FINAL REPORT ◦ FEBRUARY 2014

Evaluation of Barriers to Pacific Lamprey Migration in the Eel River Basin

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Stillwater Sciences. 2014. Evaluation of barriers to Pacific lamprey migration in the Eel River basin. Prepared by Stillwater Sciences, Arcata, California for Wiyot Tribe, Loleta, California.

Cover photos: Upper left, spawning stage Pacific lamprey in the South Fork Eel River. Upper right, surveying a longitudinal profile at a potential barrier site. Lower left, using auto-level to survey road crossing elevations. Lower right, assessing a potential barrier site.

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ACKNOWLEDGEMENTS

Stillwater Sciences would like to recognize the Wiyot Tribe Natural Resources Department (NRD) for their role in initiating and implementing this project. This report is the product of a collaborative effort in which the Wiyot Tribe provided feedback on and refinement of field protocols, conducted all fieldwork, performed data entry and management, and provided valuable reviews of the final report. We would also like to acknowledge both the Wiyot Tribe NRD and Governing Council for spearheading efforts to restore the Eel River and bring attention to the culturally and ecologically important *gou'daw* (Pacific lamprey).

We would like to thank the numerous individuals who assisted with this project by providing property access, thoughtful reviews of passage criteria, and observations and data on lampreys in the Eel River basin. In particular, Ross Taylor (Ross Taylor and Associates) provided significant information from previous fish passage assessments in the basin, as well as guidance on running the FishXing model. Margaret Lang (Humboldt State University) reviewed draft passage criteria and field protocols, and her previous passage assessments provided valuable information for assessing lamprey passage at certain sites. Christina Luzier (USFWS) coordinated technical reviews of draft passage criteria through the Columbia River Basin Lamprey Technical Workgroup. We would like to thank the following people for providing useful reviews of draft passage criteria: Mary Moser (NMFS), Ann Gray (USFWS), Bob Mueller (Pacific Northwest National Laboratory), Bianca Streif (USFWS), Chris Peery (USFWS), Jody Brostrom (USFWS), Matt Mesa (USGS), Damon Goodman (USFWS), and Ralph Lampman (Yakima Nation). Matthew Keefer (University of Idaho) and Theodore Castro-Santos (USGS) provided relevant publications and feedback on passage criteria. Damon Goodman assisted as a technical advisor on several aspects of the project, and he and Stewart Reid (Western Fishes) provided training and assistance with lamprey ammocoete species identification. Anne Elston (CDFW) provided information on, and answered questions regarding, potential barriers listed in the Passage Assessment Database. Allan Renger (CDFW), Scott Harris (CDFW), and Nick Simpson (CDFW) provided information on study sites and assistance with property access. Humboldt Redwood Company generously provided access to study sites on their properties.

The fish passage evaluation protocols described herein were based in part on the existing and widely used systematic protocols described in Taylor and Love (2003) and Clarkin et al. (2005). This project was funded through a FY 2011 U.S. Fish and Wildlife Service Tribal Wildlife Grant.

1 INTRODUCTION

1.1 Background and Objectives

The Pacific lamprey is considered an important component of freshwater ecosystems in the Pacific Northwest, both by the Native American tribes that have always depended on it for sustenance and by biologists across the region (Close et al. 2002, Petersen-Lewis 2009, Luzier et al. 2011). Widespread anecdotal accounts of declining spawning populations and reduced geographical distributions across much of the species' range have been supported by a significant reduction in the number of migrating lampreys counted at dams (Moser and Close 2003, Nawa 2003, Moyle et al. 2009, Luzier et al. 2011). Available evidence suggests that the species has declined substantially in the Eel River (Stillwater Sciences 2010), which was known to the Wiyot people as *Wiya't*, meaning abundance. The river received its English name due to the fact that it once contained large numbers of Pacific lampreys, commonly referred to as eels or *gou'daw* in Wiyot.

Despite the apparent drastic decline in the lamprey population, until recently very little effort has been made to study and monitor this important species in the Eel River basin. In response, the Wiyot Tribe and Stillwater Sciences have implemented a program to study and restore Pacific lamprey in this significant river system. Stillwater Sciences (2010) initially performed a review of available information and identified key data gaps and threats to the species in the Eel River basin. One of the most pressing needs identified by the review was identification and remediation of barriers to adult migratory passage, specifically barriers created by road crossings and other manmade barriers. Likewise, the U.S. Fish and Wildlife Service (USFWS) has identified artificial barriers to adult passage, including culverts, as a key threat to the species in recent conservation and management plans (USFWS 2010, Luzier et al. 2011).

As with anadromous salmonids, identifying and removing passage barriers to allow migrating adult lampreys access to historical holding, spawning, and rearing habitats is one of the most tangible and cost-effective ways to increase populations. A high percentage of potential barriers to salmonid passage in the Eel River basin have been identified and evaluated (Lang 2005, RTA 2005, RTA 2011, CDFW 2012); however, assessments of salmonid barriers have generally ignored passage requirements of Pacific lampreys—they are scarcely mentioned in CDFW's *Culvert Criteria for Fish Passage* (Flosi et al. 2010), and not mentioned in NMFS's Southwest Region *Guidelines for Salmonid Passage at Stream Crossings* (NMFS 2001), or *Fish Passage Design for Road Crossings* produced by CalTrans (2007).

Due to considerable differences in behavior and swimming ability between salmonids and lampreys, many fish ladders and road crossings designed to pass salmon and steelhead may impede or block passage by Pacific lampreys. For example, Pacific lampreys cannot effectively navigate many fish ladders or culverts with excessively high water velocities, vertical drops, or sharp angles.

The goal of this project was to develop a systematic approach for identifying and evaluating potential barriers to Pacific lamprey migration and apply it in the Eel River basin to produce a prioritized list of barriers requiring remediation. This is a critical step towards considering Pacific lampreys in future passage assessments and remediation designs, and ultimately restoring access to upstream habitats to increase production of the species. The project goal was achieved by implementing the following steps:

- review available information to develop passage criteria for adult Pacific lampreys,

- generate an initial list of road crossings and other potential barriers,
- narrow list by omitting locations outside of the predicted historical distribution of Pacific lamprey,
- prioritize sites for field assessment based on potential availability of Pacific lamprey habitat upstream of sites, access, and other considerations,
- conduct field-based passage evaluations, and
- produce a final prioritized list of sites requiring remediation or additional evaluation.

Section 2 of this document presents an extensive review of the physiological, physical, and hydraulic factors governing passage success and presents the passage criteria used to develop field protocols and interpret data collected at study sites to make passage status designations. Section 3 details methods and results of the passage evaluations. Section 4 discusses implications of the report findings and Section 5 makes general recommendations for improving lamprey passage in designs of road crossing replacements and retrofits.

Due to the sheer size of the Eel River basin, difficult access, and high number of potential barriers to passage (see Figure 1-1), it was necessary to limit the scope of this evaluation in the following ways. First, the focus of the evaluation was on passage of adult Pacific lampreys: (1) we did not address potential impacts of road crossings or other structures on ammocoete or juvenile movement, (2) we did not directly address passage of western brook or river lampreys, (3) we focused on manmade barriers and did not attempt to address passage at natural features such as waterfalls, debris jams, or alluvial fans associated with tributary confluences, and (4) we primarily addressed passage at road crossings, but did not systematically assess other man-made barriers (e.g., irrigation diversions, tide gates, large dams). Although ambitious in scale, this evaluation should not be viewed as comprehensive; there are numerous potential barriers in the basin that we were unable to evaluate. Notwithstanding these limitations, the criteria and systematic evaluation approach developed here can be refined and built upon in future passage assessments and as additional data on lamprey passage and barriers in the Eel River basin become available. This assessment framework may also be used as the foundation for assessing passage and prioritizing barrier removal in other watersheds throughout the species' range.

This project is part of an ongoing collaboration between the Wiyot Tribe and Stillwater Sciences to study and restore Pacific lamprey populations in the Eel River. Both the Wiyot Tribe and Stillwater Sciences participated in all aspects of this project. Stillwater Sciences' primary role was development of field protocols, field training, technical assistance, analysis, and reporting. The Wiyot Tribe provided review and feedback of field protocols, conducted the fieldwork, performed data entry and management, and reviewed the final report.

1.2 Study Area

This project aimed to identify the most important potential barriers to Pacific lamprey migration in the entire Eel River basin. The Eel River is California's third largest watershed, with an area of 9,534 km^2 (3,681 mi^2). Annual precipitation in the watershed averages 40 inches (102 cm) in the coastal lowlands, and 80–100 inches (203–254 cm) at higher elevations, accounting for 9% of California's annual run-off. The rainfall pattern in the basin is marked by wet winters and dry summers. During the period of record (1910–2009), discharge in the lower Eel River near Scotia (USGS gage 11477000) averaged 19,900 cfs for January and 138 cfs for September.

The landscape varies from estuarine habitats in the lower Eel River (tidal wetlands, freshwater marshes, sand dunes, grasslands) to redwood and Douglas-fir dominated forests in the coastal mountains, grassland and oak woodlands further inland, and rugged, high-elevation mountains at the headwaters of the Middle and North forks of the Eel River. The geology of the watershed is naturally unstable and the Eel River has a very high sediment load (Brown and Ritter 1971). Land uses in the watershed include grazing, timber management, rural and residential development, recreation, gravel extraction, and intensive marijuana cultivation.

Compared with other major river systems in the region, the Eel River is largely unregulated. However, Scott Dam, constructed in 1912 to form Lake Pillsbury in the upper mainstem Eel River, is a total barrier to anadromous fish. The river flows west approximately 10.5 miles (16.9 km) from Lake Pillsbury where it meets Van Arsdale Reservoir, created by Cape Horn Dam, which was constructed in 1907. An average of approximately 219 cfs is diverted from the Van Arsdale Reservoir and pumped south into the Russian River basin.

Figure 1-1 shows the Eel River basin divided into the following sub-basins: Lower Eel River, Van Duzen River, Lower Mainstem Eel River, South Fork Eel River, Middle Main Eel River, North Fork Eel River, Middle Fork Eel River, and Upper Mainstem Eel River. These sub-basins are referred to throughout the report to help understand locations of each study site and prioritize passage assessment and barrier remediation by region. In order to show the potential magnitude of the problem, Figure 1-1 also shows records of potential fish passage barriers in the Eel River basin that are listed in the Passage Assessment Database (PAD), which is maintained by the California Cooperative Anadromous Fish and Habitat Data Program (CalFish) and can be accessed online (https://nrm.dfg.ca.gov/PAD/default.aspx).

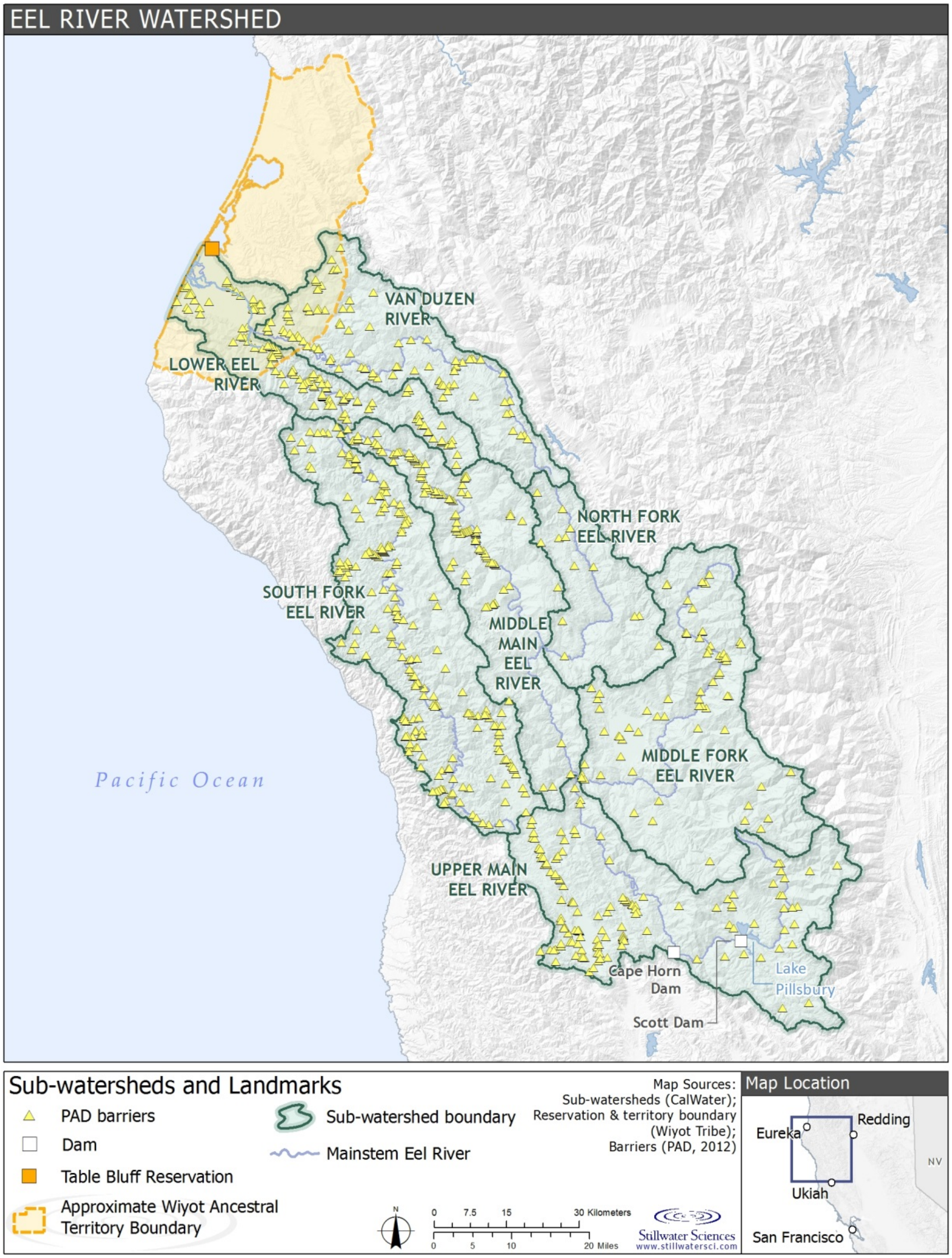


Figure 1-1. Locations of major Eel River sub-basins, Wiyot Ancestral territory, and potential barriers to fish passage listed in the Passage Assessment Database.

1.3 Pacific Lamprey Life History Overview

The Pacific lamprey is a large, widely distributed anadromous species that rears in fresh water before outmigrating to the ocean, where it grows to full size (approximately 400–700 mm [16–28 in]) prior to returning to freshwater streams to spawn. The species is distributed across the northern margin of the Pacific Ocean, from central Baja California, Mexico north along the west coast of North America to the Bering Sea in Alaska and off the coast of Japan (Ruiz-Campos and Gonzales-Guzman 1996, Lin et al. 2008). Adults migrate into and spawn in a wide range of river systems, from short coastal streams to tributaries of the Snake River in Idaho, where individuals may migrate over 1,450 km (900 mi) (Claire 2004). Pacific lampreys are widely distributed within the Eel River basin from the lower mainstem Eel River to relatively small tributaries in the upper South Fork Eel and Upper Mainstem Eel basins (Stillwater Sciences 2010); however, there are still substantial portions of the basin where extent of distribution is unknown.

Pacific lampreys typically spawn from March through July depending on water temperatures and local conditions, such as seasonal flow regimes (Kan 1975, Brumo et al. 2009, Gunckel et al. 2009). More inland, high-elevation, and northerly populations generally initiate spawning considerably later than southerly populations (Kan 1975, Beamish 1980, Farlinger and Beamish 1984, Chase 2001, Brumo et al. 2009), presumably due to cooler water temperatures. Spawning generally takes place at daily mean water temperatures from 10–18°C (50–64°F), with peak spawning around 14–15°C (57–59°F) (Stone 2006, Brumo 2006). Pacific lamprey spawning has been observed in a wide range of stream sizes, but is more prevalent in higher-order streams (active channel widths >15 m [49 ft]) than smaller, low-order streams (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009). Redds are typically constructed by both males and females in gravel and cobble substrates within pool and run tailouts and low-gradient riffles (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009; Figure 1-1). During spawning, eggs are deposited into the redd and hatch after approximately 15 days, depending on water temperatures (Meeuwig et al. 2005, Brumo 2006). The egg-sac larval stage, known as prolarvae, spend another 15 days in the redd gravels until they emerge at night and drift downstream (Brumo 2006). Adult Pacific lampreys typically die within a few weeks after spawning (Kan 1975, Brumo 2006).

After drifting downstream, the eyeless larvae, known as ammocoetes, settle out of the water column and burrow into fine silt and sand substrates that often contain organic matter (Figure 1-2). Because of their preference for fine substrates, ammocoetes are generally found in greatest abundance in low-velocity, depositional areas or off-channel habitats such as pools, alcoves, and side channels (Torgersen and Close 2004). Depending on factors influencing growth rates, they rear in these habitats from 4 to 10 years, filter-feeding algae and detrital matter prior to metamorphizing into the adult form (Pletcher 1963, Moore and Mallatt 1980, van de Wetering 1998). During metamorphosis Pacific lampreys develop eyes, a suctoral disc, sharp teeth, and more-defined fins (McGree et al. 2008). After metamorphosis, smolt-like individuals known as macropthalmia migrate to the ocean—typically in conjunction with high-flow events between fall and spring—where they feed parasitically on a variety of marine fishes (Richards and Beamish 1981, Beamish and Levings 1991, Close et al. 2002).

Pacific lampreys are thought to remain in the ocean for approximately 18–40 months before returning to freshwater as sexually immature adults, typically from late winter until early summer (Kan 1975, Beamish 1980). In the Klamath and Columbia rivers, Pacific lampreys have been reported to enter freshwater year-round (Kan 1975, Larson and Belchik 1998, Petersen Lewis 2009). Recent research suggests two distinct life histories may occur in some river systems: an "ocean maturing" life history that spawns several weeks after entering fresh water and a "stream-maturing" life history—the more commonly recognized life history of spending one year in fresh water prior to spawning (Clemens et al. 2013). After the initial upstream migration, stream-maturing individuals remain inactive, holding under boulders or similar substrate throughout the fall and winter months prior to emerging as sexually mature adults the following spring and undergoing a secondary migration into spawning areas (Robinson and Bayer 2005, Fox and Graham 2008, Lampman 2011). Unlike Pacific salmon and steelhead (and similar to the Great Lakes sea lamprey [*Petromyzon marinus*]; Bergstedt and Seelye 1995), Pacific lampreys do not necessarily home to natal spawning streams (Moyle et al. 2009). Instead, migratory lampreys likely select spawning locations based on the presence of pheromone-like bile acids secreted by ammocoetes (Bjerselius et al. 2000, Vrieze and Sorensen 2001, Yun et al. 2011). Results of recent genetics research also indicate a lack of homing behavior by Pacific lamprey—Goodman et al. (2006) found little genetic differences among Pacific lamprey individuals sampled at widely dispersed sites across their range, indicating substantial genetic exchange among populations from different streams.

2 PASSAGE CRITERIA REVIEW AND DEVELOPMENT

We conducted a thorough review of available information on Pacific lamprey passage capabilities to develop passage criteria with which to evaluate potential barriers at road crossings. The results of our review were provided to fish passage and lamprey experts for their input, which we then used to refine the initial criteria. Their comments also led to inclusion of additional considerations and discussion of uncertainties. Where possible, data from field evaluations, including Pacific lamprey surveys upstream of potential barriers, were also used to help improve understanding of passage criteria at each site. Experimental evaluation of Pacific lamprey passage was beyond the scope of this project; thus, the criteria developed in this study can provide a basis for further refinement.

