipient motion and up to bankfull flows of the crossing and of the reference channel should have similar results (Caltrans, 2007). The Bathurst Critical Unit Discharge and Modified Shields methods are recommended by U.S. Forest Service and CDFW to compare sediment transport competency (Caltrans, 2007; CDFG, 2009; Kilgore et al., 2010; USFS, 2008). These methods are used to check that the bed material in the crossing mobilizes at a similar flow as in the reference reach, and not at lower flow.

Colluvium, and key instream pieces (e.g., large rock or wood) found in the reference reach and simulated in the crossing are considered more permanent and generally designed to be immobile. Additionally, streambanks are often constructed in crossings to mimic the bank roughness and confinement found in the reference reach. These banks are typically constructed of a rock mixture sized to be immobile (USFS, 2008). In reference reaches with steeper channel types, such as natural boulder step-pool channels, the bed material only mobilizes during extreme flood events (Chin, 1998), To simulate these channel types, the bed material is sized and arranged through the crossing to be immobile up to an extreme flood event, sometimes referred to as the stable bed design flow (CDFG, 2009).

Immobile Streambed Design

The streambed within a crossing is generally designed to be immobile when:

1) the reference reach bed type is only mobilized during extreme flood events substantially greater than the channel’s bankfull flow (step-pool and cascade channel types),

2) the crossing structure is narrower than the bankfull channel such that natural streambed substrate would be mobile at lower flows in the crossing than in the upstream channel, and therefore sediment transported from upstream would not deposit in the crossing, and

3) the streambed is over steepened through the crossing compared to the reference reach, and serving as permanent grade control.

In these cases, the channel substrate is designed to be immobile, and is often referred to as engineered streambed material (ESM) (CDFG, 2008). The ESM typically consists of larger structure rock sized to remain stable at the stable bed design flow and smaller material, including fines, to fill the voids between the larger rock and control the bed porosity. Besides specifying an ESM mixture, the bed morphology and arrangement of the larger structure rock is designed to mimic either the naturally steep reference reach (if applicable) or the morphology of a natural steep stream (CDFG, 2009). Barnard, et al. (2013) and CDFG (2009) refer to these immobile channel designs as roughened channels and provide design procedures. HEC-26 (Kilgore et al., 2010) also uses a similar approach for design of immobile stream beds within culvert crossings. With the exception of mimicing an existing reference reach adajcent to the crossing, these channel types are considered hydraulic designs. These designs require hydraulic analysis showing that at fish passage flows the constructed channel hydraulics meet the swimming and leaping criteria of the target fish species and age class.

Table 2. Design guidance documents most relevant to fish and aquatic organism passage at Caltrans road-stream crossings.

Agency	Design Guidance Document Title	Description
Caltrans	Fish Passage Design for Road Crossings (Caltrans, 2007)	Developed to meet CDFW and NMFS fish passage criteria while conforming to Caltrans design practices.
CDFW	California Salmonid Stream Habitat Restoration Manual. Part XII - Fish Passage Design and Implementation (CDFG, 2009)	State of California design guidance for fish and aquatic organism passage.
WDFW	Water Crossing Design Guidelines (Barnard, et al., 2013)	3rd edition of Washington state's crossing design guidance which served as a model for comprehensive design guidance documents prepared by other state and federal agencies.
FHWA	HEC-26: Culvert Design for Aquatic Organism Passage, First Edition. (Kilgore et al., 2010)	This document presents a geomorphic simulation design procedure focused on stable bed designs the FHWA deems more applicable and less risky for providing AOP at crossings on state and federal highways.
	HDS 5: Hydraulic Design of Highway Culverts, 3rd Edition (Schall et al., 2012)	A compilation of culvert design standards, software and other tools for culvert design, culvert assessment, and culvert repair and rehabilitation.
	HDS 7: Hydraulic Design of Safe Bridges (Zevenbergen et al., 2012)	A comprehensive and detailed guidance for designing and assessing bridges. The manual presents procedures for bridge hydraulic analysis, unsteady flow analysis, and analysis of scour countermeasures.
USFS	Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings (USFS, Stream Simulation: An Ecological Approach To Providing Passage for Aquatic Organisms at Road-Stream Crossings, 2008)	The most detailed guidance on the design and implementation of stream simulation crossings for aquatic organism passage (AOP).