The goal of this review was to synthesize information on factors influencing adult Pacific lamprey passage at road crossings to help (1) develop field protocols for evaluating lamprey passage success, and (2) conduct and interpret analyses of data collected at each study site to designate status of each in terms of lamprey passage success. Specifically, a subset of the criteria developed from the review was used to parameterize the FishXing model, as described in Section 3.1.6. Lamprey passage criteria reviewed include:

- swimming performance in relation to water depth and velocity;
- ability to attach to or climb different types of substrates and structures of various types, sizes, and shapes;
- leaping ability in relation to crossing structures; and
- potential effects of migration timing, fish size and maturation stage, and water temperature on swimming ability and passage success.

Results of the passage criteria review are presented in the sections that follow. Importantly, this review is meant to serve as an initial framework for understanding Pacific lamprey passage capabilities at road crossings. The criteria we used should generally be considered preliminary; both this review and its application to assessing Pacific lamprey passage at sites in the Eel River basin will help identify key hypotheses about passage that could be experimentally tested to refine passage criteria and ultimately set more stringent passage standards.

2.1 Swimming Performance

Lampreys use an anguilliform mode of swimming, using undulatory movements to propel themselves forward (Mesa et al. 2003, Quintella et al. 2009, Keefer et al. 2010). This mode of swimming is generally considered to be less powerful compared with other fishes such as salmonids, particularly in turbulent or high-velocity water (Figure 2-1) (Bell 1990, Mesa et al. 2003, Keefer et al. 2011). Pacific lampreys, however, display a unique behavior that allows them to navigate through areas that may otherwise hinder passage. When confronted with high velocities or turbulence, they use their oral discs to attach to substrate and rest before continuing upstream (Daigle et al. 2005; Kemp et al. 2009; Keefer et al. 2010, 2011). The resulting "burst-and-attach" strategy of upstream movement also allows Pacific lampreys to climb some vertical features (Reinhardt et al. 2008, Kemp et al. 2009, Zhu et al. 2011). Pacific lampreys likely use this behavior to help them navigate through road crossings when water velocities are high, if suitable attachment points are available. The roles of attachment points and surface shapes and materials in passage success are described in more detail below.

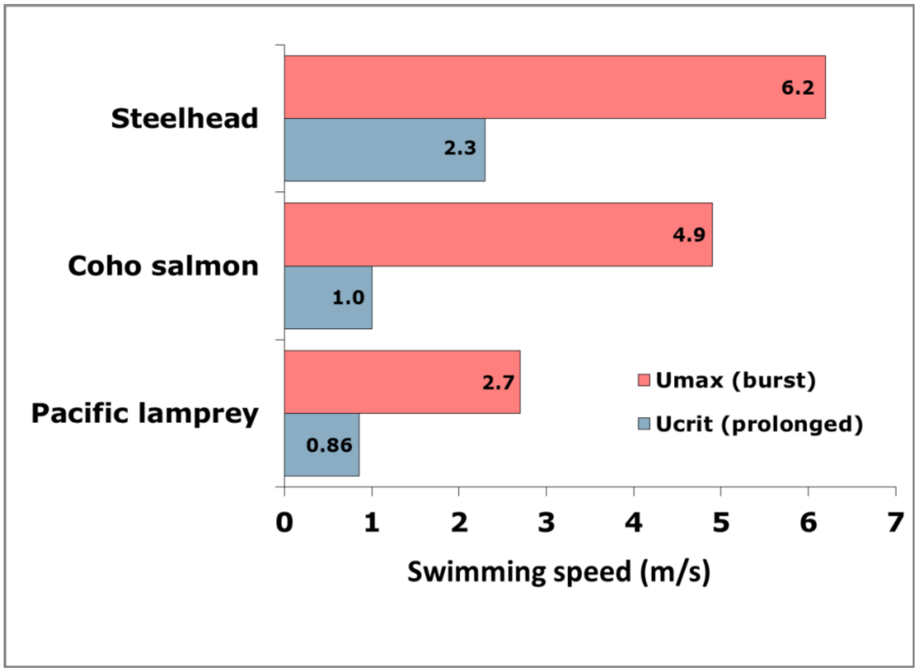


Figure 2-1. Reported swimming speeds of anadromous salmonids (Bell 1990, Lee et al. 2003) and Pacific lamprey (Keefer et al. 2010, Mesa et al. 2003).

Two metrics commonly used to describe swimming performance of fishes are (1) critical swimming speed (U_{crit}), and (2) burst swimming speed (U_{max}). U_{crit} is the maximum velocity that can be maintained by a fish for a specific period of time (typically 30 minutes) before exhaustion. U_{crit} is a specific category of prolonged swimming calculated from tests where water velocity is progressively increased (Brett 1964, Jobling 1995, Mesa et al. 2003). Energy for critical swimming is provided primarily by aerobic metabolism (Jobling 1995). U_{max} is the highest speed fish are capable of attaining, usually only for very short periods of time (<20 seconds) (Jobling 1995). Energy for burst swimming is provided predominately by anaerobic metabolism. This mode of swimming is inefficient compared with lower speeds and is used principally for predator avoidance or navigating high-velocity areas.

Table 2-1 summarizes reported values for Pacific lamprey critical (U_{crit}) and burst (U_{max}) swimming speeds and includes values reported for sea lampreys, a similarly-sized and intensively studied species, for comparison. Notably, sea lampreys are not as adept at climbing compared with Pacific lampreys (Clemens et al. 2010), and the two species may display different swimming behaviors when faced with the same obstacle.

Table 2-1. Critical (U_{crit}) and burst (U_{max}) swimming speeds for adult Pacific lamprey and sea lamprey.

Species	Swimming speed (m/s)	Source notes
Pacific lamprey		
Critical swimming speed (U_{crit})	0.86	Mean U_{crit} of untagged, sexually immature adults in a swimming tube at 15°C (Mesa et al. 2003).
Burst swimming speed (U_{max})	2.7	Approximation of U_{max} based on velocity at which sexually immature adult Pacific lampreys had difficulty migrating through a weir using burst-and-attach behavior; water temperature not reported (Keefer et al. 2010).
Sea lamprey		
Critical swimming speed (U_{crit})	1.0	Based on studies of anadromous sea lampreys in Portugal (Almeida et al. 2007, as cited by Quintella at al. 2009)
Burst swimming speed (U_{max})	>4.0	Based on studies of Great Lakes sea lamprey and similar to the 3.9 m/s reported by Hunn and Youngs (1980, as cited by Quintella et al. 2009) (Hanson 1980).

Mesa et al. (2003) reported a mean U_{crit} of 0.86 m/s for untagged, sexually immature adult Pacific lampreys from studies in a swim chamber (Table 2-1). U_{crit} represents approximate velocities that can be maintained for substantial periods of time without resting. Therefore, we infer that Pacific lampreys cannot swim long distances through areas with water velocities greater than $U_{crit,}$ or 0.86 m/s, where suitable attachment points for resting are not available (e.g., culvert corrugations are too small, porous, or degraded for attachment), or where attachment is interrupted by lips, large gaps, acute angles, or other obstructions. Daigle et al. (2005) reported that the burst-and-attach mode of swimming for Pacific lampreys becomes common when velocities exceed 0.6 m/s, suggesting that, when given a choice, lampreys likely attach and rest when velocities reach this level.

Recently, research has called into question the use of U_{crit} derived from swimming chambers for establishing velocity criteria for culverts and fishways. Because such chambers prevent fish from using the full range of behaviors exhibited by free-swimming fish, performance measured in them consistently underestimate natural abilities (Peake 2004; Castro-Santos 2004, 2005, 2006, 2011). Moreover, fish can swim at velocities greater than U_{crit} (but less than U_{max}) for shorter periods than the 30 minutes typically used to determine U_{crit} (Peake 2004, Quintella et al. 2009, Russon and Kemp 2011). Therefore, Pacific lamprey can likely swim through water velocities exceeding 0.86 m/s without attaching and resting in some road crossings—especially shorter culverts; nonetheless, 0.86 m/s can serve as a suitable, if conservative estimate of prolonged swimming speed for assessing road crossings. In practice, when running the FishXing model to assess Pacific lamprey passage (Section 3.1.6), the U_{crit} value is only applied to estimate passage success through road crossings where suitable attachment points are not available (a small portion of the sites assessed during this study).

U_{max} has not been directly measured for Pacific lampreys. Keefer et al. (2010) demonstrated that very few sexually immature adult Pacific lampreys could pass weirs when maximum water velocities exceeded 2.7 m/s. Keefer et al. (2010) also reported that burst-and-attach behavior was generally ineffective at high velocities and inferred that velocities in the range of 2.5–3.0 m/s likely represent a barrier to lampreys. Based on these observations, we therefore recommend 2.7 m/s as a reasonable value for U_{max} for assessing Pacific lamprey passage at road crossings. Accordingly, when continuous substrate (such as a flat concrete bottom culvert) or regular attachment points (such as natural cobble substrate or suitably sized culvert corrugations) are present, we hypothesize that adult Pacific lampreys can swim through areas with water velocities less than approximately 2.7 m/s. This value likely varies depending on site-specific hydraulic conditions, fish sexual maturity and size, water temperature, and other factors discussed below. Turbulence or sudden velocity changes may also affect lamprey attachment and passage success. Daigle et al. (2005) observed that lampreys are most vulnerable to displacement during the periods between successive attachments, noting that rapid changes in water velocity or direction can prevent fish from reattaching. The role of turbulence in passage success and effective water velocities that lampreys can swim through at road crossings warrants further investigation.

Furthermore, lamprey attachment to surface substrates requires expenditure of energy (Reinhardt et al. 2008) and swimming fatigue has been reported for Pacific lampreys using burst-and-attach behavior to pass high-velocity areas (Kemp et al. 2009). For this reason, velocities at which Pacific lampreys can successfully pass using burst-and-attach swimming may decrease with increasing length of a road crossing. For lamprey passage evaluations conducted in this study using the FishXing model, we conservatively assumed that Pacific lampreys can use burst-and-attach behavior (including periods of attachment and rest) for 20 minutes prior to reaching exhaustion.

When attempting to pass through locations with water velocities significantly higher than the critical swimming speed (0.86 m/s) with no suitable attachment points, Pacific lampreys are expected to use the burst swimming mode until they become fatigued, find lower velocity locations, or locate an attachment point to rest. We could find no information on how long Pacific lampreys can maintain burst swimming without attachment prior to reaching exhaustion. For the purposes of evaluating passage in this study, we used 10 s. This value is typical of that reported by the FishXing swim speed table from studies on various other fish species and is the FishXing model default value. Controlled experiments to describe time to exhaustion for Pacific lamprey burst swimming would increase confidence in evaluating passage success at sites where attachment is not possible.

2.2 Attachment Ability

As described above, when confronted with high velocities, Pacific lampreys often use their oral discs to attach to substrate and rest before continuing upstream. Their ability to attach to substrate within a road crossing is expected to be a key determinant of whether individuals can utilize burst-and-attach behavior to pass the feature. Burst-and-attach swimming allows individuals to navigate through much higher water velocities than where attachment is not possible. Adult lampreys can attach to a wide range of surface materials, sizes, and shapes (Adams and Reinhardt 2008, Reinhardt et al. 2008, Moser and Mesa 2009, Moser et al. 2011). Ability to attach is contingent on the interaction between a substrates surface characteristics and a lamprey's oral disk anatomy (Adams and Reinhardt 2008). Surfaces constructed of non-porous, slightly rough material allows the most secure attachment, permitting the oral disk and associated fimbriae to form a tight seal (Adams 2006). Recent experiments have shown that Great Lakes sea lampreys can contort their oral disk to attach to surfaces containing shallow (1-mm), medium (2-mm), and to a lesser extent, deep (3-mm) grooves that are 3-mm wide (Adams and Reinhardt 2008). However, experimental fish could not successfully attach to grooves that were narrower and deeper (1 mm wide x 3 mm deep or deeper). Lamprey could also attach to rectangular, triangular, and semi-circular grooves, albeit with varying degrees of effort required as measured by "pump rate" and "pressure leakage rate" (Adams and Reinhardt 2008). Although sea lampreys are expected to have slightly different oral disc morphology and attachment abilities compared with Pacific lampreys, these studies demonstrate that oral disc morphologies of lampreys have evolved to attach to a wide range of substrates.

CRBLTW (2004) suggested that tightly corrugated culverts may prevent lamprey attachment. Based on the work of Adams and Reinhardt (2008) and information on oral disc morphology and corrugation size, we assumed that Pacific lampreys can attach to most undamaged steel or aluminum culvert corrugations if the length of the diagonal, flat surface of a culvert corrugation is greater than or equal to the length of the oral disc as measured from the tip of the snout to the posterior edge of the oral disc. We also assume that Pacific lampreys can attach to other flat or rounded artificial and natural substrates with lengths and widths greater than or equal to the length of the oral disc.

Table 2-2 provides the range of oral disc lengths for sexually immature (initial migration into freshwater) and spawning stage male and female Pacific lampreys calculated from observed total lengths (Mesa et al. 2003, Brumo 2006) and morphometric data provided by Kan (1975). Oral disc lengths for sexually immature individuals ranged from 2.9–4.3 cm (1.1–1.7 in); whereas those for spawning-stage individuals ranged from 1.7–4.5 cm (0.7–1.8 in). Immature males and females had oral discs of similar size, while spawning males had relatively larger oral discs than females.

Table 2-2. Oral disc lengths calculated for sexually immature and mature (spawning stage) Pacific lampreys.

Maturation stage	Sex	Total length (cm)		Disc length as percent of total length[1, 2]		Calculated disc length [cm (in)][3]	
		Range	Mean	Range	Mean	Range[4]	Mean
Immature	Male	n/a	64.5[5]	4.50–6.11	5.47	2.9–3.9 (1.1–1.6)	3.5 (1.4)
Immature	Female	n/a	67.8[5]	4.90–6.28	5.42	3.3–4.3 (1.3–1.7)	3.7 (1.5)
Spawning	Male	35.5–60.0[6]	49.8[6]	5.55–7.45	6.37	2.0–4.5 (0.8–1.8)	3.2 (1.3)
Spawning	Female	31.0–55.5[6]	45.3[6]	5.53–6.92	6.25	1.7–3.8 (0.7–1.5)	2.8 (1.1)

1 Disc length = distance from the tip of the snout to the posterior edge of the oral disc (Kan 1975).
2 Data from Kan (1975).
3 Calculated by multiplying total length by percent of total length comprised of the disc length. Values also shown in inches to aid in comparison with standard culvert corrugation sizes.
4 Disc length ranges for immature fish were calculated by multiplying mean total length by range of percentages of total length comprised of the disc length.
5 Data from Mesa et al. (2003) and includes 31 individuals collected at Bonneville Dam on the Columbia River that were tagged. Length ranges were not reported. These values are within the range of lengths reported by others for sexually immature fish entering the Columbia and Willamette Rivers (Clemens et al. 2011, Reinhardt et al. 2008, Kemp et al. 2009, Keefer et al. 2009).
6 Data from Brumo (2006) and includes 946 sexually mature individuals and carcasses collected in the South Fork Coquille River, OR.

Figure 2-2 diagrams the diagonal surfaces of culvert corrugations and Table 2-3 lists diagonal surface dimensions calculated for different standard-sized culvert corrugations. Diagonal surface dimensions of corrugations generally range approximately 3.6–9.2 cm (1.4–3.6 in). Based on the sizes of Pacific lamprey oral discs (Table 2-2), we assume that successful attachment can occur on corrugations with diagonal surface dimensions greater than or equal to 4.6 cm (1.8 in) when velocities are low enough for individuals to reach the culvert inlet and maintain position long enough to attach. For the common culvert corrugation size with a diagonal surface of 3.6 cm (1.4 in) (Table 2-3), we assume that most individuals can successfully attach either because their oral discs are smaller than 3.6 cm (1.4 in) or by contorting their oral discs to attach to both the diagonal surface and part of the adjacent "trough." Lamprey ability to attach to culvert corrugations of varying size and shape remains a significant uncertainty. We suspect that it is more difficult for individuals to form initial suction and maintain it on culverts with smaller corrugations compared with larger corrugations. Experiments to determine attachment success on corrugations of different sizes would be relatively easy to conduct and would increase confidence in evaluating passage at culverts.

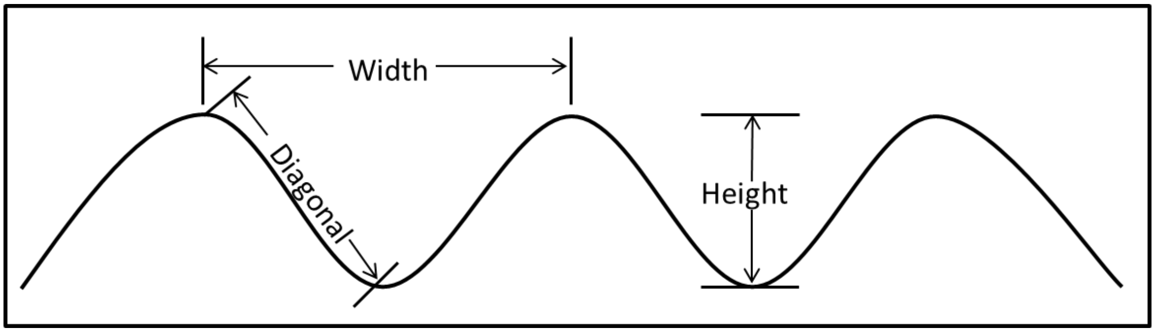


Figure 2-2. Measurements of culvert corrugations relevant to lamprey attachment.

Table 2-3. Common dimensions of culvert corrugations as listed in Taylor and Love (2003) and anticipated ability of adult Pacific lamprey to attach to each.

Culvert corrugation dimensions [cm (in)]			Culverts typically having dimensions	Hypothesized Pacific lamprey attachment ability[2]
Width	**Height**	**Diagonal[1]**		
6.78 (2.67)	1.27 (0.50)	3.63 (1.43)	Most corrugated metal pipes <60 inches diameter	Most individuals
7.62 (3.00)	2.54 (1.00)	4.57 (1.80)	Most corrugated metal pipes ≥60 inches diameter	All but the largest individuals
12.70 (5.00)	2.54 (1.00)	6.83 (2.69)	Typically found in pipes with helical corrugations	All individuals
15.24 (6.00)	5.08 (2.00)	9.17 (3.61)	Structural plate pipes and structural plate pipe arches	All individuals

[1] Calculated using Pythagorean Theorem with the equation: $diagonal = \sqrt{\left(\frac{1}{2}width\right)^2 + height^2}$
[2] Assumed based on range of oral disc sizes (Table 2-2).

An additional uncertainty regarding passage through corrugated culverts with water velocities approaching $U_{\max}$ is whether individuals can use burst-and-attach behavior on corrugations as effectively as on flat surfaces. On uniformly flat surfaces lampreys can burst forward while maintaining their body's position flush (in plane) with the substrate, releasing suction on the substrate only momentarily before re-attaching (Reinhardt et al. 2008, Keefer et al. 2011). It is not clear whether lampreys can use this "inching forward" approach to traverse culvert corrugations (by attaching to corrugation peaks, diagonal surfaces, and troughs sequentially) at high velocities or whether they can only attach to diagonal surfaces and must release until they reach the next diagonal surface. We theorize that individuals can "inch forward" more successfully on culverts with larger corrugations. In cases when individuals cannot "inch forward," but must release and can only re-attach to diagonal surfaces, velocities they can pass are likely lower than those they can pass on flat surfaces (i.e., less than U_{max}). Additionally, more time may be required for successful attachment to non-flat surfaces, particularly tightly corrugated culverts. Lampreys are more likely to be swept downstream while attempting to attach; therefore, water velocities that Pacific lampreys can successfully swim through using burst-and-attach behavior may decrease with smaller corrugation sizes.