Table 3. Summary of relevant agency criteria for minimum crossing span and crossing slope and length limitations.

State	Agency	Design Type	Crossing Width Criteria	Crossing Slope Criteria	Stream Channel Slope Limitation	Crossing Length Criteria
CA	Caltrans	Active channel (NMFS)	1.5x active channel width	0% (flat)	3% or less	<= 100 ft
		Low slope (CDFW)	1.25x bankfull width	natural channel slope	1% or less	<= 75 ft
		Stream simulation	> bankfull width; 6 ft minimum	similar to reference reach	up to 6%, in some cases higher	------
	CDFW	Stream simulation	>= bankfull width; 6 ft minimum	appx the stream slope, < 6%	up to 6%	------
		Low slope	1.25x bankfull width	natural channel slope	1% or less	<= 75 ft
WA	WDFW	No slope culvert	1.25x active channel bed width	0% (flat)	3% or less	Culvert slope x Culvert length<= 20% of diameter
		Stream simulation	1.25X bankfull width + 2 ft (most suitable for BFW of 10-15 ft)	<+/-1.25x upstream channel slope	all slopes	Length to span ratio of <= 10
Federal	USFS	Stream simulation	>= bankfull width in the reference reach	Within 25% of reference reach slope	If >6%, design for stable or retained bed materials	
	FWHA	Hydraulic	>= active channel width	No specifications, relies on hydraulic modeling to confirm immobile bed material and suitable fish passage hydraulics		

Table 4. Bed material design criteria.

State	Agency	Design Type Name	Crossing Substrate Material	Crossing Embedment
CA	Caltrans	Active channel (NMFS)	natural recruitment	max 40% of culvert height at inlet and 20-40% at culvert outlet
		Low slope (CDFW)	natural recruitment (L<50 ft) or backfill w/ native (L: 50-75 ft)	20-40% throughout culvert
		Stream simulation	similar to reference reach	below low vertical adjustment potential (VAP) of the channel bed
	CDFW	Stream simulation	if slope is >3%, the bed inside the culvert is to be arranged in a series of step-pools with the drop at each step not exceeding the max drop at culvert outlet (Table 7 in CDFG 2009).	30-50% of the culvert height (NA with bottomless culverts)
		Low slope	natural recruitment (L<50 ft) or backfill w/ native (L 50-75 ft)	20-40% of culvert height
OR	ODFW	Streambed simulation	*	*
		Non-embedded culvert	*	*
WA	WDFW	No slope culvert	similar bed to adjacent stream reach	20-40% throughout culvert
		Stream simulation	similar bed to adjacent stream reach, or if wood/roots dominate the upstream slope then a more stable bed material may be required	30-50% throughout culvert (n/a if open bottom)
Federal	USFS	Stream simulation	similar bed to adjacent stream reach	min 2xD_{90} below lower vertical adjustment potential (VAP) of the channel bed
	FHWA	Hydraulic	designed to remain stable at design flood peak	min 20% for box and pipe-arch, 30% for circular and elliptical, 2 ft min

**Oregon design criteria are created on a case-by-case basis with input from Oregon's Dept. of Fish and Wildlife. General guidelines and criteria for stream-road crossings can be found through the Oregon Dept. of Fish and Wildlife.*

Design Analysis Software and Supplemental Tools

Numerous modeling and analysis tools are necessary during design for analyzing the hydraulics, sediment transport, resilience, and fish passage at stream crossings. For many conditions, standard design procedures and workflow are well defined, but site characteristics are often unique so additional analysis will often be required. The design/analysis process is also often iterative, alternating between design and analysis, before the design is finalized. This section describes the common tools used for analysis and design for all sites as well as supplemental tools that can assist in intermediary calculations needed for design. For both the necessary and supplemental design tools, this section describes their application and limitations.

Hydraulic Modeling Software

Hydraulic models are commonly used to analyze the hydraulics and flood capacity of road-stream crossing designs. Most of the available models are also capable of evaluating scour and sediment transport. The most common software packages used for this application are HEC-RAS 1D and 2D, and SRH-2D (Brunner & CEIWR-HEC, 2020; Lai, 2008). Use of SRH-2D within Aquaveo's Surface-water Modeling System (SMS) graphical user interface (GUI) by departments of transportation (DOTs) is encouraged and supported by FHWA, especially for use at crossings where aquatic organism passage is required.

One-dimensional models simulate hydraulics in the longitudinal direction, the principal direction of flow. The simulated velocity and depths are the average values over the entire channel cross-section. One-dimensional models have simpler inputs, are more computationally efficient and until recently have been the standard for design and analysis. One dimensional models provide good estimates of water depths for a given discharge but cannot provide detailed analysis of complex flow patterns such as areas of concentrated or split flow and eddies.

Two-dimensional models simulate depth and velocity in the longitudinal and transverse directions, while assuming a depth-averaged velocity in the vertical direction. The additional hydraulic detail provided by a 2D model is important for conditions such as multi-opening crossings, flow around bridge piers and footings, flow across floodplains and around bridge approaches, flow around channel bends or islands, braided channels, and skewed crossings. Two dimensional models are also capable of providing detailed analysis of the hydraulic conditions at fish passage flows. This capability is important in the design of streambeds and selection and placement of forcing rocks because the effect of different rock size and placement can be iteratively evaluated in the design process.

Research comparing 1-D and 2-D hydraulic models has found that there remains a place for analysis using 1-D hydraulic models because of their significantly shorter computer run times (Deal et al., 2017). One-dimensional modeling can also provide adequate analysis for sites where transverse flow characteristics are negligible, but greater understanding of flow patterns can be obtained by 2D hydraulic modeling. Use of 1D models to conduct preliminary site analyses and to develop 2D hydraulic models for final designs is also common.

All hydraulic models require high quality input data including topography/bathymetry data (survey, LiDAR or raster DEM) and associated coordinate system, hydraulic roughness data, boundary conditions, and flow data (Brunner & CEIWR-HEC, 2020). Depending on the specified boundary conditions, discharge or water surface elevation must be inputted for the boundaries as either a constant, time series, or rating curve (Lai 2008). Water surface elevation is required at exit boundaries if the flow is subcritical. For sediment transport analysis, additional data is required: bed surface and subsurface particle size distribution, sediment transport data for suspended and bed loads over a range of flows, floodplain surface characterization, and erodibility of floodplain surfaces.

HEC-RAS 1D and 2D

HEC-RAS, the Hydrologic Engineering Center-River Analysis System, was developed and is maintained by the Institute for Water Resources of the U.S. Army Corps of Engineers. This software is free and one of the most common hydraulic modeling tools for these applications. The current version of the software is version 6+ with initial releases in 2020. HEC-RAS can simulate steady or unsteady flow hydraulics in one- and two-dimensions. The software also includes options for analyzing bed mobility/sediment transport, water temperature, and contaminant transport.

HEC-RAS can simulate channel networks, dendritic systems, or single reaches under subcritical, supercritical, and mixed flow regimes. The effects of infrastructure, channel modification and other obstructions such as bridges, culverts, diversions and tide gates can be accounted for in the simulations (Brunner & CEIWR-HEC, 2020). Steady flow analysis is used to calculate the water surface profiles and hydraulic conditions for various design flows of interest (e.g., flood flow, fish passage flows). Unsteady flow analysis can simulate one-dimensional and two-dimensional unsteady flow through channel networks by routing user specified hydrographs through the defined channel system (Brunner & CEIWR-HEC, 2020).

HEC-RAS can also be used to analyze sediment transport and channel bed evolution through scour and deposition. This capability was originally limited to HEC-RAS 1D but with Version 6.+ is now also available for 2D analysis. Sediment transport and mobile bed analysis use bed grain size fraction and sediment loading entering the reach to simulate scour and deposition as well as hydraulic sorting and armoring. HEC-RAS is designed to simulate long-term trends for scour and deposition within the stream channel that might result from changes in the frequency and duration of flow, sediment load or modifying the channel geometry (Brunner & CEIWR-HEC, 2020).