2.3 Leaping Ability

Due to their body type, poor swimming ability, and lack of paired fins, Pacific lampreys have extremely limited ability to leap. Consequently, their upstream passage is expected to be precluded by most culverts or other impediments that are perched above the water surface elevation or that have an overhanging ledge (Moser and Mesa 2009, Figure 2-3). Some culverts have hydraulic control points downstream that can act to raise water surface elevation to the height of the culvert entrance once flows are high enough (Taylor and Love 2003), permitting lampreys to enter and pass upstream when hydrologic conditions allow. These factors were considered during lamprey passage evaluations and subsequent FishXing analyses.

Figure 2-3. Examples of perched road crossings or tailwater control weirs found in the Eel River basin. Clockwise from upper left: Oil Creek (PAD ID 736789), Dinner Creek (PAD ID 723276), Stitz Creek (PAD ID 715449), Strawberry Creek (PAD ID 715429)

2.4 Climbing Ability

In addition to using burst-and-attach behavior to move forward on horizontal or low-gradient surfaces, Pacific lampreys can ascend steep or vertical surfaces by attaching their oral disc to the surface, rapidly compressing and then straightening the body, while momentarily releasing suction (but maintaining contact) and then re-attaching (Reinhardt et al. 2008, Kemp et al. 2009, Keefer et al. 2011, Zhu et al. 2011).

The ability and inclination of Pacific lampreys to climb steep surfaces has important implications for remediating passage obstacles. Lamprey passage structures consisting of inclined ramps have been successfully used to improve passage through both mainstem Columbia River dams (Moser et al. 2011) and smaller, low-head dams (Jackson and Moser 2013). Smaller-scale ramps have recently been used to improve lamprey passage at culverts with baffles (M. Fox, Confederated Tribes of Warm Springs, pers. comm., 8 November 2013).

Their ability to climb also allows Pacific lampreys to ascend and pass some waterfalls, boulder cascades, and other features that are considered barriers to salmon and steelhead (e.g., Eaton Roughs on the Van Duzen River). For the purposes of this study, we did not assume that documented natural barriers to salmon and steelhead migration in the Eel River basin necessarily represented the upper limit to Pacific lamprey migration. Assessing the potential of natural features to impede Pacific lamprey passage, however, was outside the scope of this study.

Vertical features with abrupt right angles, such as fish ladder steps, concrete culvert outlet aprons (Figure 2-4), or velocity control weirs may impede or prevent lamprey passage (Moser et al. 2002, Keefer et al. 2010). Due to uncertainties in the ability of Pacific lampreys to ascend and pass over such features, when evaluating passage for this study, we assumed that they could not pass unless the water surface met or exceeded the elevation of the top of the vertical surface (e.g., locations where a backwater effect would raise the water surface at certain flow thresholds). This was a conservative assumption that likely underestimated Pacific lamprey passage success, since lampreys can probably swim over some small steps or drops or possibly attach to and climb a horizontal surface beyond a small step. These uncertainties are discussed further in the context of fishways, culvert baffles, and weirs below.

Figure 2-4. Example of culvert outlet apron with a vertical step at a crossing of Butte Creek (PAD 715481).

2.5 Water Depth

Road crossings must have sufficient water flowing through them for Pacific lampreys to successfully pass. Minimum water depth requirements at road crossings are unknown. For the purposes of this study, we conservatively assumed Pacific lampreys require water depths of at least 3 cm (0.1 ft) for successful passage, based on evidence from Moser et al. (2011) indicating they can pass inclined ramps with water depths of 3 cm. It is likely that individuals can swim for short distances through shallower water, but we leaned towards being conservative (i.e., underestimating passage capabilities) when conducting FishXing model analyses.

2.6 Fishways, Culvert Baffles, Weirs

Many road crossings are modified using internal structures such as baffles or weirs designed to improve upstream fish passage by retaining natural streambed substrates, reducing water velocity, or increasing water depth (Figure 2-5). Some crossings also have fishways leading into perched culvert inlets or manmade hydraulic control structures (e.g., concrete or rock weirs) designed to raise the water level of the pool at a culvert outlet. Due to their variable and complex influences on water velocity, depth, substrate composition, and other factors affecting passage, developing a standard set of passage criteria for such features is difficult as is using standard field and analytical protocols to establish whether road crossings with retrofits present passage barriers to Pacific lampreys. For this reason, passage status at many of these sites may remain uncertain without detailed studies. However, the same velocity criteria applied to unmodified culverts should also apply to these structures. That is, water velocities that lampreys can swim through will be the same regardless of site complexity.

Figure 2-5. Examples of internal structures and modifications at road crossings in the Eel River basin. Internal baffles (top left; Fish Creek, PAD 707157), step-pool fishways at outlet (top right and bottom left; Elk Creek, PAD 707107), and tailwater control weir (bottom right; Rohner Creek at 12th St. in Fortuna, CA).

Since culvert internal structures and retrofits are typically designed specifically to improve salmonid passage and often disregard lamprey-specific requirements (e.g., CalTrans 2007), many may hinder lamprey migration, particularly if they contain sharp angles or require leaps. Laboratory and field experiments indicate that, when water velocities are high, Pacific lamprey have difficulty passing features that have squared corners such as vertical steps or vertical slot weirs in fish ladders (Moser et al. 2002, Daigle et al. 2005, Keefer et al. 2010). Such sharp angles prevent lampreys from maintaining attachment as they move around a corner (Moser et al. 2002, Moser and Mesa 2009). These same studies demonstrated that Pacific lampreys have significantly higher passage success through fishways with rounded, instead of squared, corners on bulkheads.

In cases where tailwater control weirs or internal baffles are designed to allow unimpeded lamprey passage (e.g., rounded corners or lamprey passage systems installed), they may improve passage success by increasing the range of passable stream flows. For example, tailwater control weirs or baffles may help lamprey enter a perched culvert, slow water velocities at the outlet or within the crossing during high flows, and increase depths during summer low flows.

2.7 Other Factors Affecting Passage

2.7.1 Fish size and maturation

Both within and between lamprey species, larger individuals have greater absolute swimming speeds (Beamish 1974, Clemens et al. 2010, Castro-Santos 2011). Slower swimming speeds are expected to translate to lower passage success for smaller fish as evidenced by Keefer et al. (2009), who reported that adult Pacific lamprey passage through Columbia River dams was significantly size dependent, with the largest fish being two to four times more likely to pass than the smallest fish. Likewise, Jackson and Moser (2012) found that fish length was a highly significant factor controlling lamprey passage success at low head irrigation diversion dams.

Pacific lampreys do not feed between the onset of freshwater migration and spawning and they shrink an estimated 18–30% in length during this time (Kan 1975, Beamish 1980, Chase 2001, Clemens et al. 2009, Jackson and Moser 2012). Consequently, swimming speeds of smaller, spawning-stage individuals may be considerably lower than the swimming speeds applied in this study based on values derived from studies of larger, sexually immature individuals (Table 2-1). The effects of maturation level on swimming performance is particularly relevant to evaluation of road crossings, since a considerable portion of migration into tributaries—where many road crossings are located—likely occurs during the secondary migration to spawning (See Section 2.7.2).

It is unclear how other morphological changes associated with maturation, such as changes in fin structure, affect swimming ability. However, it is likely that spawning stage individuals have less energetic reserves than new migrants from the ocean, which may further decrease their swimming abilities.

2.7.2 Adult migration timing

Defining the time periods when most upstream migration is expected to occur is an important aspect of evaluating potential barriers to fish migration. Likewise, it is imperative to understand how passage ability at a given site varies with stream flow conditions. Defining migration periods allows estimation of the range of stream flows (and thus hydraulic conditions) lampreys typically experience upon reaching a road crossing. These minimum and maximum migration flows (also known as passage flows) are then used in analyses (e.g., FishXing) to determine how passage success at a given site varies with stream flow.

Notably, recent research suggests two distinct Pacific lamprey adult life history strategies may occur in some river systems: an "ocean maturing" life history that likely spawns several weeks after entering fresh water and a "stream-maturing" life history—the widely recognized strategy where one year is spent in fresh water prior to spawning (Clemens et al. 2013).

After entering fresh water from the ocean, adults of the stream-maturing life history typically spend approximately one year in freshwater prior to spawning (Robinson and Bayer 2005, Clemens et al. 2009, Lampman 2011, Starcevich et al. 2013). The adult freshwater residence period can be divided into three distinct stages: (1) Initial migration from the ocean to holding areas, (2) pre-spawning holding, and (3) secondary migration to spawning sites (Robinson and Bayer 2005, Clemens et al. 2010, Starcevich et al. 2013). Probable seasonal timing for each of these stages of the stream-maturing life history in the Eel River basin is summarized below.

2.7.2.1 Initial migration

The initial migration from the ocean to upstream holding areas in the Eel River is expected to occur from approximately January until early August (Stillwater Sciences 2010, McCovey 2011). In the Eel River and the nearby Klamath River, entry into freshwater from the ocean generally begins in January and ends by June (Petersen-Lewis 2009, McCovey 2011, Stillwater Sciences 2010). Most individuals cease upstream migration by mid-July, though some individuals continue moving into August (McCovey 2011, Starcevich et al. 2013).

2.7.2.2 Pre-spawning holding

The pre-spawning holding stage begins when individuals cease upstream movement, generally in June or July, and continues until fish begin their secondary migration to spawn, generally in March or April. During the holding period, most fish remain stationary throughout the summer and fall, but some individuals undergo additional upstream movements in the winter following high flow events (McCovey 2011, Starcevich et al. 2013). Most Pacific lampreys remain in mainstem rivers and larger tributaries during the pre-spawning holding stage (Robinson and Bayer 2005, Clemens et al. 2009, Fox et al. 2010, McCovey 2011), but some individuals hold in mid-size and smaller tributaries (Fox et al. 2010, Stillwater Sciences 2010). For example, in the Eel River basin, adults have been documented holding in the summer in relatively small streams, including Fox and Rock creeks in the South Fork Eel sub-basin (B. Trush, McBain & Trush, pers. comm. 2 May 2010), Ryan Creek, a tributary to Outlet Creek (S. Harris, CDFW, pers. comm., 21 May 2010), and Cahto Creek, a tributary to Tenmile Creek in the upper South Fork Eel sub-basin (D. Goodman, USFWS, unpubl. data, 2012).

2.7.2.3 Secondary migration to spawn

Following the pre-spawning holding period, individuals undertake a secondary migration from holding areas to spawning areas. This migration generally begins in March and continues through July, by which time most individuals have spawned and died (Robinson and Bayer 2005, Stillwater Sciences 2010, Lampman 2011, Starcevich et al. 2013). During this secondary migration, movement to spawning areas can be upstream or downstream (Robinson and Bayer 2005, Lampman 2011, Starcevich et al. 2013). Additionally, individual Pacific lampreys have been documented spawning in multiple locations, moving substantial distances (up to 16 km) in the spring between spawning areas (Starcevich et al. 2013). For this reason, individuals may encounter multiple road crossings during this period. Most Pacific lampreys are thought to spawn in mainstem rivers and larger tributaries (Robinson and Bayer 2005, Gunckel et al. 2009, Fox et al. 2010, Starcevich et al. 2013), but some individuals spawn in smaller streams (J. Strange, Stillwater Sciences, pers. comm., 14 June 2012; R. Taylor, RTA, pers. comm., 29 March 2013; Stillwater Sciences 2010).

Life-history timing for the freshwater stages of adult Pacific lampreys is shown in Figure 2-6. Since most potential passage barriers occur in tributaries, understanding timing of migration into tributaries is particularly important. We infer that the key passage period for sexually immature adults entering tributaries on their initial migration occurs from February through July. The key passage period in tributaries for individuals undergoing winter movements and the secondary migration to spawn is from December through June (Figure 2-6). Since migration of adult Pacific lampreys occurs over a broad period, they are expected to experience a range of flow conditions as they encounter road crossings, ranging from winter base flows in the winter through early spring to lower flows in the later spring and early summer.

Table 2-4. Approximate life history timing and key passage periods for freshwater stages of stream-maturing adult Pacific lampreys of a single run cohort in the Eel River.

Adult freshwater stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Initial migration from ocean[1,2,3,4]																			
Pre-spawning holding[2,3,5]																			
Secondary migration and spawning[1,3,6,7]																			
Key passage periods	initial migration											Winter[5] and spawning migrations							

[1] Stillwater Sciences (2010)
[2] McCovey (2011)
[3] Starcevich et al. (2013)
[4] Some individuals may enter freshwater as early as November. In the Klamath River, this early run was historically more common than today (Petersen-Lewis 2009, Larson and Belchik 1998).
[5] Some individuals make upstream movements during winter following high flow events (McCovey 2011, Lampman 2011, Starcevich et al. 2013).
[6] Robinson and Bayer (2005)
[7] Lampman (2011)

2.7.3 Water temperature

Lampreys, like most other fish species, are obligate poikilotherms; that is, they do not have the ability to metabolically control their body temperature. Consequently, their body temperature fluctuates nearly in unison with that of surrounding water and thus changes in temperature greatly influence both their behavioral and physiological processes (Clemens et al. 2009, Moser and Mesa 2009, Lampman 2011, Starcevich et al. 2013). Fish swimming performance is reduced at water temperatures above and below levels they typically experience (Castro-Santos 2011), leading us to expect water temperature to affect Pacific lamprey passage ability. Hanson (1980) showed that sea lamprey swimming activity (in terms of individuals attempting to approach an experimental flume) increased with increasing water temperatures. Sea lamprey swimming speed was also found to be positively related to water temperature at temperatures from 5 to 15°C (Beamish 1974). In contrast, a recent study in which Pacific lampreys were exposed to daily mean temperatures up to approximately 20°C during migration, indicated temperature was negatively correlated with passage success at low-head diversion dams (Jackson and Moser 2012). More information on the effects of water temperature on swimming ability and passage success of Pacific lampreys at road crossings is needed. In particular, it would be valuable to identify low and high temperature thresholds that significantly reduce passage success.

2.8 Passage Criteria Summary

Table 2-5 summarizes factors affecting Pacific lamprey passage at road crossings and lists key uncertainties. As discussed above, it is important to note that the values listed here are preliminary and meant to serve as a basis for further understanding passage criteria for lamprey. This review and its application to assessing passage at sites in the Eel River basin will help identify key hypotheses that can be experimentally tested to refine passage criteria at road crossings. In our assessment, we used these criteria conservatively; that is, we erred on the side of underestimating passage ability when considerable uncertainties existed at a given site. Additionally, the passage status of sites was designated as “unknown” when uncertainties were too large to permit a reliable prediction of lamprey passage ability.

Table 2-5. Summary of factors affecting adult Pacific lamprey (PL) passage at road crossings and key uncertainties.

Passage criteria	Explanation/value	Source	Key uncertainties	FishXing application
Swimming performance				
Critical swimming speed (U_{crit})	At sites lacking attachment points for resting, assume PL can pass when water velocities <0.86 m/s.	Mean critical swimming speed of sexually immature adult PL at 15°C = 0.86 m/s (Mesa et al. 2003).	- Value may underestimate PL swimming performance during passage through road crossings. - Length of time (and distance) critical swimming speed can be sustained.	Applied as "Prolonged speed" parameter = 0.86 m/s.
Burst swimming speed (U_{max})	At sites with suitable attachment points for resting, assume PL can pass using burst-and-attach behavior when water velocities <2.7 m/s.	Velocities of 2.5–3.0 m/s impeded sexually immature adult PL passage through weir, despite availability of attachment points (Keefer et al. 2010).	- Time to exhaustion at burst swimming speed. - Ability to burst-and-attach on corrugated culvert surfaces.	Applied as "Burst speed" parameter (when Prolonged speed exceeded).
Time to exhaustion using burst-and-attach swimming behavior	If suitable attachment points available, assume PL can engage in burst-and-attach swimming for 20 minutes before exhaustion.	Conservative estimate.	- Time to exhaustion using burst-and-attach swimming behavior. - Factors affecting exhaustion.	Applied at sites with suitable attachment points.
Time to exhaustion at burst speed	If suitable attachment points *not* available, assume time to exhaustion at burst speed is 10 s.	Default value in FishXing model; extrapolated from studies on other fish species.	Time to exhaustion at burst swimming speed.	Applied at sites without attachment points.
Minimum water depth	Assume minimum water depth for successful passage ≥3 cm (0.1 ft).	Conservative value based on evidence that PL can ascend inclined ramps with 3cm depth (Moser et al. 2011).	- Behavioral avoidance of shallow water. - Relationship between depth and distance PL can pass. - Effects of depth on swimming speed.	Used to parameterize minimum water depth.
Attachment, leaping, and climbing capabilities				
Attachment substrate material	PL can attach to a wide range of non-porous artificial and natural materials. Damaged or rusted out bottoms may preclude attachment.	Adams and Reinhardt 2008; Reinhardt et al. 2008; Moser and Mesa 2009; Moser et al. 2011.	Variation in energetic demand between different attachment surfaces and relationship to exhaustion time.	Used to help determine which swim speed and exhaustion criteria are applied.

Passage criteria	Explanation/value	Source	Key uncertainties	FishXing application
Attachment substrate shape and configuration	PL can attach to a wide range of substrate shapes. Discontinuities in surface (e.g., deep slots or grates) and 90° corners at baffles, weirs, or fish ladders lowing may impede or block passage.	Adams and Reinhardt 2008; Reinhardt et al. 2008; Kemp et al. 2009; Moser and Mesa 2009; Moser et al. 2011.	- Ability to attach to culvert corrugations with different shapes and configurations. - Ability to attach to and use burst-and-attach behavior on non-uniform substrate surfaces such as corrugations. - Effects of attachment shape on swimming performances.	Used to help determine which swim speed and exhaustion criteria are applied.
Attachment substrate size	- Assume PL can attach to substrates with minimum surface length and width ≥ diameter of oral disc. - Assume *all* PL can attach to corrugations with diagonal surface dimensions >4.6 cm (1.8 in) and *most* can attach to most smaller corrugation sizes by contorting their oral discs.	Based on reported oral disc diameters and common culvert corrugation sizes.	- Effects of various size culvert corrugations on attachment, burst swimming speed, and exhaustion time. - Smaller corrugation sizes may reduce velocities that can be passed using burst-and-attach swimming.	Used to determine whether burst-and-attach swimming behavior is possible and thus which exhaustion criteria is applied.
Climbing ability	PL can climb most wetted vertical or steeply sloped surfaces (assuming attachment criteria are met); however, they have difficulty passing vertical features ending in abrupt right angles.	Reinhardt et al. (2008), Kemp et al. (2009), Keefer et al. (2011), Zhu et al. (2011).	Ability to attach to and climb slightly perched culvert outlets or concrete outlet aprons with right angle steps.	Not applied, but used to assist with interpretation of results at some sites.
Leaping ability	PL cannot leap. Crossing outlets perched above downstream water surface elevation are assumed impassable at that flow.	Conservative assumption based on Moser and Mesa (2009) and professional judgment.	Ability to swim up or attach to and climb slightly perched culverts.	Used to parameterize “Max Leap Speed”.

3 PASSAGE EVALUATION AND PRIORITIZATION FOR REMEDIATION

3.1 Methods

3.1.1 Stream channel network development and attribution

Geographic Information Systems (GIS) was used throughout the project for identifying potential barriers, and as a tool for rapidly focusing the evaluation, streamlining the site selection process, and prioritizing sites for field assessment and remediation in the massive Eel River basin. Specifically, we developed a high-resolution channel network attributed with contributing drainage area and channel gradient. This channel network helped locate each potential barrier in the larger Eel River basin and predict upstream habitat potential. The process of developing and attributing the channel network is described below.

Eel River channels were developed from the USGS National Hydrography Dataset (NHD) High dataset at a scale of 1:24,000. NHD-High channels were downloaded, merged, and edited (missing channels added, grossly misaligned paths corrected, and small first-order channels removed) to create a complete, homogeneous, single-line channel network for the Eel River basin.

Channel gradient for each GIS arc (the smallest discrete sections of the channel network) was calculated by intersecting the resultant channel network with 10-m elevation contours derived from the USGS 1/3-arc-second National Elevation Dataset (NED) digital elevation model (DEM) and dividing the elevation difference between upstream and downstream ends by the length between them. Confluence nodes, created in the generation of the channel network, were removed from this calculation since they were not intersected by an elevation contour. Using exclusively vector channel data and the 10-m contours eliminates artifacts introduced by using the source digital terrain model data (averaging local differences in slope between neighboring DEM cells) and provides the best available approach to calculating channel gradient in the project area.

Drainage area for each arc in the channel network was calculated by obtaining the contributing area to 10-m grid-cells and overlaying arc endpoints and tributary junctions. Drainage area was calculated using the hydrological functions in ESRI's ARCINFO, which fills artificial sinks in the DEM and allows flow routing along the path of steepest elevation drop in the terrain.

Following channel network attribution, contributing drainage area and length of upstream channels with gradients in specified ranges (0–1%, 1–2%, 2–4%, 4–8%, 8–12%, and >12%) were calculated for each potential barrier site. These data were used in site prioritization and prediction of upstream habitat potential as described above.

3.1.2 Site selection

The systematic process used to identify potential barriers to Pacific lamprey adult passage in the Eel River basin and select sites for field evaluation is summarized in Figure 3-1 and detailed in the sections that follow.

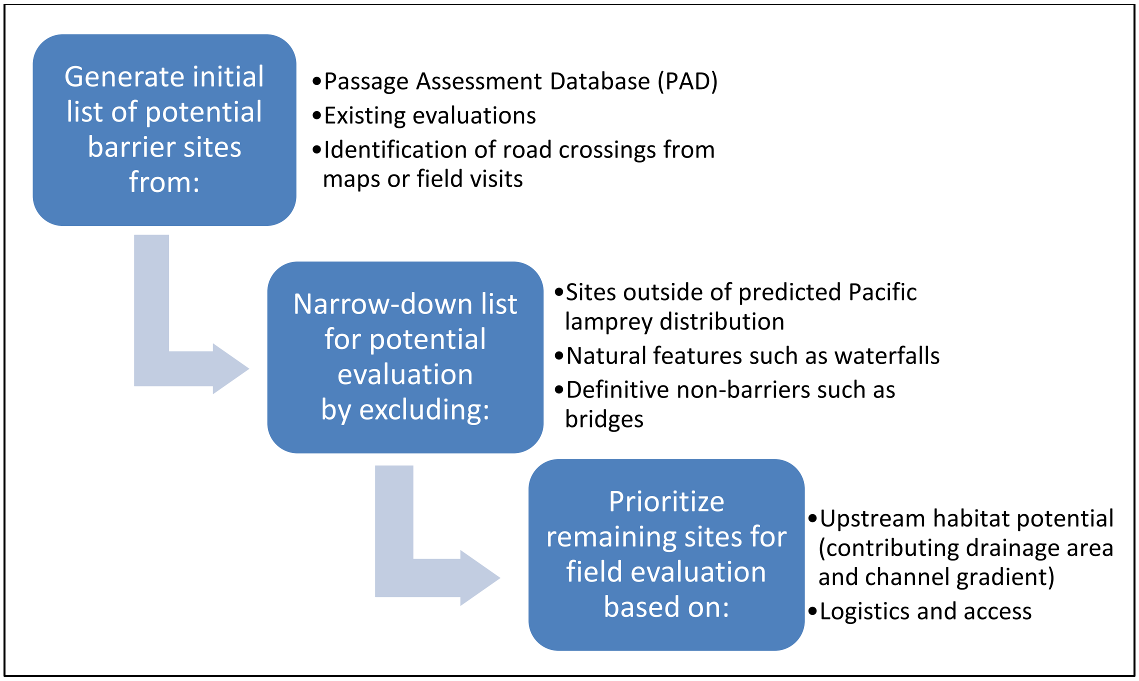


Figure 3-1. Process used to select potential barriers requiring further evaluation.

3.1.2.1 Initial list of potential barriers

A list of potential barriers to Pacific lamprey migration in the Eel River basin was compiled to serve as the starting point for identifying passage barriers. The primary source of information for the initial list was the September 2012 Passage Assessment Database (PAD), which is maintained by the California Cooperative Anadromous Fish and Habitat Data Program (CalFish) (CDFW 2012). The PAD is a periodically updated, map-based inventory of potential barriers to anadromous fish in California. While not comprehensive, the PAD contains most available information on potential barriers to fish passage in the Eel River basin, including records of road crossings, diversions, dams, tide gates, and natural features such as waterfalls. In addition to potential barriers identified from a query of the PAD, we identified a number of other potential barriers not listed in the PAD by (1) reviewing recent fish passage evaluation reports (e.g., Lang 2005, RTA 2011), and (2) examining watersheds of interest using Google Earth to locate road crossings not in the PAD.

3.1.2.2 Narrowed down list of potential barriers

The initial list of potential barriers from the PAD included numerous sites crossing very small, high-gradient streams not expected to support Pacific lamprey populations, currently or historically. Therefore, to streamline and focus the evaluation, the initial list was narrowed-down by excluding sites not expected to be within the historical distribution of the species. Historical and current distribution records from the Eel River and other watersheds in the region were first reviewed to help understand the smallest channels typically utilized by Pacific lampreys. Adult Pacific lampreys have been documented holding in Fox Creek and Rock Creek, small tributaries to the upper South Fork Eel River, with drainage areas of approximately 2.7 km^2 and 7.5 km^2, respectively (B. Trush, McBain and Trush, pers. comm., 20 May 2010). Pacific lampreys have been observed spawning in Ryan Creek (tributary to Outlet Creek) at a location with a drainage area of approximately 5.7 km^2 (R. Taylor, RTA, pers. comm., 29 March 2013). Pacific lamprey ammocoetes have been documented in Broaddus Creek (tributary to Outlet Creek) and holding adults and ammocoetes in Cahto Creek (tributary to Tenmile Creek) at locations with drainage areas of approximately 15 km^2 (D. Goodman, USFWS, unpubl. data, 2012). Based on these observations and Pacific lamprey upper distribution data from studies in other northwestern streams (Stone 2006, Gunckel et al. 2009, Starcevich and Clements 2013, Dunham 2013), we applied a minimum basin size criterion of 2 km^2 to exclude potential barriers crossing very small streams; that is, only sites located in channels with a contributing drainage area larger than 2 km^2 were included for potential evaluation. This criterion was selected to be conservative, erring on the side of including streams that may be smaller than that currently used by Pacific lamprey. Lamprey distribution surveys in the Eel River basin planned for 2014 will help validate use of this minimum stream size criterion. Refer to Section 3.1.1 for more information on how contributing drainage area was estimated for each site.

After excluding sites with a contributing drainage area smaller than 2 km^2, the list of potential barriers was further reduced based on site-specific information provided in the PAD or existing reports (e.g., Lang 2005, RTA 2011). Specifically, PAD records that were definitively not barriers, such as large bridges or properly-sized, open-bottom arch culverts over natural channels, were omitted from the list. Some sites listed as bridges in the PAD were not omitted from the list of sites for possible evaluation since it was unclear whether associated infrastructure would be a passage barrier. Finally, PAD records for sites that were not manmade, such as waterfalls, cascades, debris jams, or alluvial fans associated with tributary confluences were excluded from potential as evaluating these features was beyond the scope of this study.

3.1.2.3 Prioritization for field evaluations

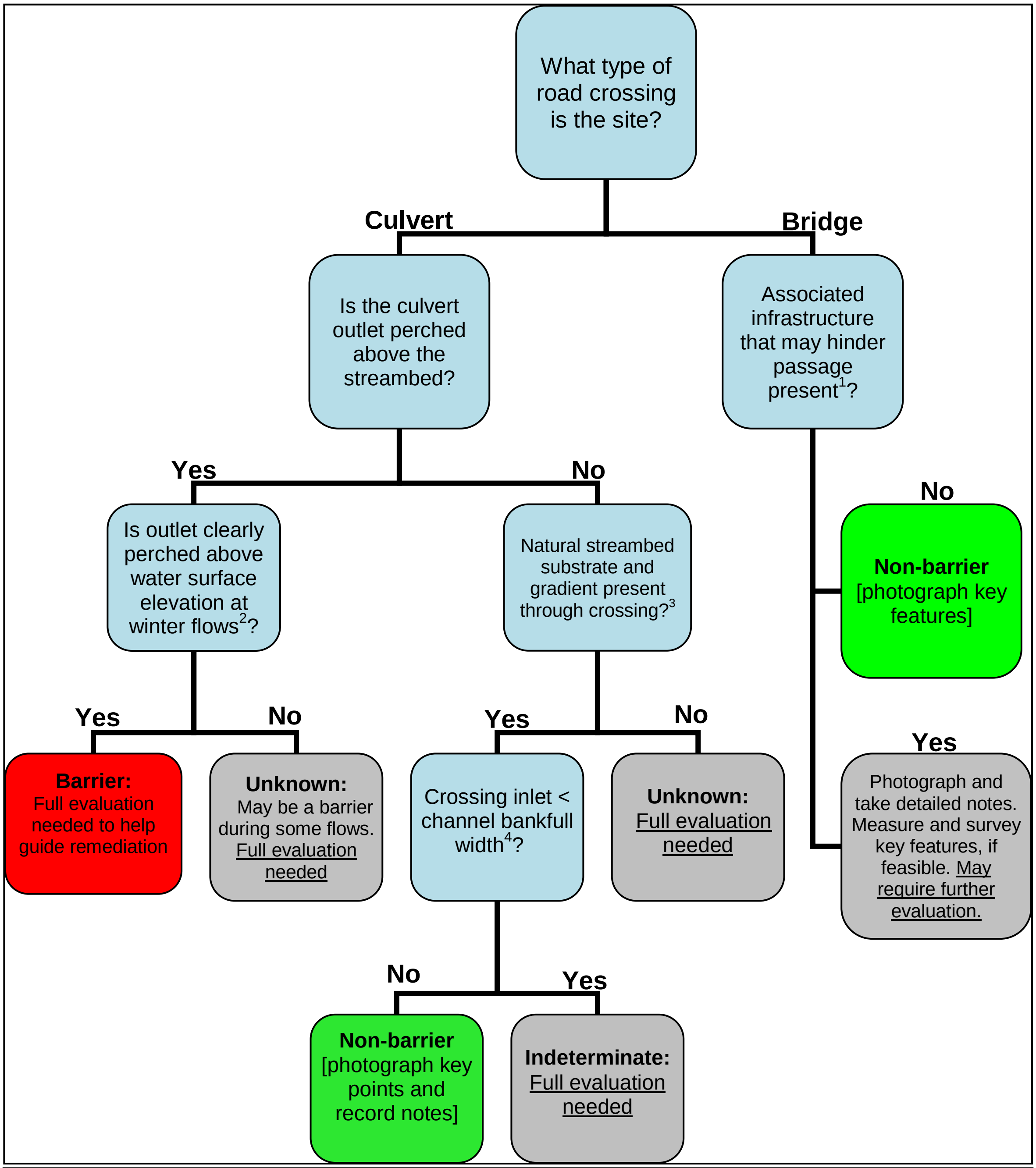
Due to the sheer size and general inaccessibility of the Eel River basin, field assessment of all potential manmade barriers within the predicted Pacific lamprey distribution was not feasible. Consequently, we systematically selected a subset of those sites for field evaluation. Relative habitat potential upstream of each crossing was used as the primary prioritization factor for selecting field sites. Then factors such as landowner access, accessibility, safety, proximity to high priority sites, and drive time were taken into consideration in making final site selections. Relative habitat potential upstream of each site was based on contributing drainage area upstream of each crossing and length of low-gradient channel upstream (calculated using GIS analyses as described in Section 3.1.1). Larger streams are generally more likely to be used by Pacific lampreys for spawning and have a greater amount of suitable habitat per unit length than smaller streams (Stone 2006, Gunckel et al. 2009). Lower-gradient channels are generally expected to contain more high quality lamprey spawning and rearing habitat compared with high-gradient channels due to greater deposition of fine sediments and spawning gravels (Torgersen and Close 2004, Lê et al. 2004, Gunckel et al. 2009). To compare potential availability of upstream low gradient habitat between sites, we calculated length of channel with gradient less than 2% upstream of each crossing but downstream of locations in the channel network where contributing drainage area <2 km^2 (the smallest drainage areas assumed to support Pacific lamprey). In general, we prioritized evaluation of sites with larger drainage areas; however, we were more likely to visit sites with smaller drainage areas if they had significant amounts of low-gradient habitat upstream. We also opportunistically assessed some sites that were not necessarily high priority when they were near, or on the way to, high priority sites.

3.1.3 Field evaluations

Field-based evaluations aimed at determining passage status for potential Pacific lampreys barriers were carried out between October 2012 and October 2013. The Wiyot Tribe's Natural

Resources Department (NRD) conducted all fieldwork, with initial training and periodic technical assistance provided by Stillwater Sciences.

In some cases, information provided by the PAD was insufficient to make an office-based determination as to whether a full passage evaluation was required. Thus, upon arriving at a selected field site, we used an initial passage evaluation filter to objectively determine whether a full evaluation was required (Figure 3-2).



1 Examples include trash racks, vertical steps, or significant channel constriction from abutments.
2 Use active channel indicators at outlet to approximate high flow water surface elevation.
3 Streambed substrate is continuous throughout the crossing and the streambed gradient and particle size similar to the adjacent channel.
4 Measured upstream of structure and away from its zone of influence (i.e. upstream of aggradational wedge caused by inlet control).

Figure 3-2. Initial passage evaluation filter used to help designate barrier status and whether field sites required evaluation.

If we determined that a full field evaluation was required for a given site, we did the following:

- assessed physical characteristics of the road crossing and adjacent channel as related to lamprey passage criteria,
- qualitatively evaluated spawning and rearing habitat upstream and downstream of the site, and
- sampled for the presence of Pacific lamprey ammocoetes upstream and downstream of the site.

3.1.3.1 Physical characteristics of crossing and channel

The primary purpose of field evaluations was to determine whether a given road crossing represented a barrier to adult Pacific lamprey migration. We developed a protocol for assessing the physical characteristics of each site related to lamprey passage based in large part on protocols designed for salmonids (Taylor and Love 2003, Clarkin et al. 2005); however, we refined and modified these protocols for Pacific lampreys.

Assessing physical characteristics of a site consisted of:

- describing the location and physical characteristics of the crossing on a site information form,
- surveying a longitudinal profile of the channel through the crossing,
- conducting a cross-sectional survey of the tailwater control (the hydraulic control point in the channel that controls water surface elevation at the culvert outlet),
- photographing key features, and
- making a detailed sketch of the site showing key features and the adjacent channel.

The site information form showing which data were collected at each site is provided in Appendix A, along with the other data sheets used in passage assessment. This form was based largely on standard datasheets provided by Clarkin et al. (2005), but modified to include lamprey-specific considerations such as attachment points (substrate surfaces where lampreys can attach and rest or use burst-and-attach swimming). For conducting longitudinal profile and tailwater control cross section surveys, we followed the methods described in Taylor and Love (2003) and Clarkin et al. (2005). The primary purpose for collecting this data was to analyze passage ability across a range of flows using FishXing. The longitudinal profiles provide relative elevations of, and distances between, crossing inlets and outlets (allowing calculation of slope) and key points in the channel upstream and downstream of the crossing. The tailwater control cross section allows prediction of tailwater water-surface elevations across the range of flows at which lamprey migration is expected to occur. Typically, tailwater surface elevation increases with increasing flow, sometimes allowing lampreys access to what may otherwise be a perched culvert outlet at lower flows. Several study sites were too complex to evaluate reliably with FishXing, for example, those with complex weirs or culverts with internal modifications or fish ladders. Therefore, we did not conduct longitudinal profile or tailwater cross-section surveys at these sites. In other cases, to avoid duplication of effort, we used recently collected longitudinal profile and tailwater cross-section survey data provided by Ross Taylor Associates (RTA). Site photographs and detailed site sketches were useful during data analysis, results interpretation, and passage designation. Example site sketches are provided in Appendix B.

Data from past fish passage evaluations in the Eel River basin were also used to evaluate lamprey passage potential at some field sites visited. These data were taken from existing reports (RTA

2000, 2005, 2011; Lang et al. 2005) or unpublished raw data provided by RTA. Generally, these evaluations contained information on physical characteristics of the site and longitudinal profile and tailwater cross-section survey data that could be used to estimate lamprey passage using FishXing. In some cases (e.g., when sites were easily accessible or near other field sites), a partial assessment was completed at sites where existing data were available to add lamprey-specific information and evaluate distribution and habitat in relation to the site.

3.1.3.2 Habitat assessment

The primary objective of habitat assessments was to describe relative quality of Pacific lamprey spawning and rearing habitats in the vicinity of each site as input into the prioritization of sites requiring remediation. A secondary objective was to improve understanding of habitat factors that might limit lamprey production in the basin (Stillwater Sciences 2014). Following assessment of passage potential, Pacific lamprey spawning and rearing habitats were qualitatively characterized both upstream and downstream for a minimum target of 100 m of channel. Professional judgment was used to qualitatively categorize both spawning and rearing habitat quantity and quality across the surveyed reaches as Poor, Fair, Good, or Excellent relative to other reaches. In addition, detailed notes on habitat suitability were recorded and photos were taken to help support qualitative designations. These habitat surveys provide a snapshot of lamprey habitat quality and were used in conjunction with other available information (such as GIS-predicted channel gradient and CDFW Stream Inventory Reports) when making conclusions about the overall habitat potential of each stream.

Water quality parameters—including water temperature, conductivity, salinity, dissolved oxygen concentration, pH, and turbidity—were also measured at select field sites to evaluate the existence of other potentially limiting factors. Water quality methods and a results summary prepared by the Wiyot Tribe’s NRD are presented in Appendix C.

3.1.3.3 Pacific lamprey presence-absence surveys

Where access allowed and suitable habitat existed, electrofishing surveys were conducted both downstream and upstream of each crossing visited in the field to assess presence/absence of Pacific lamprey ammocoetes and juveniles (eyed ammocoetes and macropthalmia). These surveys were used to help inform passage status designations. For example, if Pacific lamprey ammocoetes were found upstream, the crossing could not be considered a total barrier; if they were not found in suitable habitat upstream, but were found immediately downstream, the crossing may be a passage barrier. In addition to sampling at potential barriers, we opportunistically sampled a number of streams adjacent to barrier sites (typically the confluence of tributaries and larger streams). These surveys also provided much needed information on lamprey distribution in Eel River basin, summarized in a separate report that explores potential limiting factors (Stillwater Sciences 2014). Finally, if a barrier is eventually selected for removal/retrofit, these surveys will provide baseline data for evaluating post-implementation passage effectiveness.

An ETS AbP-2 backpack electrofisher specifically designed to capture ammocoetes and juvenile lampreys was used to sample likely rearing habitat (low-velocity areas containing fine, silty substrate) upstream and downstream of each site. All such habitat was sampled until one of the following occurred: (1) access was restricted, (2) approximately 100 m of channel was sampled, or (3) no suitable rearing habitat was present within 100 m of the barrier. In some instances, more than 100 m of channel was sampled.

Electrofishing surveys were carried out by a field crew consisting of the electrofisher operator and one or two netters. A single-pass of slow-pulse shocking was applied to all suitable habitat for approximately 60–90 s per square meter of habitat. Direct current was delivered using the primary slow-pulse electrofishing channel at three pulses per second to induce ammocoete emergence from substrate. A 25% duty cycle and 3:1 burst-pulse train cycle were applied. When necessary to aid in capture, ammocoetes that emerged were stunned with the secondary fast-pulse electrofishing channel with a direct current of 30 pulses/s. Peak output voltage for both channels was typically 125 V. Sampling effort upstream and downstream of each site was recorded as seconds of time the slow-pulse current was applied using the built-in timer on the AbP-2 electrofisher. Length of stream surveyed was estimated using GPS coordinates of sampling start and end points and the measuring tool on Google Earth.