For many design applications, both the one-dimensional and two-dimensional versions of HEC-RAS are used. One-dimensional simulations are initially developed to aid in calibrating the 2D analysis and the results are used to identify locations where 2D hydraulics are important such as flow concentration along outer channel bends and around structures. Moving from a 1D to a 2D hydraulic analysis is especially important for regions of rapidly changing flow direction, detailed channel and floodplain simulations and analysis of structures. HEC-RAS 2D is developing rapidly with new features added each release. Currently, it can simulate structures such as bridges in 2D and culverts by patching a 1D solution into a 2D analysis using the structures analysis algorithms available in and developed for HEC-RAS 1D. Both versions of HEC-RAS also allow scour calculations through bridges and around other structures if this option is selected.

SRH-2D

SRH-2D (Sedimentation and River Hydraulics – 2D River Flow Modeling) is a hydraulic model developed by the U.S. Bureau of Reclamation’s Dr. Yong Lai. The software solves two-dimensional depth-averaged dynamic wave equations (the St. Venant equations) using a finite-volume numerical method over a flexible mesh (Lai, 2008). Third-party graphical user interfaces (GUI), such as Aquaveo’s SMS, allow for further visualization of the outputs of the model. SRH-2D is useful for designs with significant lateral effects, such as in-stream structures, skewed alignments, channel bends, multiple channels, and complex floodplains. FHWA is working with Aquaveo to integrate FHWA hydraulic analyses into SRH-2D within SMS and funds the use of this modeling platform and trainings by state DOTs.

SMS (Surface-water Modeling System) is a graphical user interface (GUI) that links SRH-2D to external hydraulic models, including HEC-RAS and to FHWA hydraulic analysis tools. The benefit of using SRH-2D with the SMS GUI is the ease of importing data and the data visualization and export capabilities for the model outputs. The software allows the user to import numerous file types: raster images, topography, elevation/bathymetry data, ArcGIS shapefiles, CAD files, and delimited text files and spreadsheets. For transportation projects, SRH-2D is often used in combination with the FHWA's design procedures and analysis tools for culverts (HDS 5 and HY-8) and bridges (HDS 7). SMS incorporates the FHWA's HY-8 culvert analysis software to couple the 1D culvert analysis into 2D simulations of the structure and adjacent channel, similar to HEC-RAS. For analysis of bridges, SRH-2D can simulate pressurized flow due to bridge deck inundation and has features to output hydraulic data needed for bridge scour analysis for direct use in the FHWA's Hydraulic Toolbox (described below).

Supplemental Design and Analysis Tools

In addition to 1-D and 2-D hydraulic modeling, a range of more specialized tools are often needed for crossing design. These supplemental tools are used to develop input parameters for the hydraulic models and provide more detailed analysis of different site characteristics such as detailed culvert barrel hydraulics, fish passage conditions or perform geomorphic analyses to inform understanding of channel stability. The tools discussed here include only those that are public domain and are commonly used by departments of transportation or other government agencies.

FHWA HY-8

The HY-8 Culvert Hydraulic Analysis program is FHWA's primary tool for 1D analysis of culvert hydraulics. This software is used to analyze culvert hydraulics based on the culvert geometry, size, and material for a particular crossing, using input data of design discharges, tailwater channel geometry, a roadway cross-section, and an embankment template (Schall et al., 2012). The current software version 7.60 (FHWA, 2019) calculates the headwater depth and a water surface profile through the culvert barrel for design discharges or other discharges of interest. Version 7.50 published in 2016 added calculators for designing culverts with immobile streambeds for aquatic organism passage following FHWA's design procedure as described in HEC-26 (Kilgore et al., 2010). This version also incorporated a calculator to correct the predicted 1D culvert average velocity to a 2D velocity variation across a cross section to account to for boundary layer effects that may produce areas of reduced velocities for fish passage. HY-8 is included in SMS software to model culverts and other pressure flow sections as 1D elements in SRH-2D.

FHWA Hydraulic Toolbox

FHWA Hydraulic Toolbox is a set of calculators that performs common hydrologic and hydraulic analyses and design computations. This toolbox includes rational method and overland flow hydrology, channel hydraulics and channel lining design, weirs, gutter flow, detention basins, bridge abutment and contraction scour, riprap selection and design, and culvert assessments (Bergendahl & Arneson, 2014). The FHWA Hydraulic Toolbox can save multiple different hydraulic calculations relevant for a given project together, analyze different design options, and create documentation as output to design reports. Several results and output options for SRH-2D are designed for direct input into the Hydraulic Toolbox to be used for additional analysis, such as bridge scour calculations, needed for a particular site design. The methods implemented in the Hydraulic Toolbox are kept current with FHWA design documents such as HEC-23: *Bridge Scour and Stream Instability Countermeasures* (FHWA 2009). The current software version is Version 5.0.