All captured lampreys were anesthetized with MS-222, measured to the nearest 1 mm, identified to genus (either *Entosphenus* or *Lampetra*) by examining caudal fin and ventral pigmentation (Goodman et al. 2009), and categorized by life stage (ammocoetes, eyed ammocoetes, macropthalmia, or adult). Field crew received training in lamprey ammocoete identification prior to conducting surveys and referenced a field identification key for western lampreys as needed (Reid 2012). After recovering from anesthesia, all captured individuals were released to their original collection location.

3.1.4 Passage status designation

A multipronged approach was used to evaluate the extent to which each field site represented a barrier to adult Pacific lamprey migration. For each site, evidence from one or more of the following was used along with passage criteria (Section 2) to inform designation of passage status:

- results of the initial passage evaluation filter,
- field observations and data from physical assessment of the site,
- professional judgment,
- FishXing analysis,
- ammocoete sampling results,
- existing information from the PAD, and/or
- results from past fish passage evaluations.

Based on evidence from these sources, sites were assigned into one of the following barrier status categories for Pacific lamprey:

Passage designation	Description
Total barrier	Barrier to passage at all migration flows.
Partial barrier	Barrier to passage at only a portion of migration flows.
Non-barrier	Not a barrier to passage at any migration flows.
Unknown	Insufficient information available to make a passage designation.

Some sites designated as *Partial Barrier* or *Non-barrier* may allow passage at some flows, but may interrupt or impede migration at other flows compared with the natural channel, increasing energetic costs and reducing fitness. These sites are sometimes referred to as obstacles in this report.

3.1.5 Partial assessments

The field crew did not carry out the full suite of field protocols at every site visited, usually for one of the following reasons:

- the site was not a crossing or clearly did not present a barrier,
- the site was unambiguously a total barrier due to having an extremely perched outlet,
- evaluation was deemed low-priority due to small stream size and poor habitat potential,
- the crew was nearby and elected to assess the site, but did not have time for a full assessment, or
- the site was not accessible due to being on private property.

Where possible, each of these sites was assessed with the initial passage evaluation filter (Figure 3-2) and photo-documented to help inform the potential need for future visits or to allow for potential designation of passage status. Additionally, habitat and ammocoete presence-absence were carried out at a number of these sites when time and access allowed. Despite not conducting full passage evaluations, we were able to make informed passage designations at a number of sites that were unambiguous non-barriers or total barriers using the initial passage evaluation filter and professional judgment. For partially assessed sites where barrier status was not clear-cut, we erred on the side of designating sites as *Unknown*. In cases where the site appeared to be a partial barrier based on professional judgment, we added a secondary designation of "*likely partial barrier*." These sites require additional assessment and were not included in the final prioritized list of sites requiring remediation.

3.1.6 FishXing analysis

For sites where it was not possible to determine passage status from field evaluations alone and sufficient data were available, the free analytical program "FishXing" (Version 3.0) was used to predict lamprey passage ability across the range of stream flows expected to occur during migration.

Detailed information about the model and the software can be downloaded from the FishXing website (http://stream.fs.fed.us/fishxing/). The following is an overview of the FishXing model from the online manual:

> FishXing is a unique software tool for the assessment and design of culverts for fish passage. FishXing models the complexities of culvert hydraulics and fish performance for a variety of species and crossing configurations. The model has proven useful in identifying culverts that impede fish passage, leading to the removal of numerous barriers. As a design tool, FishXing accommodates the iterative process of designing a new culvert to provide passage for fish and other aquatic species.
>
> FishXing is an interactive software package that integrates a culvert design and assessment model for fish passage. The software models organism capabilities against culvert hydraulics across a range of expected stream discharges. Water surface profiles can be calculated for a variety of culvert shapes using gradually varied flow equations. The program then compares the flows, velocities and leap conditions with the swimming abilities of the fish species of interest. The output includes tables and graphs summarizing the water velocities, water depths, and outlet conditions, then lists the limiting fish passage factors and flows for each culvert.

3.1.6.1 Model Parameterization

Data from field measurements of physical characteristics of each crossing and the adjacent channel were used along with passage criteria developed for adult Pacific lampreys (Section 2) as input parameters to the FishXing model. Figure 3-3 below provides an example of the input screen of the model user interface. The approach we used for parameterizing each component of the model is described in the sections that follow.

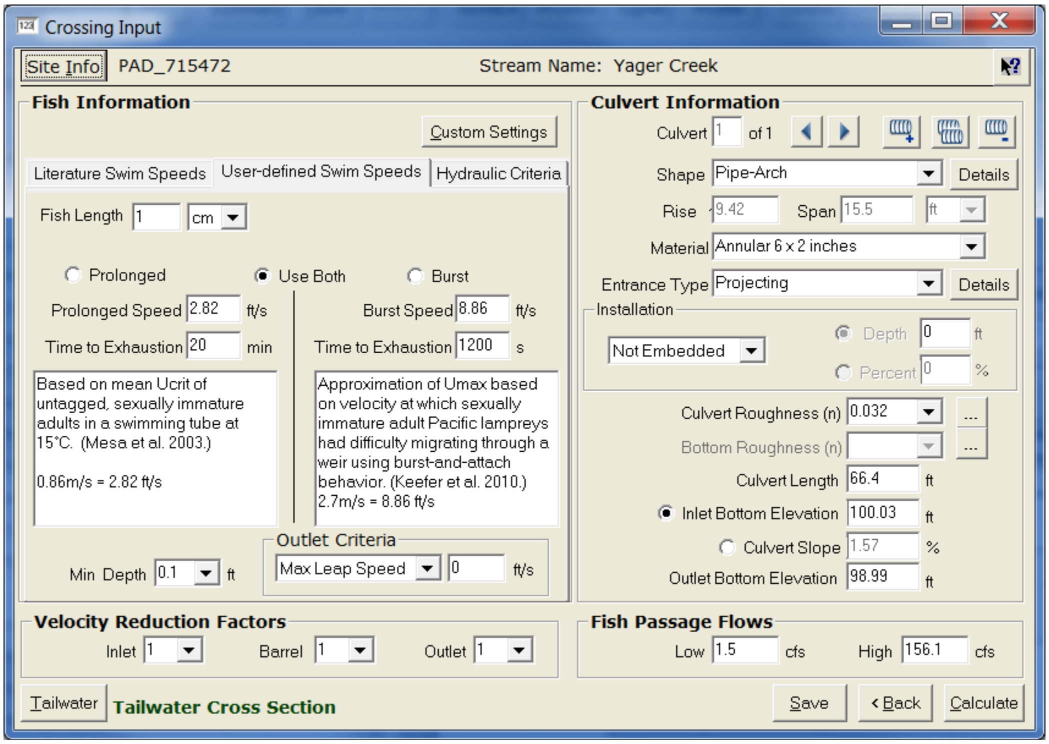


Figure 3-3. Example of FishXing user interface where model parameters are entered.

Physical characteristics of site

For each site, FishXing requires data on the crossing shape, material, entrance type, bottom roughness, length, inlet and outlet elevations, and slope. These parameters were entered based on field measurements and the longitudinal profile cross-section survey described in Section 3.1.3.1.

The tailwater control downstream of the culvert outlet was parameterized in FishXing in one of two ways: (1) entering elevation data from a tailwater cross-section survey tied into the longitudinal profile; or (2) "the constant water surface method," which makes the simplifying assumption that tailwater elevation does not change with changes in flow. This method requires entry of the water surface and bottom elevations of the outlet pool.

In general, we attempted to parameterize the model using the tailwater cross-section method, but applied the constant water surface method when there was not an obvious hydraulic control, or in a few cases where the tailwater cross section was surveyed in the incorrect location. When using the constant water surface method at some sites where there was a hydraulic control (but where reliable tailwater control survey data were lacking), we "gamed" the model by inputting a range of hypothetical tailwater water surface elevations to evaluate how depth and water velocities within the crossing might vary with stream flow. Results from this approach were viewed with caution, but in cases where the model predicted the site was either not a barrier or a total barrier across the broad range of water surface elevations used in model gaming, we could confidently assign a barrier status designation.

Migration flows

For streams with sizes similar to our study streams (contributing drainage areas ranging approximately 2–50 km^2), we expect that upstream migration of adult Pacific lamprey is naturally delayed during extreme high-flow events and also low-flow periods when water depths through riffles may impede passage. Therefore, we only evaluated passage at road crossings at the range of flows expected during migration in a natural stream channel. For the purposes of FishXing, at each site, the "high migration flow" was defined as the 5% exceedance flow during the core lamprey migration period of December through July. The "low migration flow" was defined as the 90% exceedance flow during the same period. Figures 3-4 provides a hypothetical example of a flow duration curve for a gaged stream during the migration period, with 5% and 90% exceedance flows indicated. These values relate to the low and high "Fish Passage Flow" values required as input by the FishXing model (Figure 3-3).

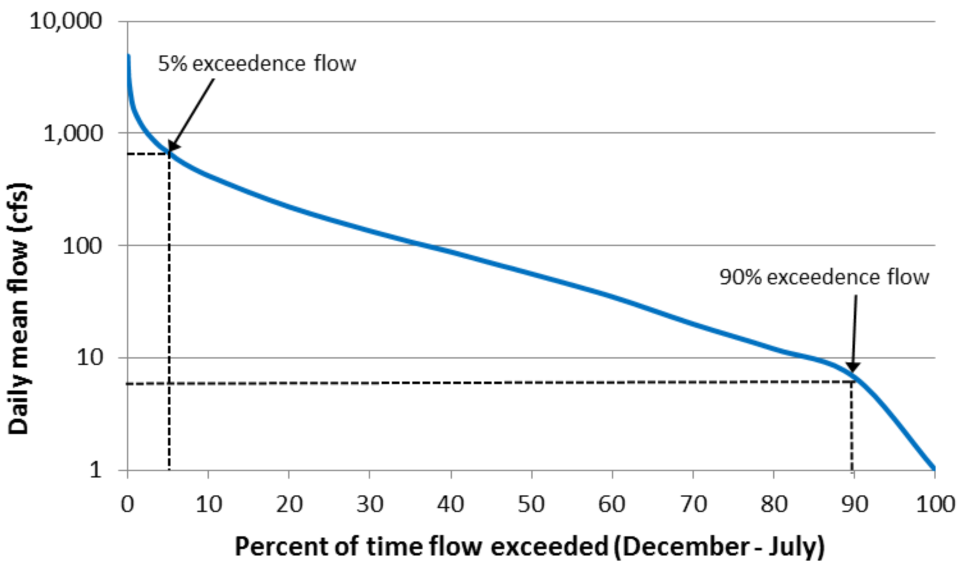


Figure 3-4. Example flow duration curve used to estimate fish migration flows. Data from Bull Creek, 1961–2003 (USGS gage 11476600).

Because most study sites were on ungaged streams, we estimated migration flows at each site based on data from nearby gaged streams with similar elevations, aspect, and rainfall patterns. Approximate annual rainfalls were based on mean annual precipitation data from 1981 to 2010 (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu). We used the approach described by Taylor and Love (2003), whereby migration flows at ungaged sites were calculated by multiplying exceedance flows (90% and 5% in this case) at gaged sites by the ratio of the gaged stream's drainage area to the ungaged stream's drainage area at the study site. This simplified approach assumes that discharge and exceedance flows are proportional to drainage area. Refer to Taylor and Love (2003) and the FishXing user manual for more information on defining and calculating migration flows (http://www.fsl.orst.edu/geowater/FX3/help/FX3_Help.html). Appendix D shows the data used to calculate upper and lower migration flows for each fully-assessed study site.

Lamprey biological parameters

Biological parameters ("Fish Information" in the model) applied in FishXing were based on the review of Pacific lamprey passage criteria (Section 2). The parameter values used are summarized in Table 3-1. Due to a lack of experimental studies defining passage criteria and considerable uncertainties in many of these values, we erred on the side of selecting conservative values. Key uncertainties in passage criteria are discussed in more detail in Section 2.

Table 3-1. Biological parameter values applied in the FishXing model for Pacific lamprey.

FishXing parameter	Value	Notes / rationale
Fish length	1 cm	Value selected to disable model features that allow fish to enter some perched culverts by swimming.
Prolonged swim speed	2.82 ft/s (0.86 m/s)	Based on mean critical swimming speed of untagged, sexually immature adults in a swimming tube at 15°C (Mesa et al. 2003). Applied in the model until water velocities in the crossing exceeded the value.
Prolonged—time to exhaustion	1200 s (20 min)	Typical time it takes for a fish to reach exhaustion during prolonged (or critical) swimming. Did not come into play in model runs since passage always occurred more quickly than 20 minutes when water velocities were below the prolonged swimming speed.
Burst swim speed	8.86 ft/s (2.70 m/s)	Approximate maximum swimming speed based on velocities at which sexually immature adult Pacific lampreys had difficulty migrating through a weir using burst-and-attach behavior (Keefer et al. 2010).
Burst-and-attach—time to exhaustion	1200 s (20 min)	Applied when crossing had ample attachment points and burst-and-attach behavior was considered possible. Assumes individuals can attach and rest between bouts of burst-and-attach behavior and will not exhaust for at least 20 minutes.
Burst only—time to exhaustion	10 s	Applied when burst-and-attach behavior was not considered possible due to lack of suitable attachment surfaces. Typical value reported in FishXing swim speed table from studies on various other fishes and also model default value.
Maximum leaping speed	0 ft/s	Set to zero as recommended for fish that cannot jump such as lampreys. Does not allow fish to enter culvert outlet until the tailwater surface elevation is equal to outlet elevation.
Velocity reduction factors	1.0	Was not applied due to uncertainty as to how lampreys utilize low-velocity areas within culverts.
Minimum water depth	0.1 ft (3 cm)	Conservative value based on evidence from Moser et al. (2011) that Pacific lampreys can swim up inclined ramps with a water depth of 3 cm.

Outlet criteria

FishXing allows the user to apply either a maximum outlet drop or max leap speed to model ability of fish to enter the culvert outlet. We applied a leap speed of zero in accordance with the FishXing help manual, which recommends this for fish that cannot leap. Thus, if a fish is unable to swim into the outlet at designated flow, FishXing reports a leap barrier at that flow. FishXing is set up in a way that assumes a fish is able to swim into a culvert outlet when any of the following conditions are satisfied:

1. the water surface elevation of outlet pool (also known as the tailwater) is greater than or equal to the elevation of the culvert outlet;
2. the outlet drop is less than or equal to one half the fish length; or

3. the “plunge distance” is less than or equal to the fish length.

The second (2) and third (3) conditions are designed to allow fish to swim up the plunging water of slightly perched outlets. We disabled these parameters because we assumed lamprey generally cannot pass such obstacles. Since there may be flow conditions in which lampreys can swim or climb into some slightly perched outlets or concrete outlet aprons, our model results may underestimate the range of flows lampreys can enter some sites.

3.1.7 Prioritization for barrier remediation

We employed a two-phase approach for ranking sites for remediation based on projected benefits to Eel River lamprey populations. In Phase 1, all barrier sites were assigned an initial ranking score based on the severity of the barrier, stream size, and upstream habitat potential. In Phase 2, a number of other factors were considered (see 3.1.7.2) and professional judgment used to assign each site a final priority rating of *Low*, *Medium*, or *High*. The final list of prioritized barriers was stratified by *Small*, *Medium*, and *Large* stream-size categories to compare relative priority among similarly-sized streams. The sections below detail this approach.

3.1.7.1 Phase 1—Initial ranking

In Phase 1, we computed an initial ranking score that incorporated the extent to which each site is a barrier to lamprey migration, stream size (based on drainage area), and upstream habitat potential based on length of low-gradient channel. Barrier sites were then sorted by the initial ranking score to create a list that was used as a starting point for Phase 2 prioritization. The initial ranking factors and scoring process applied to each are described below.

Extent of barrier
The extent to which each site was predicted to be a barrier to Pacific lamprey migration was a key ranking factor, with more passable sites receiving lower scores and less passable sites higher scores. The range of score values assigned to each category were designed to give the extent of barrier score significant weight relative to the stream size and low-gradient scores described below.

Scoring

Percent of migration flows passable	Score
80–100%	0
60–80%	3
40–60%	6
20–40%	9
<20%	12
0% (Total barrier)	15

Stream size
Larger streams are more likely to be used by Pacific lampreys for spawning and have a greater amount of suitable habitat per unit length than smaller streams (Stone 2006, Gunckel et al. 2009). Therefore, stream size was a key ranking factor for prioritizing barrier remediation, with larger streams receiving higher scores than smaller streams.

Scoring

The stream size score was computed by dividing the contributing drainage area upstream of each site by four. For example, a crossing with contributing drainage area of 20.8 km^2 would be given 5.2 for a stream size score.

Low-gradient habitat

Lower gradient channels are generally expected to contain more high quality lamprey spawning and rearing habitat compared with high-gradient channels due to greater deposition of fine sediment and spawning gravels (Torgersen and Close 2004, Lê et al. 2004, Gunckel et al. 2009). To compare potential availability of upstream low-gradient habitat between sites, we calculated length of channel with gradient less than 2% upstream of each crossing but downstream of locations in the channel network where contributing drainage area is 2 km^2 (the smallest channels assumed to support Pacific lamprey).

Scoring

The low-gradient habitat score was obtained by dividing the number of kilometers of channel upstream of the barrier with gradient < 2% by two. For example, a crossing with 2.4 km of upstream channel with gradient < 2% would be given a low-gradient habitat score of 1.2.

3.1.7.2 Phase 2—final prioritization

In order to highlight the overall need for and relative benefits of barrier remediation across all sites, we considered a number of other factors in addition to the initial ranking scores and used professional judgment to assign each site a final priority rating of *Low*, *Medium*, or *High*. These factors included one or more of the following:

- relative habitat quality upstream of the site based on field observations, CDFW Stream Inventory Reports, and other evidence;
- condition and size of the culvert;
- relative cost and feasibility of remediation;
- likelihood that remediation would provide a significant benefit to other fish species; and
- presence, location, and barrier status of other crossings in each stream.

Because of the marked preference of Pacific lampreys for larger rather than smaller streams, and the fundamental differences in habitat potential between streams of varying sizes, we stratified the final list of barrier sites into small (2–6 km^2), medium (7–15 km^2), and large (16–40 km^2) stream-size categories based on the distribution of contributing drainage areas of the study sites.

3.1.7.3 Interpretation of priority ratings

When interpreting final priority ratings, sites designated as *High* priority should be considered higher priority for remediation than sites designated as *Medium* and *Low* priority—regardless of stream-size category. However, a barrier site in a large-sized stream should be considered higher priority than a site in a medium- or small- sized stream with the same priority rating. For example, a *Low* priority site in a medium-sized stream should be considered higher priority than a *Low*-priority site in small-sized stream. Table 3-2 outlines the relative priority order that should be used when interpreting final rankings of barrier sites in each stream-size category and priority rating.

Table 3-2. Barrier remediation priority rankings by stream-size category.

Relative priority order	Stream-size category	Priority rating
1	Large	High
2	Medium	High
3	Small	High
4	Large	Medium
5	Medium	Medium
6	Small	Medium
7	Large	Low
8	Medium	Low
9	Small	Low

3.1.8 Prioritization for future assessment

We were unable to evaluate all potential barriers to Pacific lamprey in the Eel River basin due to its large size, the inaccessibility of large parts of the basin, and the large number of potential barriers. For this reason, we developed a prioritized list of sites that should be considered for future assessment using the narrowed down list of potential barriers from the PAD (Section 3.1.1.2) as the starting point. The list was prioritized based on stream size and availability of low-gradient habitat upstream, using the scoring system described in Phase 1 described above (excluding the extent of barrier score). The final list was stratified by Eel River sub-basins (Figure 1-1) to assist stakeholders in prioritizing future assessments for regions of interest.

3.2 Results

3.2.1 Site selection

3.2.1.1 Initial list of potential barriers

The initial list of potential barriers in the Eel River basin contained 866 unique sites from the following sources:

- 821 sites in the Eel River basin resulting from queries of the PAD in September 2012,
- 29 new railroad crossings listed in RTA (2011) but not the PAD (36 sites were already accounted for in the September 2012 PAD query), and
- 16 additional sites discovered during field surveys or through Google Earth.

3.2.1.2 Narrowed down list of potential barriers

The initial list of 866 potential barriers was narrowed down to 321 by excluding

- 239 sites with contributing drainage areas < 2 km^2 (smaller than the minimum stream size criterion);
- 251 natural features, as determined based on information in the PAD;
- 37 bridges crossing natural channels; and
- 18 sites listed in the PAD that were manmade, but outside the scope of this study, including diversions, low-flow fords, and major dams.

3.2.2 Passage evaluation and status designation

We visited 56 potential barrier sites, 22 of which were fully evaluated using the field protocols described in Section 3.1.2 (Table 3-3). The remaining 34 sites were not fully assessed for reasons described in Section 3.1.3, but passage designations were made where available information was sufficient. In addition, we were able to make a passage designation at a site in the South Fork Eel sub-basin that was not visited based on information and photos provided by CDFW.

Table 3-3. Number of potential barrier sites visited and assessed by sub-basin.

Sub-basin	Full assessment	Partial assessment	Total
Lower Eel	8	11	19
Middle Fork	1	0	1
Middle Main	2	3	5
South Fork	7	6[1]	13
Upper Main	1	11	12
Van Duzen	3	4	7
Total	22	35	57

[1] Includes one site that was not visited that we had sufficient information to assess.

Sufficient evidence was available to make passage designations for 44 of the 57 sites visited (Table 3-4). Twenty sites were designated as *Non-barrier*, 10 as *Partial barrier*, and 11 as *Total barrier*. An additional three sites were designated as *Partial barrier*, but given the qualifier “potential total barrier” due to the likelihood they were total barriers. The remaining 12 sites were assigned a passage status as “*Unknown*” due to insufficient information.

Table 3-4. Summary of passage designations made for fully and partially assessed sites.

Passage designation	Number of sites		
	Full assessment	Partial assessment	All
Non-barrier	5	16	21
Partial barrier	10	0	10
Partial barrier, potential total barrier	2	1	3
Total barrier	4	7	11
Unknown	1	11	12

Table 3-5 below lists each site where full or partial assessments were carried out and provides passage designations for each. Appendix E lists the 22 sites where full assessments were carried out and provides additional assessment results and other information related to passage designations. Appendix F provides the following site-specific data and rationale for passage designations of fully assessed sites:

- location information
- work performed at site
- crossing physical characteristics
- substrate and suitable lamprey attachment points within crossing
- channel characteristics
- passage designation

- evidence for passage designation
- additional potential barriers in stream
- crossing photographs

Appendix G lists the 34 partially assessed sites and provides additional site-specific information and rationale for passage designations.

Table 3-5. Sites assessed for Pacific lamprey passage status and resulting passage designations.

PAD ID[1]	Stream	Road name	Sub-basin	Passage designation
Fully assessed sites				
715457	Rohner Cr.	Main St.	Lower Eel	Non-barrier
715459	Strongs Cr.	S. Fortuna Blvd.	Lower Eel	Non-barrier
715460	Strongs Cr.	Hwy 101	Lower Eel	Partial barrier
715449	Stitz Cr.	Shively Rd.	Lower Eel	Total barrier
713221	Mountain Cr.	Alderpoint Rd.	Lower Eel	Partial barrier
715476	Mill Cr.	Alderpoint Rd.	Lower Eel	Partial barrier
705816	Francis Cr.	Port Kenyon Rd.	Lower Eel	Unknown
705815	Russ Cr.	Centerville Rd.	Lower Eel	Partial barrier, potential total barrier
715481	Butte Cr.	Hidden Valley Rd.	Van Duzen	Partial barrier
715472	Yager Cr.	Redwood House Rd.	Van Duzen	Partial barrier
715429	Strawberry Cr.	HRC Road 4	Van Duzen	Total barrier
707107	Elk Cr.	Hwy 101	South Fork Eel	Total barrier
736751	Harper Cr.	Bull Cr. Flats Rd.	South Fork Eel	Total barrier
NIP	Cuneo Cr.	n/a; just d/s of Bull Cr. Flats Rd. bridge.	South Fork Eel	Partial barrier, potential total barrier
707157	Fish Cr.	Avenue of the Giants	South Fork Eel	Partial barrier
707096	Tenmile Cr.	Hwy 101	South Fork Eel	Partial barrier
706954	Cedar Cr.	Hwy 101	South Fork Eel	Partial barrier
707115	Red Mountain Cr.	Hwy 101	South Fork Eel	Non-barrier
711992	Poison Oak Cr.	Dyerville Loop Rd.	Middle Main Eel	Non-barrier
715485	Poison Oak Cr.	Dyerville Loop Rd.	Middle Main Eel	Non-barrier
707091	Long Valley Cr.	Hwy 101 (road-fill)	Upper Main Eel	Partial barrier
715027	Goforth Cr.	Hwy 162	Middle Fork Eel	Partial barrier
Partially assessed sites				
715452	Rohner Cr.	Smith Lane	Lower Eel	Non-barrier
NIP	Rohner Cr.	12th St.	Lower Eel	Partial barrier, potential total barrier
NIP	Rohner Cr.	Hwy 101	Lower Eel	Non-barrier
NIP	Strongs Cr.	Riverwalk Dr.	Lower Eel	Non-barrier
705818	Barber Cr.	Grizzly Bluff Rd.	Lower Eel	Total barrier
736789	Oil Cr.	Blue Slide Rd.	Lower Eel	Total barrier
715477	Knack Cr.	Alderpoint Rd.	Lower Eel	Total barrier

PAD ID[1]	Stream	Road name	Sub-basin	Passage designation
736846	Little Burr Cr.	Alderpoint Road	Lower Eel	Total barrier
NIP	Dean Cr.	Sequoia Rd., Rio Dell	Lower Eel	Unknown
715448	Dean Cr.	Hwy 283 / Wildwood Ave.	Lower Eel	Total barrier
NIP	Bear Cr.	HRC logging road	Lower Eel	Non-barrier
723653	Butte Cr.	Hidden Valley Rd.	Van Duzen	Unknown, likely minimal impact
NIP	Swift Cr.	Spur Rd off Hidden Valley Rd.	Van Duzen	Non-barrier
715462	Blanton Cr.	Yager-Lawrence Mainline	Van Duzen	Non-barrier
715474	Root Cr.	Private timber road (HRC)	Van Duzen	Non-barrier
737364	Cedar Cr.	n/a; remnant of hatchery structure near SF Eel confluence	South Fork	Unknown, likely obstacle
706987	Rattlesnake Cr.	Hwy 101	South Fork	Unknown, likely minimal impact
707109	Foster Cr.	Hwy 101	South Fork	Non-barrier
715526	Rattlesnake Cr.	n/a; trash rack just upstream of Hwy 101	South Fork	Unknown, likely Non-barrier
706963	Hollow Tree Cr.	n/a; concrete sill at old hatchery site	South Fork	Non-barrier[2]
705826	Frenchman Cr.	Harris Rd.	Middle Main	Unknown, likely partial
705988	Mud Cr.	Zenia-Bluff Rd.	Middle Main	Non-barrier
713224	Carter Cr.	Alderpoint Rd.	Middle Main	Unknown, likely Non-barrier
705896	Ryan Cr.	Ryan Cr. Rd.	Upper Main	Non-barrier
707085	South Fork Ryan Cr.	Hwy 101	Upper Main	Unknown
707086	North Fork Ryan Cr.	Hwy 101	Upper Main	Total barrier
707092	Long Valley Cr.	Hwy 101	Upper Main	Non-barrier
707094	Long Valley Cr.	Hwy 101	Upper Main	Unknown, likely partial
712813	South Fork Ryan Cr.	Hamman Driveway	Upper Main	Non-barrier[3]
713110	Reeyes Canyon Cr.	Hwy 101	Upper Main	Unknown, likely partial
706962	Haehl Cr.	E. Hill Rd.	Upper Main	Non-barrier
707075	Bloody Run Cr.	Hwy 162	Upper Main	Non-barrier
713155	Trib to Outlet Cr.	Hwy 162	Upper Main	Unknown
718572	Corral Cr.	Hwy 162	Upper Main	Non-barrier
758555	Haehl Cr.	Railroad bridge in Willits	Upper Main	Total barrier

1 NIP = not in PAD.
2 Site was not visited, but photos showing clearly remediated channel were provided (T. Tollefson, CDFW, pers. comm., 3 July 2013).
3 Remediation of site with open-bottom arch culvert in progress on survey date.

3.2.3 Habitat assessments

A total of 34 sites were qualitatively assessed for Pacific lamprey habitat quality upstream and downstream of potential barriers (Table 3-6). Twenty of the 54 sites assessed for passage (Table

3-3) were not assessed for habitat quality due to lack of access. These habitat assessments were used in conjunction with other available information on habitat potential when making overall conclusions about habitat quality at each site as related to remediation priority.

Table 3-6. Results of qualitative Pacific lamprey habitat assessments upstream and downstream of study sites.

PAD ID[1]	Stream	Ammocoete habitat characterization		Spawning habitat characterization	
		Upstream	Downstream	Upstream	Downstream
705816	Francis Cr.	n/a	Excellent	n/a	Poor
705988	Mud Cr.	Poor	Poor	Poor	Poor
706954	Cedar Cr.	Fair	Good	Excellent	Fair
706962	Haehl Cr.	Poor	Poor	Poor	Poor
707075	Bloody Run Cr.	Poor	Poor	Poor	Poor
707091	Long Valley Cr.	Poor	Poor	Poor	Poor
707094	Long Valley Cr.	Fair	Fair	Fair	Fair
707096	Tenmile Cr.	Excellent	Good	Fair	Poor
707107	Elk Cr.	Poor	Good	Fair	Good
707109	Foster Cr.	n/a	Good	n/a	Good
707115	Red Mountain Cr.	Fair	Poor	Fair	Poor
707157	Fish Cr.	Poor	Poor	Poor	Fair
711992	Poison Oak Cr.	Poor	Poor	Good	Poor
713110	Reeyes Canyon Cr.	Poor	Fair	Poor	Fair
713221	Mountain Cr.	Poor	Poor	Poor	Poor
715027	Goforth Cr.	Poor	Poor	Poor	Poor
715429	Strawberry Cr.	Fair	Good	Poor	Poor
715449	Stitz Cr.	Good	Good	Poor	Poor
715457	Rohner Cr.	Good	n/a	Poor	n/a
715459	Strongs Cr.	Good	Good	Poor	Fair
715460	Strongs Cr.	n/a	Good	n/a	Poor
715472	Yager Cr.	Fair	Fair	Poor	Poor
715474	Root Cr.	Excellent	Excellent	Good	Poor-fair
715476	Mill Cr.	Poor	Poor	Poor	Poor
715481	Butte Cr.	Fair	Fair	Good	Good
715485	Poison Oak Cr.	Poor	Poor	Poor	Fair
715526	Rattlesnake Cr.	Good	Good	Poor	Poor
722439	Chadd Cr.	Good	Good	Good	n/a
736751	Harper Cr.	Poor	Poor	Poor-fair	Poor
736752	Cuneo Cr.	Poor	Poor	Good	Fair
736789	Oil Cr.	Fair	Poor	Fair	Poor
737364	Cedar Cr.	Good	Poor-fair	Fair	Poor
NIP	Bear Cr. at HRC logging road	Poor	Poor	Fair	Fair
NIP	Dean Cr. at Hwy 283/ Wildwood Ave.	Good	Poor	Fair	Poor

1 NIP = not in PAD.

3.2.4 Pacific lamprey presence-absence

A total of 37 locations were sampled for Pacific lamprey presence-absence, of which 29 were also assessed for passage (Table 3-7). Twenty-seven of the 57 sites assessed for passage (Table 3-3) were not sampled for ammocoetes due to lack of access, lack of water, or high conductivity. Pacific lamprey ammocoetes were detected at 12 of the sites sampled; although 6 of these detections were from opportunistic samples of larger streams near the confluence with smaller streams assessed for passage. The smallest streams where Pacific lampreys were detected in our relatively limited effort were Butte and Foster creeks, with contributing drainage areas at sample sites of 20.1 km^2 and 22.8 km^2, respectively. Ammocoetes in the genus *Lampetra* (western brook or river lampreys) were detected at 10 sites, the smallest of which was Oil Creek, with a drainage area of 4.7 km^2 at the sample site. Pacific lamprey and *Lampetra* species were only found together at two locations, both at tributary confluences in the Lower Eel River. Pacific lampreys were detected upstream of five potential barrier sites assessed for passage (Cedar Cr. [PAD ID 737364], Cedar Cr. [PAD ID 706954], Rattlesnake Cr. [PAD ID 715526], Butte Creek [PAD ID 715481], and Red Mountain Cr. [PAD ID 707115]), which helped verify that passage was possible. There were no potential barrier sites sampled both upstream and downstream where Pacific lampreys were detected downstream, but not upstream.

Table 3-7. Results of ammocoetes electrofishing surveys (n/s = not sampled; n/r = not recorded; n/a = not applicable).

PAD ID	Stream	E-fishing effort (seconds of slow pulse shocking)		Number of ammocoetes detected by species[1]					
				Downstream			Upstream		
		Downstream	Upstream	ET	LS	UK	ET	LS	UK
705816	Francis Cr.	747	0	0	4	0	n/s	n/s	n/s
705826	Frenchman Cr.	267	0	0	0	0	n/s	n/s	n/s
705988	Mud Cr.	464	290	0	0	0	0	0	0
706954	Cedar Cr.	520	351	8	0	0	3	0	2
706962	Haehl Cr.	312	329	0	0	0	0	0	0
707096	Tenmile Cr.	613	507	0	0	0	0	0	0
707107	Elk Cr.	995	364	0	0	0	0	0	0
707109	Foster Cr.	953	n/a	2	0	100[2]	n/a	n/a	n/a
707115	Red Mountain Cr.	0	1,066	n/s	n/s	n/s	1	0	0
707157	Fish Cr.	342	441	0	0	0	0	0	0
711992	Poison Oak Cr.	142	443	0	0	0	0	0	0
713110	Reeyes Canyon Cr.	259	433	0	0	0	0	0	0
713221	Mountain Cr.	363	285	0	0	0	0	0	0
715429	Strawberry Cr.	216	186	0	0	0	0	0	0
715449	Stitz Cr.	745	519	0	0	0	0	0	0
715457	Rohner Cr.	0	1,151	n/s	n/s	n/s	0	22	3
715459	Strongs Cr.	1,273	921	0	20	7	0	30	0
715460	Strongs Cr.	2,270	0	0	19	1	n/s	n/s	n/s
715472	Yager Cr.	909	379	0	0	0	0	0	0
715474	Root Cr.	878	1,028	0	12	5	0	7	21
715476	Mill Cr.	700	590	0	0	0	0	0	0
715481	Butte Cr.	1,337	912	12	0	1	2	0	0
715485	Poison Oak Cr.	0	142	0	0	0	0	0	0
715526	Rattlesnake Cr.	0	360	n/s	n/s	n/s	7	0	100[2]
722439[4]	Chadd Cr.	0	1,800	n/s	n/s	n/s	0	9	0
736751	Harper Cr.	425	461	0	0	0	0	0	0
736752	Cuneo Cr.	910	230	0	0	0	0	0	0

PAD ID	Stream	E-fishing effort (seconds of slow pulse shocking)		Number of ammocoetes detected by species[1]					
				Downstream			Upstream		
		Downstream	Upstream	ET	LS	UK	ET	LS	UK
736789	Oil Cr.	1,230	904	0	1	0	0	0	0
737364	Cedar Cr.	530	520	0	0	0	8	0	0
736749[4]	Cow Cr.	1,318	0	0	0	0	n/s	n/s	n/s
NIP	Bear Cr. at HRC logging road	319	752	0	0	0	0	0	0
Sites without road crossings that were sampled for lamprey presence-absence									
Eel River at Stitz Cr. confluence[3]		n/r	n/a	1	5	3	n/a	n/a	n/a
Eel River at Strongs Cr. confluence		n/r	n/a	5	18	0	n/a	n/a	n/a
Price Cr. near mouth		n/r	n/a	0	3	0	n/a	n/a	n/a
Bull Cr. at Cuneo Cr. confluence		n/r	n/a	10	0	1	n/a	n/a	n/a
Larabee Cr. near Thurman Cr. confluence		822	n/a	5	0	0	n/a	n/a	n/a
Rattlesnake Cr. between Elk and Mad creeks		1629	n/a	7	0	0	n/a	n/a	n/a
Yager Cr.at Strawberry Cr. confluence		n/r	n/a	4	0	4	n/a	n/a	n/a

1 ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species
2 Values are an estimate; approximately 100, 10–15 mm long ammocoetes were detected at these sites.
3 Captured at the confluence of Stitz Creek and a disconnected side channel of the Eel River and most likely originated from the Eel River.
4 These sites were at road crossings but not assessed for passage.

3.2.5 Prioritization for remediation

Table 3-8 below lists the initial ranking score and relative priority for remediation of the 24 sites designated as *Barrier* or *Partial* Barrier. Four of the 24 barrier sites were rated as *High* priority for remediation, while eight were rated as *Medium* priority, and twelve as *Low* priority. Appendix H provides data used for determining extent of barrier, stream size, and low-gradient habitat scores and computing initial ranking scores, as well as full justification for final ratings of remediation priority. Refer to Section 3.1.5 for information on how initial ranking scores and relative priorities were assigned and interpreting results of prioritization.

Table 3-8. Relative priority for remediation of barrier sites surveyed in the Eel River basin.

PAD ID	Stream	Road name	Passage designation	Initial ranking score	Relative priority for remediation
Large streams					
707091	Long Valley Cr.	Hwy 101 (road-fill)	Partial barrier	19.3	High
715472	Yager Cr.	Redwood House Rd.	Partial barrier	14.9	High
706954	Cedar Cr.	Hwy 101	Partial barrier	15.3	Medium
715481	Butte Cr.	Hidden Valley Rd.	Partial barrier	12.1	Medium
715460	Strongs Cr.	Hwy 101	Partial barrier	11.9	Low
Medium streams					
758555	Haehl Cr.	Railroad bridge in Willits	Total barrier	21.7	High
NIP	Cuneo Cr.	n/a; just d/s of Bull Cr. Flats Rd. bridge.	Partial barrier, potential total barrier	15.1	High
715449	Stitz Cr.	Shively Rd.	Total barrier	17.6	Medium
NIP	Rohner Cr.	12th St.	Partial barrier, potential total barrier	16.6	Medium
707107	Elk Cr.	Hwy 101	Total barrier	15.1	Medium
705815	Russ Cr.	Centerville Rd.	Partial barrier, potential total barrier	13.0	Medium
707096	Tenmile Cr.	Hwy 101	Partial barrier	10.9	Medium
707157	Fish Cr.	Avenue of the Giants	Partial barrier	9.1	Medium
715476	Mill Cr.	Alderpoint Rd.	Partial barrier	14.5	Low
715027	Goforth Cr.	Hwy 162	Partial barrier	11.5	Low
Small streams					
705818	Barber Cr.	Grizzly Bluff Rd.	Total barrier	17.7	Low
736789	Oil Cr.	Blue Slide Rd.	Total barrier	16.8	Low
715429	Strawberry Cr.	HRC Road 4	Total barrier	16.2	Low
736846	Little Burr Cr.	Alderpoint Road	Total barrier	16.0	Low
736751	Harper Cr.	Bull Cr. Flats Rd.	Total barrier	16.0	Low
715448	Dean Cr.	Hwy 283 / Wildwood Ave.	Total barrier	15.9	Low
707086	North Fork Ryan Cr.	Hwy 101	Total barrier	15.8	Low
715477	Knack Cr.	Alderpoint Rd.	Total barrier	15.6	Low
713221	Mountain Cr.	Alderpoint Rd.	Partial barrier	13.0	Low

3.2.6 Prioritization for future assessment

Potential barrier sites that were not assessed in this project but that should be considered for future assessment are listed in Appendix I. These sites are prioritized based on GIS-predicted stream size and length of low-gradient channel for each of the major Eel River sub-basins (Figure 1-1). These prioritized lists were provided to serve as starting points for selecting sites most in need of further assessment in each sub-basin. Several of the sites listed in Appendix I are bridges according to the PAD, but were included because they may have associated infrastructure that could present passage problems for lampreys. Many of these bridge sites likely only require a brief field visit to confirm passage status. In the Lower Eel River sub-basin (Table I-1), several of the highest priority sites are tide gates in the Salt River. Evaluation of these sites was beyond the scope of this study, but future assessment would be valuable—particularly with the ongoing restoration of the Salt River. In the Upper Main Eel sub-basin (Table I-7), sites upstream of Scott Dam are included in the prioritized list, but should be considered lower priority since Scott Dam is a total barrier to anadromous fish. If Scott Dam is removed or passage is provided in the future, then these sites would become higher priority.