USFS FishXing

The U.S. Forest Service (USFS) FishXing software was developed to assist in assessing and designing culverts for fish passage (USFS, 2012). The current version (version 3) calculates 1D culvert hydraulics similar to HY-8 and includes a fish swimming performance database for a variety of species. The swimming capabilities of target fish species are compared to the culvert hydraulics at selected fish passage design flows to evaluate whether passage would be possible at the simulated flow. The output includes water surface profile and detailed water depths through the culvert, water velocities through the culvert barrel, and identifies the cause and location within the crossing that limits fish passage (USFS, 2012).

The FishXing software has been widely used as an assessment tool to identify fish passage barriers and to assist in prioritizing sites for replacement or modification (USFS, 2012). The FishXing software is recognized and recommended in many stream crossing design manuals (e.g., Barnard et al., 2013; Bates & Kirn, 2009; Caltrans, 2007; Hotchkiss & Frei, 2007; NMFS, 2001).

USFS Stream Channel Flow Resistance Coefficient Computation Tool

The USFS Stream Channel Flow Resistance Coefficient Computation Tool (hereafter referred to as ‘Resistance Coefficient Tool’) was developed by Steven Yochum for the USFS National Stream and Aquatic Ecology Center (2018). The resistance coefficient tool assists in selecting flow resistance coefficients for stream channels, such as the Manning’s roughness coefficient (n) and Darcy-Weisbach friction factor (f). The user inputs characteristics of bed and bank grain material, bedforms, streambank and cross-section variability, sinuosity, vegetation, large instream wood, and other obstructions. The software outputs multiple estimates of Manning’s n and Darcy-Weisbach f. Nine quantitative methods are applied within the software for redundancy (Yochum, 2018).

References

Barnard, R., Johnson, J., Brooks, P., Bates, K., Heiner, B., Klavas, J., . . . Powers, P. (2013). *Water Crossing Design Guidelines.* Olympia, WA: Washington Department of Fish and Wildlife. Retrieved from http://wdfw.wa.gov/hab/ahg/culverts.htm

Barnard, R., Yokers, S., Nagygyor, A., & Quinn, T. (2015). An Evaluation of the Stream Simulation Culvert Design Method in Washington State. *River Research and Applications* , 1376–1387.

Bates, K., & Kirn, R. (2009). *Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont.* Vermont Department of Fish and Wildlife.

Beier, P. (2012). Conceptualizing and Designing Corridors for Climate Change. *Ecological Restoration*, 312-319.

Bergendahl, B. S., & and Arneson, L. A. (2014). *FHWA Hydraulic Toolbox Version 4.2 Desktop Reference Guide.*

Brunner, G. C.-H. (2020). *HEC-RAS River Analysis System User's Manual Version 6.0 Beta.* Davus: US Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (HEC). Retrieved from https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_UsersManual.pdf

Cafferata, P., Donald Lindsay, D., Spittler, T., Wopat, M., Bundros, G., Flanagan, S., . . . Short, W. (2017). *Designing Watercourse Crossings for Passage of 100-Year Flood Flows, Wood, and Sediment (Updated 2017).* California Natural Resources Agency, Department of Forestry and Fire Protection. State of California.

Caltrans. (2007). *Fish Passage Design for Road Crossings.* California Department of Transportation.

Caltrans. (2020). *Caltrans Multi-Species Benefits*. Retrieved from https://www.arcgis.com/apps/MapSeries/index.html?appid=2e345c26f68741129c346eb7a1f4ef5c

Castro, J., & Beavers, A. (2016). Providing Aquatic Organism Passage in Vertically Unstable Streams. *Water, 8*(133), 20. Retrieved from https://doi.org/doi:10.3390/w8040133

Cayan, D. R., Maurer, E. P., Dettinger, M. D., Tyree, M., & Hayhoe, K. (2008). Climate Change Scenarios for the California Region. *Climatic Change, 87*, 21-42. Retrieved from https://doi.org/10.1007/s10584-007-9377-6

CDFG. (2002). *Culvert criteria for fish passage. Appendix IX-A in California Salmonid Stream Habitat Restoration Manual Vol II.* California Department of Fish and Game. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=22612&inline

CDFG. (2009). *California Salmonid Stream Habitat Restoration Manual. Part XII - Fish Passage Design and Implementation.* California Department of Fish and Game.