4 DISCUSSION AND CONCLUSIONS

Considerable uncertainties remain regarding Pacific lamprey passage capabilities and criteria for evaluating potential barriers to their migration (see Section 2). Many of the criteria proposed in this report should be considered preliminary, but the study lays the groundwork for developing key hypotheses related to lamprey passage at road crossings. These hypotheses could be experimentally tested in controlled environments (artificial streams with simulated road crossings) or through observations of lamprey behavior at road crossings during migration to refine passage criteria and improve capacity for using the FishXing model to evaluate lamprey passage.

In the first step of this evaluation, we developed an initial list of potential barriers sites. Although the PAD and other sources used to develop this list included the vast majority of the potential barriers in most areas of the basin, it should not be viewed as comprehensive; we located at least 16 additional potential manmade barriers not listed in the PAD and there are likely numerous others—particularly in remote sub-basins such as the North Fork Eel and Middle Fork Eel.

In the second step of the evaluation, we narrowed down the initial list of potential barriers to 321 sites that were considered for assessing lamprey passage. We carried-out passage assessments of 57 potential barriers, identifying 24 total or partial barriers, and designating an additional 21 sites as non-barriers. When assigning passage status to potential barriers, we generally erred on the side of underestimating adult lamprey passage success. For example, the extent to which lampreys may be able to surmount slightly perched concrete steps ending in right angles (which are common on culvert outlet aprons) is unclear. For this reason, we conservatively assumed that passage at such features was not possible unless the water surface elevation at the outlet tailwater was as high or higher than the top of the vertical surface of the step. Since lampreys can possibly swim or climb over some small steps or drops, this assumption may have resulted in underestimating Pacific lamprey passage success at several sites. Despite this and other uncertainties, we identified several clear-cut total barriers, several other sites that, at a minimum, represent major obstacles, and we were able to confidently identify numerous sites that were definitive non-barriers to adult Pacific lamprey passage. When uncertainties in FishXing model results and passage criteria at a given site were too large to make reliable passage designations, we erred on the side of designating the site as "*Unknown*" passage status. As understanding of lamprey passage criteria improves, it may be possible to re-assess these sites using existing data, including re-running the FishXing model.

The FishXing model was the primary means for evaluating passage conditions and making status designations at many of the sites we assessed. Importantly, FishXing is a model, which is intrinsically a simplified representation of the actual conditions occurring at each site. For example, the model predicts average velocity at each point along the length of a crossing, but irregularities in structures and substrates, as well as complex flow patterns, may create lower-velocity areas within the crossing that make successful passage more likely. Consequently, the model is expected to underestimate the range of flows that would be passable based on water velocities at many sites. In addition, FishXing was primarily designed to evaluate passage conditions for salmonids, which have substantially different swimming performances and behaviors than Pacific lampreys. Notwithstanding these differences and model uncertainties, we were able to develop a process for applying FishXing to assess lamprey passage, taking into account such lamprey-specific factors as how swimming performance may vary with availability of suitable attachment points. Overall, the model proved useful for understanding water depth and velocity conditions at each site based on field measurements. At some sites, FishXing results allowed us to make clear designations of passage status. For example, if a site was not perched, had ample attachment points, and predicted velocities were well below the maximum swimming speed criteria at all migration flows, we could confidently conclude that the site was not a passage barrier. For all sites, model results were interpreted cautiously and were used in conjunction with field data and observations and other available evidence when determining potential for lamprey passage success.

After assessing passage and designating passage status, we developed a prioritized list of barriers to migration that can be used to determine where remediation will result in the greatest benefit to lamprey populations in the basin relative to other barriers identified in this study (Table 3-9, Appendix H). This list includes four sites rated as *High* priority for remediation, eight as *Medium* priority, and twelve as *Low* priority. Remediation of barriers rated as *High* should be considered most pressing in terms of benefitting the Pacific lamprey population in the basin. Nonetheless, remediation of certain barriers rated "*Low*" priority may still benefit the population and should not be overlooked—particularly if opportunities to replace these barriers arise, such as replacing damaged culverts or as part of efforts to improve passage for anadromous salmonids.

In general, we rated barriers on small streams (contributing drainage area <6 km^2) as *Low* priority for remediation, in part because these streams were generally predicted to have less suitable Pacific lamprey spawning and rearing habitat than large streams, and in part because Pacific lamprey are usually not expected to use streams of this size—particularly when channel gradients are high. Recent studies indicate that Pacific lampreys prefer larger streams for spawning (Stone 2006, Gunckel et al. 2009), and in our limited presence-absence surveys we only detected the species at locations in streams draining areas larger than approximately 20 km^2. Despite this finding, the extent to which adult Pacific lampreys may utilize small streams for over-summer holding remains an uncertainty. A small number of adults have been observed holding in Fox and Rock Creeks, small tributaries to the Upper South Fork Eel River with drainage areas of approximately 2.7 and 7.5 km^2, respectively (B. Trush, McBain and Trush, pers. comm, 2012). It is possible that some small headwater streams provide superior water quality or other conditions preferred for holding compared with larger, lower-gradient reaches. If future surveys determine that Pacific lampreys do regularly use small streams for holding, then the relative importance of remediating barriers in these watersheds may go up. As summer stream flows and water quality become further degraded in the Eel River basin, small headwater streams may play an increasingly important role for Pacific lamprey holding, spawning, and rearing.

The prioritized list of barriers requiring remediation serves as a valuable basis for selecting sites for removal, replacement, or retrofit to improve Pacific lamprey passage in the Eel River basin. Although we touched on factors such as culvert condition and relative feasibility of remediation at each site (Appendices F, G, and H), a more thorough cost-benefit analysis that quantifies factors such as suitability of culvert sizing (risk of failure in relation to flood frequency) and road fill-volume is needed to determine which priority sites make the most sense to remediate.

In addition to providing a prioritized list of barriers for remediation, we provide an extensive list of potential manmade barriers in the Eel River basin that may require future evaluation to determine whether they are barriers to Pacific lamprey migration. This list, prioritized by upstream habitat availability, can be used by stakeholders to quickly identify potential barriers within each major sub-basin that are predicted to be most important to evaluate for Pacific lamprey passage.

When discussing barriers in the Eel River basin, it is important to mention the Potter Valley Project dams, which impede fish migration into the upper mainstem Eel River and its tributaries. Assessing passage and upstream habitat potential at Cape Horn Dam and Scott Dam was beyond the scope of this study; however, it is clear that both sites, especially Scott Dam, are key barriers in the basin and better understanding their population-level impacts on Pacific lampreys and other anadromous fishes is a high priority. Some percentage of adult Pacific lampreys approaching the fish ladder at Van Arsdale Fisheries Station at Cape Horn Dam pass successfully upstream, but large numbers hold in the fish ladder annually, suggesting it is a major obstacle to migration (Stillwater Sciences 2010). There has been a recent effort by CDFW and USFWS to modify the fish ladder to improve lamprey passage. However, even with these improvements, recent data suggest that less than 50% of migrating lampreys successfully pass, and median travel time from the bottom of the ladder to the top is 28 days (D. Goodman, USFWS, pers. comm. 1/10/2014). Approximately 10 miles upstream of Van Arsdale Reservoir, Scott Dam is a total barrier, blocking access to potentially hundreds of miles of high quality spawning and rearing habitat for lampreys and other migratory fishes.

The systematic and stepwise process we developed for identifying and narrowing down potential barriers, evaluating adult Pacific lamprey passage, and prioritizing sites for remediation is an important step towards addressing lamprey passage at road crossings, both in the Eel River basin and across the species' range. We view this effort as an ongoing work in progress, and foresee that the approach will be built upon and modified as sites are remediated, criteria are refined, new barriers are identified and evaluated, and the list of barriers requiring remediation is re-prioritized.

5 GUIDELINES FOR REMEDIATION

While many tribal, state, and federal agencies have begun to consider lamprey passage when designing culvert replacements and retrofits, existing fish passage design guidelines neglect to address lampreys and even recommend designs that may obstruct their passage (e.g., NMFS 2001, CalTrans 2007, Flossi et al. 2010). Recent salmon passage projects, while well-intentioned, continue to overlook lamprey passage criteria (e.g., Figure 5-1).

Figure 5-1. Example pool-weir fish ladder designed to improve salmon passage, but not well designed for Pacific lamprey passage. Source: http://www.pressdemocrat.com/article/20140109/articles/140109595

Once sites are selected for remediation, site-specific treatment designs that consider local watershed conditions need to be developed. We make basic recommendations for approaches to remediating each barrier site in Appendix H. Below are additional general guidelines that should be followed when designing lamprey-friendly road crossings (adapted / expanded from Streif 2009).

- Where possible, barrier culverts should be replaced with a bridge or open-bottom culvert designed using the stream simulation design approach (USDA Forest Service Stream Simulation Working Group 2008).
- When concrete weirs or baffles are a necessary part of a passage design, ensure they have smooth, rounded surfaces with no 90° angles or sharp corners in high velocity areas.
- Consider creating alternative lamprey passage routes, or orifices along the bottom under weirs.
- Ensure culvert bottoms have regular, and ideally continuous, attachment points constructed with a non-porous, slightly rough material.
- At high-velocity sites, consider including velocity refuges, or rest areas with adequate attachment points.
- Minimize turbulent flows and provide gradual transitions from low- to high-velocity areas with smooth surfaces for attachment. Lampreys may be swept downstream between successive attachments by rapid changes in water velocity or direction (Daigle et al. 2005).
- Ensure edges of culvert bottoms (along the walls), which are typically preferred migration routes during high flows, are free of potential obstructions such as sharp-angled baffles.
- Where replacement of a perched culvert or culvert outlet apron is not possible or is cost-prohibitive, consider installing lamprey passage systems or similarly designed lamprey ramps (Moser et al. 2011). These systems take advantage of the unique attachment and climbing behavior of Pacific lampreys and have been used to improve passage efficiency through large hydropower dams (Keefer et al. 2010, Moser et al 2011). Similar technology

has recently been applied by Oregon Department of Transportation and Oregon Department of Fish and Wildlife to improve lamprey passage through culverts with internal baffles (Figure 5-2). Design and installation of these ramps are relatively simple and affordable compared with culvert replacement in most cases (M. Fox, Confederated Tribes of Warm Springs, pers. comm., 8 November 2013). We recommended exploring this approach for short- or long-term remediation of 10 of the 24 barriers sites identified in this study.

Figure 5-2. Example of installation of lamprey ramps to improve passage in Threemile Creek, Oregon.

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Appendices

Appendix A

Eel River Pacific Lamprey Passage Evaluation Datasheets

Eel River Passage Assessment – Site Checklist

PAD ID #:____________________

Field date: _____ /_____ /_____

Stream Name:________________

Field site checklist:

(1) ☐Use initial passage filter to identify what data needs to be collected at site.

(2) ☐Fill out "Site Information Form" [*2 pages: basic information on streambed retention, substrate size, and attachment points within crossing*].

(3) ☐Survey longitudinal profile.

(4) ☐Survey tailwater cross-section.

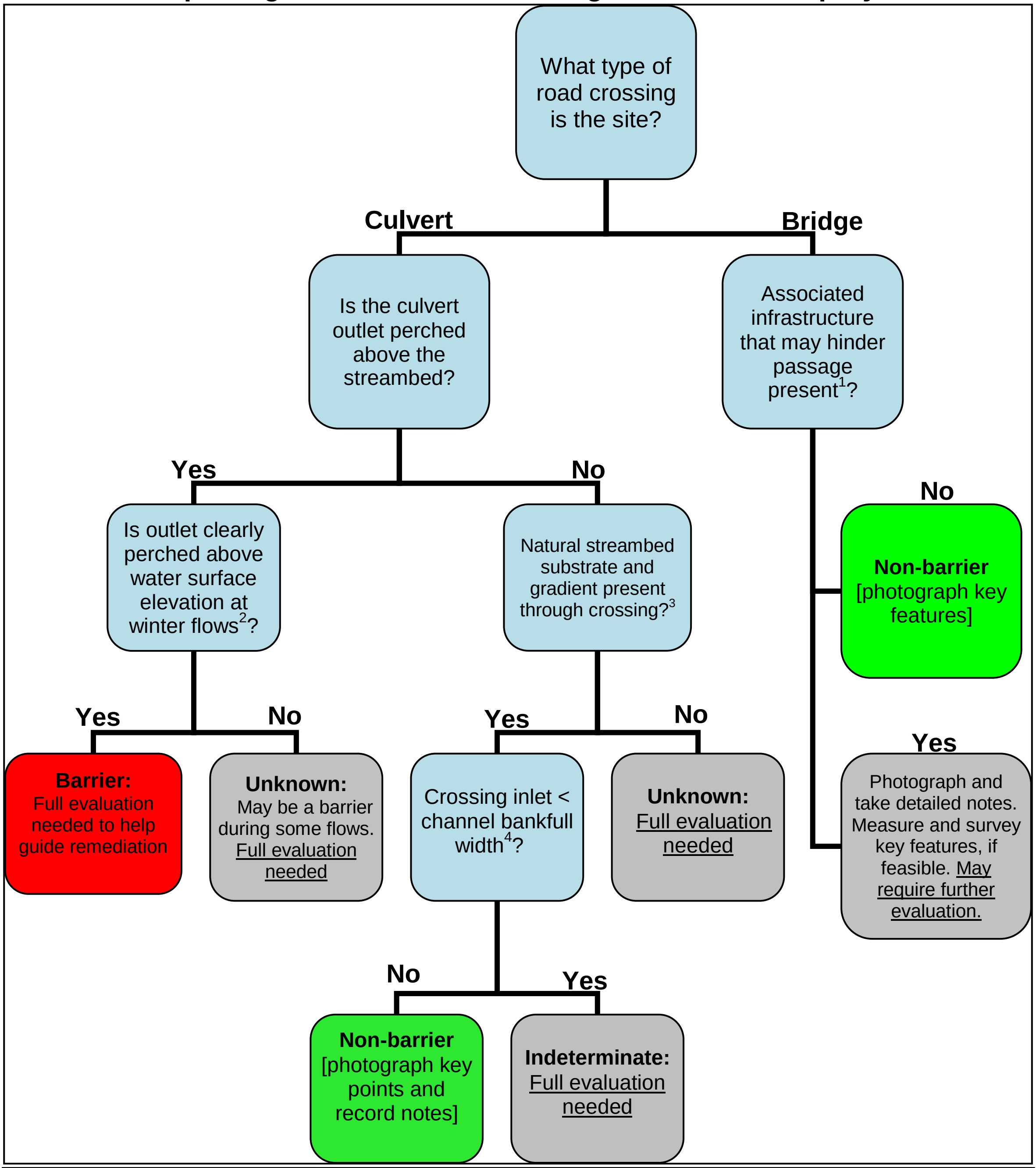
(5) ☐Take photographs of key features at site and record photo #s on datasheet.

(6) ☐Make a site sketch to show key features.

(7) ☐Culvert evaluation QA/QC -- review all datasheets for completeness and legibility.

(8) ☐Implement ammocoete distribution and habitat surveys upstream and downstream of road crossing.

Initial passage filter for road crossings for Pacific lamprey



Footnotes:

[1] Examples include trash racks, vertical steps, or significant channel constriction from abutments.

[2] Use active channel indicators at outlet to approximate high flow water surface elevation.

[3] Streambed substrate is continuous throughout the crossing and the streambed gradient and particle size similar to the adjacent channel.

[4] Measured upstream of structure and away from its zone of influence (i.e. upstream of aggradational wedge caused by inlet control).

Field date: _____ /_____ /_____ PAD ID #:________

LOCATION INFORMATION: **Survey crew initials ______________________________**

Road name / number: ____________________ **Stream name:** ______________________ **Tributary to:** ______________________

Sub-basin name: ☐Lower Eel ☐Van Duzen ☐South Fork Eel ☐Middle Main Eel

☐North Fork Eel ☐Middle Fork Eel ☐Upper Main Eel **Land ownership:** ______________

Latitude (N):_______________________ **Longitude (W):**__________________**GPS waypoint:**____________

CROSSING STRUCTURE:

Shape
□Circular
□Box
□Open-bottom arch
□Pipe-arch
□Ford
□Vented ford
□Bridge
□Other: _______________

Dimensions (inches)
Width: _________Height: _________
Rust line: ___________ (feet above crossing bottom)
Slope breaks in pipe? □No □Yes

Ford data: sag _______
F_1 ________
F_2 ________

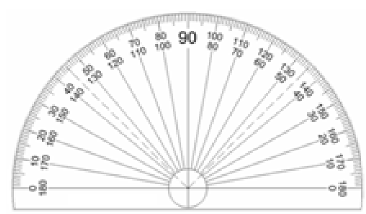
Multiple structures at Site?
□No □Yes
Describe & photo if yes:

Structure shape comments____

Structure material
□Spiral CMP
□Annular CMP Steel Aluminum
□Structural plate
□Concrete
□PVC
□Wood or log
□Other: ____________________

Corrugations
□2 2/3 x ½ inch
□3 x 1 inch
□5 x 1 inch
□6 x 2 inch (SSP only)
□None
□Other: ______________________

Skew from road



Degrees _________

Inlet type
□Projecting
□Mitered
□Wingwall □<30° □30-45° □>45°
□Headwall
□Apron
□Trashrack
□Other: ____________________________

Outlet configuration
□at stream grade
□cascade over rock
□free-fall into pool
□free-fall onto rock
□outlet apron
□Other: _________________
____

Baffles, weirs, or other internal structures?
□No □Yes > Describe:______________________
____
____
Fish ladder at outlet? □No □Yes
Describe material, size, & shape:______________
____
____

Tailwater Control: □pool tailout □log weir □boulder weir □concrete weir □other_______________________________________

Pipe condition: □Breaks inside culvert (Location________________) □Fill eroding □Debris plugging inlet (% blockage______)
□Bent inlet □Bottom worn through □Poor alignment with stream □Debris in culvert (rock or wood) □Bottom rusted through
□Water flowing under culvert □Other ___________________________
Describe overall condition____
____
____

Additional site comments:

Eel River Passage Assessment – Site Information (pg. 2 of 2)

PAD ID #:__________
Structure_____of_____

STREAMBED SUBSTRATE RETENTION IN STRUCTURE

□No substrate in structure
□Discontinuous layer of substrate in structure: begins at _______ ft ends at ________ft (*measured from inlet*)
□Substrate is continuous throughout structure
If present, substrate depth at inlet ________ft substrate depth at outlet ________ ft
□Unknown / not accessible

SUBSTRATE PARTICLE SIZES (*rank 1 to 3 in by type of substrate occupying the most streambed area*)