CDFG. (2010). *California Salmonid Stream Habitat Restoration Manual, 4th Edition.* State of California, The Resources Agency, California Department of Fish and Game, Wildlife and Fisheries Division. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=22610&inline

Cederholm, C. J., & Scarlett, W. J. (1981). Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. In B. E. L, & S. E. O, *Salmon and Trout Migratory Behavior Symposium.*

Chin, A. (1998). On the Stability of Step-Pool Mountain Streams. *Journal of Geology, 106*, 231-234.

Christiansen, C., Filer, A., L. M., O'Shaughnessy, E., Palmer, M., & Schwartz, T. (2014). *Cost-Benefit Analysis of Stream-Simulation Culverts.* Wisconsin Department of Natural Resources. Retrieved from https://lafollette.wisc.edu/images/publications/cba/2014-culvert.pdf

CTC and Associates, L. (2012). *Comparing Life Cycle Costs of Fish- and Wildlife-Friendly Culverts with Conventional Culvert Designs.* Sacramento, CA: Caltrans Division of Research and Innovation.

CTC and Associates, LLC. (2017). *Fish Passage Programs: Survey of Practice.* Sacramento, CA: Caltrans Division of Research, Innovation and System Information.

Deal, E. C., Parr, A. D., & & Young, C. B. (2017). *A Comparison Study of One- and Two-Dimensional Hydraulic Models for River Environments.* The University of Kansas: Kansas Department of Transportation KS-17-02.

Dettinger, M. (2011). Climate Change, Atmospheric Rivers, and Floods in California - A Multimodel Analysis of Storm Frequency and Magnitude Changes1: Climate Change, Atmospheric Rivers, and Floods in California - A Multimodel Analysis of Storm Frequency and Magnitude Changes. *Journal of the American Water Resources Association, 47*(3), 514-523. Retrieved from https://doi.org/10.1111/j.1752-1688.2011.00546.x

Duffy, P. A. (2006). Simulations of Present and Future Climates in the Western United States with Four Nested Regional Climate Models. *Journal of Climate, 19*(6), 873–895. Retrieved from https://doi.org/10.1175/JCLI3669.1

FHWA. (2009). *Hydraulic Engineering Circular Number 23, Volume II. Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance-Third Edition.* https://www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/09112.pdf: Publication No. FHWA-NHI-09-112.

FHWA. (2019). *HY-8 Version 7.60.* https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/.

Furniss, M., Ledwith, T., Love, M., McFadin, B., & Flanagan, S. (1998). *Response of Road-Stream Crossings to Large Flood Events in Washington, Oregon, and Northern California.* San Dimas, California: USFS San Dimas Technology and Development Center.

Gershunov, A., Shulgina, T., Clemesha, R. E., Guirguis, K., Pierce, D. W., Dettinger, M. D., . . . Ralph, F. M. (2019). Precipitation regime change in Western North America: The role of Atmospheric Rivers. *Scientific Reports, 9*(9944), 1-11. Retrieved from https://doi.org/10.1038/s41598-019-46169-w

Gillespie, N., Unthank, A., Campbell, L., Anderson, P., Gubernick, R., Weinhold, M., . . . Kirn, R. (2014). Flood effects on road-stream crossing infrastructure: economic and ecological benefits of stream simulation designs. *Fisheries*, 62-76.

Harrelson CC, R. C. (1994). *Stream Channel Reference Sites: An Illustrated Guide to Field Technique.* Fort Collins, CO: .S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hayhoe, K., Cayan, D., Field, C., Frumhoff, P., Maurer, E., Miller, N., . . . Neilson, R. (2004). Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences of the United States of America, 101*(34), 12422. Retrieved from https://doi.org/10.1073/pnas.0404500101

Hernick, M., Kozarek, J., Lenhart, C., & Nieber, J. (2019). *Minnesota Guide for Stream Connectivity and Aquatic Organism Passage through Culverts.* St. Paul: Minnesota Department of Transportation. Retrieved from http://mndot.gov/research/reports/2019/201902.pdf

Hotchkiss, R. H., & and Frei, C. M. (2007). *Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report.* Turner-Fairbank Highway Research Center: U.S. Department of Transportation, Federal Highway Administration, Office of Infrastructure Research and Development.

Kahler, T., & Quinn, a. T. (1998). *Juvenile and Resident Salmonid Movement and Passage.* Washington State Department of Transportation, Final Report WA-RD 457.1.

Kilgore, R., Bergendahl, B., & Hotchkiss, R. (2010). *Culvert Design for Aquatic Organism Passage, Hydraulic Engineering Circular No. 26, First Edition.* Publication No. FHWA-HIF-11-008, HEC-26: Federal Highway Authority.

Kim, J. (2005). A Projection of the Effects of the Climate Change Induced by Increased CO 2 on Extreme Hydrologic Events in the Western U.S. *Climatic Change, 68*(1), 153-168. Retrieved from https://doi.org/10.1007/s10584-005-4787-9

Lai, Y. G. (2008). *SRH-2D version 2: Theory and User's Manual.* Denver, CO: U.S. Department of the Interior, Bureau of Reclamation .

Maurer, E. P. (2007). Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios. *Climatic Change, 82*(3), 309-325. Retrieved from https://doi.org/10.1007/s10584-006-9180-9

MDOT. (2016). *Fish Passage Policy and Design Guidelines.* Augusta, ME: Maine Department of Transportation.

Molinar, M., & Walth, J. (2020). Caltrans' Fish Passage Program and the FishPAC: An Overview Webinar. Retrieved from https://c91a0cf6-a658-40a8-aeca-aa67e8d0dc95.filesusr.com/ugd/0e48c2_e6373773fb3645cda623bb4ee95c423a.pdf

Montgomery, D. R., & Buffington, J. M. (1993). *Channel classification, prediction of channel response, and assessment of channel condition.* Report TFW-SH10-93-002 prepared for the SHAMW committee of the Washington State Timber, Fish, and Wildlife Agreement.

Mote, P. W., & Salathé, E. P. (2010). Future climate in the Pacific Northwest. *Climatic Change, 102*(1), 29-50. Retrieved from https://doi.org/10.1007/s10584-010-9848-z

Neelin, J. D., Langenbrunner, B., Meyerson, J. E., Hall, A., & Berg, N. (2013). California Winter Precipitation Change under Global Warming in the Coupled Model Intercomparison Project Phase 5 Ensemble. *Journal of Climate, 26*, 6238-6256. Retrieved from https://doi.org/10.1175/JCLI-D-12-00514.1

Nickelson, T., Rodgers, J., Johnson, S., & Solazzi, a. M. (1992). Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. *Can. J. Fish. Aquat. Sci., 49*, 783-789.

NOAA. (2001). *Guidelines for Salmonid Passage at Stream Crossings.* NOAA Fisheries, NMFS SW Region. National Marine Fisheries Service, Southwest Region. Retrieved from https://archive.fisheries.noaa.gov/wcr/publications/hydropower/fish_passage_at_stream_crossings_guidance.pdf

NOAA. (2020). *About Atmospheric Rivers: AR Portal*. Retrieved from NOAA Physical Sciences Laboratory: https://www.psl.noaa.gov/arportal/about/

ODFW. (2020, 10 26). *Fish Passage*. Retrieved from Oregon Department of Fish and Wildlife: https://www.dfw.state.or.us/fish/passage/

Peterson, J. K., & McAllister, K. (2014). Fish Passage Design Aids Wildlife Crossing in Washington State—State of the Practice. *TRB 93rd Annual Meeting Compendium of Papers.* Transportation Research Board. Retrieved from http://docs.trb.org/prp/14-2246.pdf

Pierce, D. W., Das, T., Cayan, D. R., Maurer, E. P., Miller, N. L., Bao, Y., . . . Tyree, M. (2013). Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. *Climate Dynamics, 40*(3), 839-856. Retrieved from https://doi.org/10.1007/s00382-012-1337-9

Ralph, F. M., Coleman, T., Neiman, P. J., Zamora, R. J., & Dettinger, M. D. (2013). Observed Impacts of Duration and Seasonality of Atmospheric-River Landfalls on Soil Moisture and Runoff in Coastal Northern California. *Journal of Hydrometeorology, 14*(2), 443-459. Retrieved from https://doi.org/10.1175/JHM-D-12-076.1

Sandercock, F. (1991). Life History of Coho Salmon. In C. Croot, & L. Marcolis, *Pacific Salmon Life Histories* (pp. 397- 445). Vancouver: UBC Press.

Scarlett, W. J., & Cederholm, C. J. (1983). Juvenile coho salmon fall- winter utilization of two small tributaries of the Clearwater River, Jefferson County, Washington. In J. M. Walton, & D. Houston, *Proceedings of the Olympic Wild Fish Conference.* Port Angeles, Washington.

Schall, J., Thompson, P., Zerges, S., Kilgore, R., & Morris, J. (2012). *HDS 5: Hydraulic Design of Highway Culverts, 3rd Edition.* Denver: U.S. Department of Transportation, FHWA. Retrieved from https://www.fhwa.dot.gov/engineering/hydraulics/pubs/12026/hif12026.pdf

Schumm, S. A., D, H. M., & Watson, C. C. (1984). *Incised Channels: Morphology, Dynamics, and Control.* Littleton, CO: Water Resources Publications.

Skeesick, D. (1970). The fall migration of juvenile coho salmon into a small tributary. *Fish. Comm. Oregon Rep, 2*, 90-95.

Timm, A., Higgins, D., Stanovick, J., Kolka, R., & Eggert, S. (2017, May). Quantifying Fish Habitat Associated with Stream Simulation Design Culverts in Northern Wisconsin. *River Research and Applications, 33*(4), 567-577. doi:https://doi.org/10.1002/rra.3117

TRB. (2017, April 13). *TRB Webinar Program.* Retrieved June 5, 2018, from TRB Online Publications: http://onlinepubs.trb.org/onlinepubs/webinars/170413.pdf

Tschaplinski, P., & Hartman, G. F. (1983). Winter distribution of juvenile coho salmon (Oncorhynchus kisutch) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Can. J. Fish. Aquat. Sci., 40*, 452-461.

University of New Hampshire. (2009). *New Hampshire Stream Crossing Guidelines.* Retrieved from https://www.nae.usace.army.mil/Portals/74/docs/regulatory/StreamRiverContinuity/nh_stream_crossing_guidelines_unh_web_rev_2.pdf

USFS. (2008). *Stream Simulation: An Ecological Approach To Providing Passage for Aquatic Organisms at Road-Stream Crossings.* San Dimas, CA: USFS National Technology and Development Program.

USFS. (2012). *FishXing—Software and Learning Systems for Fish Passage through Culverts.* www.fs.fed.us/biology/nsaec/fishxing/.

Ward, R., Anderson, J., & Petty, J. (2008). Effects of road crossings on stream and streamside salamanders. *Journal of Wildlife Management*, 760-771.

WDFW. (1999). *Fish Passage Design at Road Crossings.* Olympia, WA: Washington Department of Fish and Wildlife.

Wilhere, G., Atha, J., Quinn, T., Helbrecht, L., & Tohver, I. (2016). *Incorporating Climate Change into the Design of Water Crossing Structures.* Washington Department of Fish and Wildlife, Habitat Program – Science Division. Retrieved from https://wdfw.wa.gov/sites/default/files/publications/01867/wdfw01867.pdf

Wolman, M., & Leopold, L. (1957). *River flood plains: some observations on their formation.* Washington, DC: US Geological Survey, US Government Printing.

Yochum, S. (2018). *Flow Resistance Coefficient Selection in Natural Channels: A Spreadsheet Tool.* Technical Summary TS-103.2. USDA Forest Service. Retrieved from https://www.fs.fed.us/biology/nsaec/assets/yochum2017flowresistancespreadsheettoolts-103-2.pdf

Zevenbergen, L., Arneson, L., Hunt, J., & Miller, A. (2012). *HDS 7: Hydraulic Design of Safe Bridges.* Fort Collins: US Department of Transportation, FHWA. Retrieved from https://pdf4pro.com/download/hds7-hydraulic-design-of-safe-bridges-5b644d.html