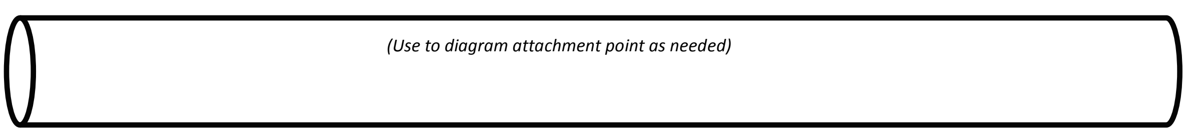
Location	**Bedrock** (>4096 mm)	**Boulder** (256-4096 mm)	**Cobble** (64-256 mm)	**Gravel** (2-64mm)	**Sand** (<2 mm)	**Silt/Clay**	**Other**	**Notes**
In crossing								
At downstream tailwater control								

LAMPREY ATTACHMENT POINTS

(1) Downstream of crossing outlet
Distance from first suitable attachment point within crossing to first suitable attachment point downstream of crossing ______________(ft)
Describe attachment point/s:____

(2) Upstream of crossing inlet
Distance downstream from last suitable attachment point within crossing to first suitable attachment point upstream of crossing ______________(ft)
Describe attachment point/s:____

(3) Within crossing: (*not including corrugations*)
□Natural stream bed throughout crossing with ample suitable attachment points.
□Corrugations present (*size & type described above*)
□Significant damage to corrugations that may preclude attachment? Describe locations and type:___________
____
□Smooth, flat throughout: describe surface material:____
□Discontinuous attachment points: describe type/s, locations, and distances between points that are >1' apart:____



Upstream

BANKFULL CHANNEL WIDTHS (ft): (*measure outside of culvert influence*)

Bankfull width: (1)________ (2) ________ (3) ________ (4) _________ (5) _________ Average ________

Distance from site: (1)________ (2) ________ (3) ________ (4) _________ (5) _________

Measurements taken: □u/s of inlet or □ d/s of outlet

Eel River Passage Assessment — Long Profile and Tailwater Cross Section Survey Datasheet

DATE:_____/______/_______ **PAD ID#______________**

SURVEY CREW:______________ **Structure _____of______**

Long Profile Survey (*all measurements in feet*)

Station	**BS (+)**	**HI**	**FS (-)**	**Elevation**	**Water surface depth**	**Station Description and Notes**
				100.00	n/a	Temporary Benchmark

Tailwater Cross Section Survey:

Station	**BS (+)**	**HI**	**FS (-)**	**Elevation**	**Water surface depth**	**Station Description and Notes**

**See reference page for survey terminology and list of key points for long profiles and cross sections.*

Eel River Passage Assessment – Photos and Comments

PAD ID #:__________

Field date: _____ /_____ /_____

SITE PHOTOGRAPHS

Photo # /s	**Location**	**Comments** *(note which structure if more than one)*
	Inlet from upstream	
	Outlet from downstream	
	Tailwater control	

ADDITIONAL SITE COMMENTS

Eel River Passage Assessment — Datasheet Reference Page

Survey terms / abbreviations

Station = distance along profile from starting point
BS (+) = backsight: rod reading at point of known elevation
FS (-) = foresight: rod reading taken at any point
HI = height of instrument

Long Profile survey points (key):

TWC-RP = tailwater control of first resting pool upstream of inlet
PU_1 = Points upstream of inlet (take several to show channel slope upstream of and downstream of TWC-RP)
Inlet = Inlet invert (lowest elevation culvert inlet)
PW_1 = Points within culvert (take at least one to show water surface profile)
Outlet = Outlet invert (lowest elevation at culvert outlet
MD = Max depth = take elevation of channel and water depth at deepest location of outlet pool
TWC = tailwater control of outlet pool (taken in thalweg of tailwater control)
PD_1 = Points downstream of outlet (take several to show channel slope downstream of TWC)

Tailwater Control survey points (key):

LBF = left bankfull	Thalweg
LEW = left edgewater	RT = Right toe of bank
LT = left toe of bank	REW = right edge water
CS_1 = points within cross section	RBF = right bankfull

Elements to include in Site Sketch:

- PAD ID#
- Field Date
- North Arrow
- Direction of stream flow
- Culvert/channel alignment
- Lay of tape (if needed)
- Photo point locations and numbers (as appropriate)
- Wingwalls and inlet / outlet aprons
- Multiple structures
- Baffle configurations
- Weirs and other instream structures
- Debris jams inside, upstream and downstream near site, depositional bars
- Trash racks, screens, standpipes etc. that may affect passage
- Damage to or obstacle inside structure
- Location of Riprap for bank armoring or jump pool formation
- Tailwater cross-section location

Eel River Lamprey Passage Assessment — Electrofishing Data Form

Stream: ______________________ **Date:** ___________ **PAD# or Site ID:** ___________

Upstream start time: ______________ **Stop time:** ______________ **Datasheet page**____**of**____

Downstream start time: ______________ **Stop time:** ______________ **E-fish Crew:** ______________

Total shock time (seconds on slow pulse timer)

Upstream of crossing = ____________________ **Downstream of crossing =** ___________________

Fish Capture Data

Direction from crossing (US or DS)	Species	Tally *(for fish not measured)*	Length (mm)	Life stage	Fish comments / photo numbers
					1
					2
					3
					4
					5
					6
					7
					8
					9
					10
					11
					12
					13
					14
					15
					16
					17
					18
					19
					20
					21
					22
					23
					24
					25
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					36
					37
					38
					39
					40
					41

Species: ET = Pacific lamprey; LS = *Lampetra* species (Western brook lamprey or River lamprey); UK = Unknown ; NC = Not Captured
Life stage: A = ammocoete, E = eyed ammocoete (*partially transformed, but not silvery*), M = macropthalmia (*large eye and silvery*) D = adult

Eel River Lamprey Passage Assessment — Habitat Evaluation Form

Stream: ______________________ Date: __________ PAD# or Site ID: ____________________ Page____of____

Start time: ____________________ Stop time: ____________________

Extent of habitat surveyed:

Upstream of crossing:

	Latitude (N)	Longitude (W)
Start		
End		

Stream distance surveyed (ft) =

Downstream of crossing:

	Latitude (N)	Longitude (W)
Start		
End		

Stream distance surveyed (ft) =

Site comments / photo #s

Upstream of crossing:

Ammocoete habitat characterization: Poor Fair Good Excellent (circle one)

Spawning habitat characterization: Poor Fair Good Excellent (circle one)

Upstream habitat comments:

Downstream of crossing:

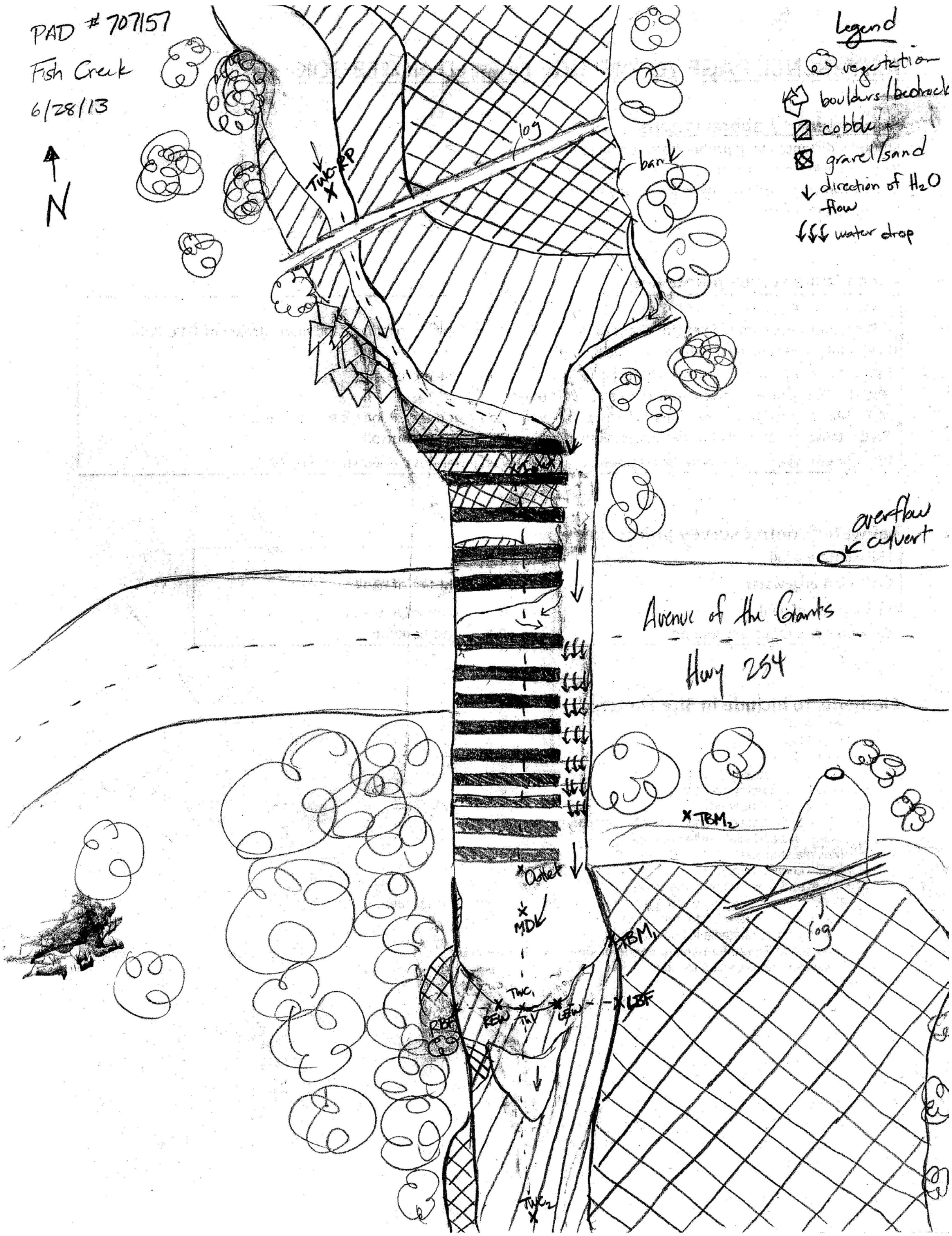
Ammocoete habitat characterization: Poor Fair Good Excellent (circle one)

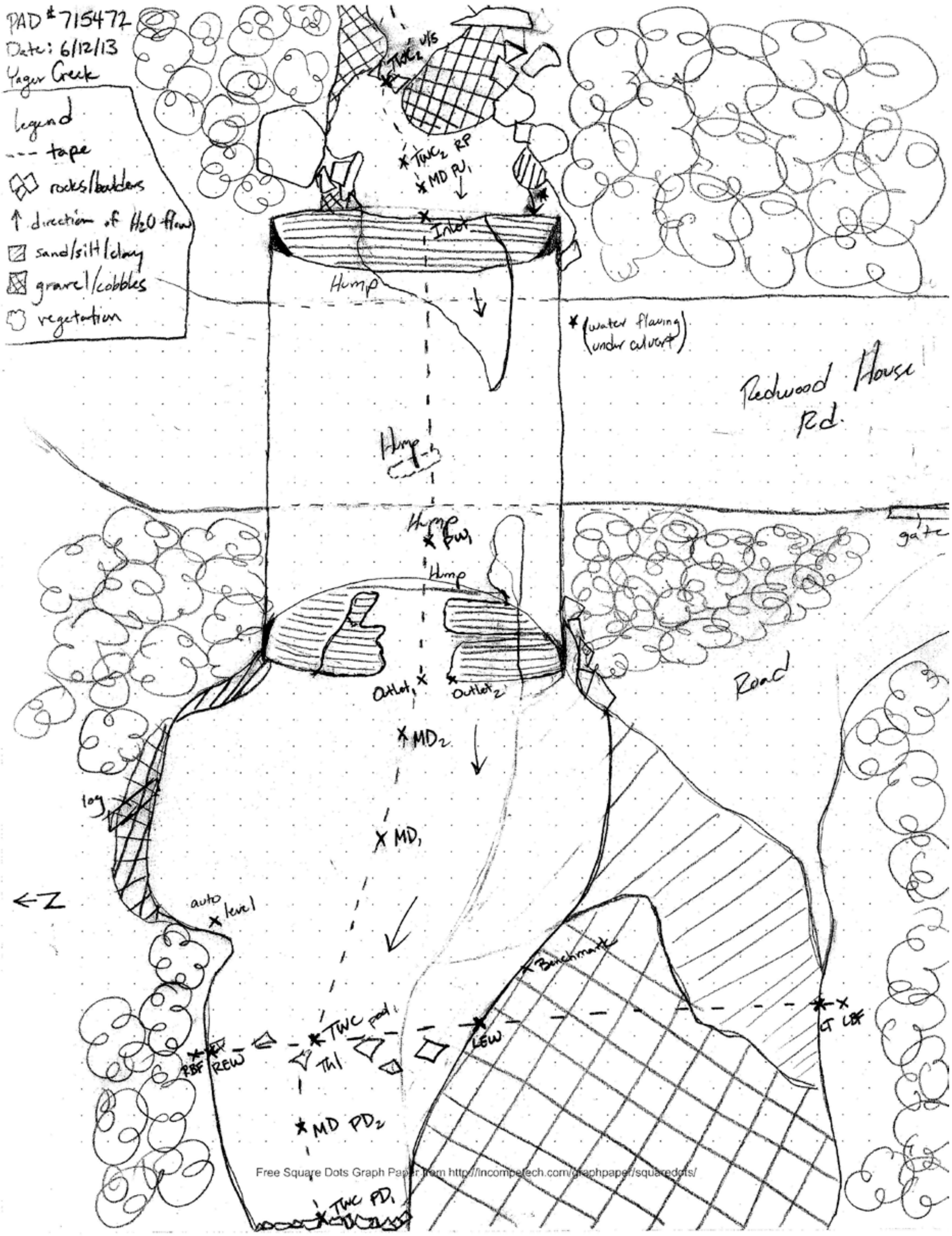
Spawning habitat characterization: Poor Fair Good Excellent (circle one)

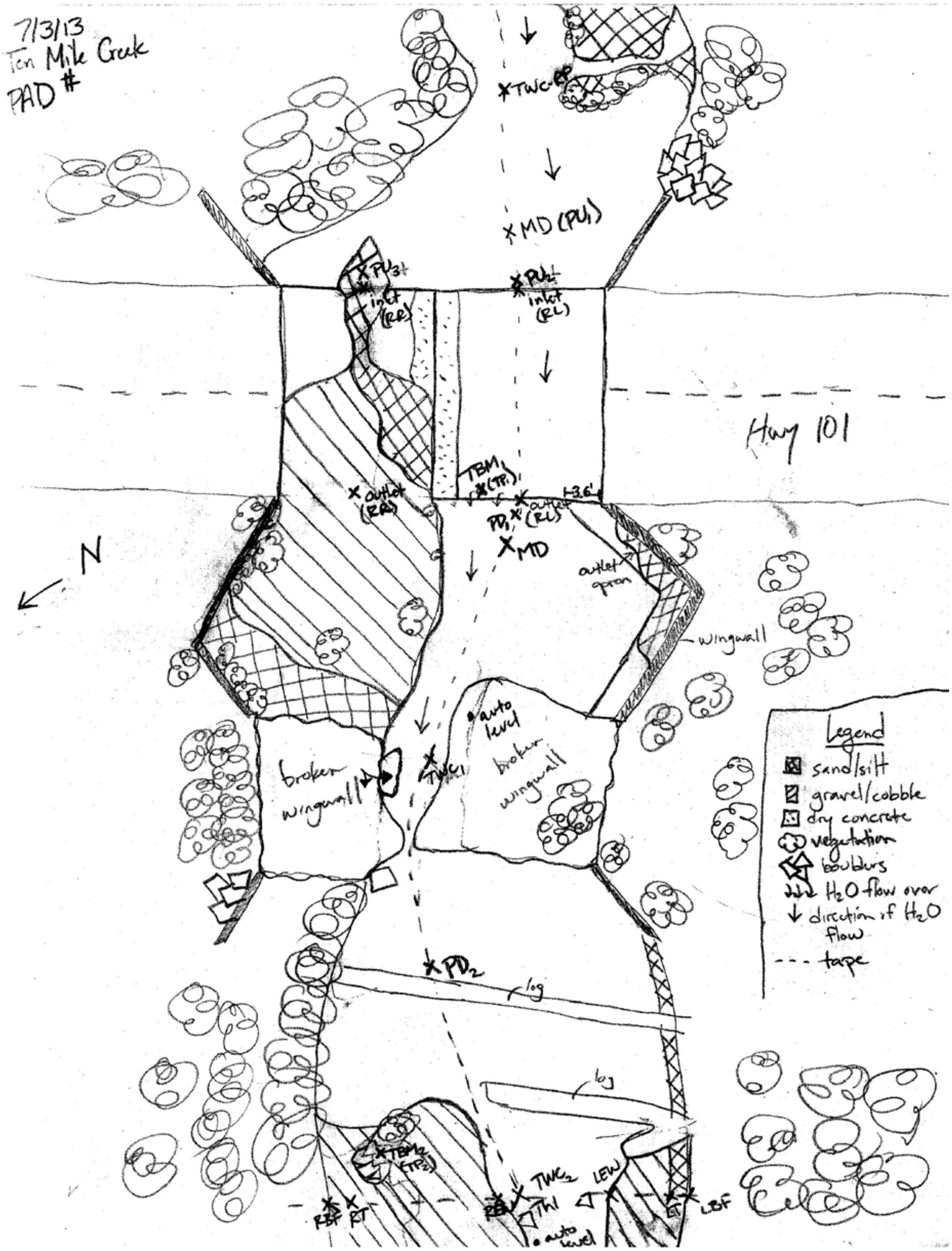
Downstream habitat comments:

Appendix B

Site Sketch Examples


PAD # 707157
Fish Creek
6/28/13
N
Legend
vegetation
boulders/bedrock
cobble
gravel/sand
direction of H2O flow
water drop
log
bank
TWC RP
overflow culvert
Avenue of the Giants
Hwy 254
TBM2
Outlet
MDL
TBM1
TWC1
REW
THV
LEW
RBF
LBF
log
TWC2


PAD # 715472
Date: 6/12/13
Yager Creek
Legend
tape
rocks/boulders
direction of H2O flow
sand/silt/clay
gravel/cobbles
vegetation
U/S
TWC2
TWC2 RP
MD PU1
Inlet
Hump
(water flowing under culvert)
Redwood House Rd.
Hump
Hump
PU1
Hump
gate
Outlet1
Outlet2
Road
MD2
log
MD1
auto level
Benchmark
TWC pool
RBF
REW
Thl
LEW
LBF
MD PD2
TWC PD1
Free Square Dots Graph Paper from http://incompetech.com/graphpaper/squaredots/


7/3/13
Ten Mile Creek
PAD #
MD (PU1)
PU3
inlet (RR)
PU2
inlet (RL)
Hwy 101
TBM1 (TP1)
outlet (RR)
PD1
outlet (RL)
3.6'
MD
N
outlet apron
wingwall
auto level
broken wingwall
TWC1
broken wingwall
Legend
sand/silt
gravel/cobble
dry concrete
vegetation
boulders
H2O flow over
direction of H2O flow
tape
PD2
log
log
TBM2 (TP2)
RBF
RT
REW
TWC2
Thl
LEW
LBF
auto level

Appendix C

Wiyot Tribe Water Quality Monitoring Methods and Results

Wiyot Tribe Water Quality Monitoring Methods

The Tribe currently collects, evaluates, and shares water quality monitoring data at regularly sampled sites under a United States Environmental Protection Agency's (USEPA) Clean Water Act §106 Water Pollution Control Program grant. Under this grant, the Tribe generated a Quality Assurance Program Plan (QAPP) that ensures the quality assurance (QA) and quality control (QC) procedures used to document technical data generated during projects are accurate, precise, complete, and representative of actual field conditions. QA is defined as an integrated program designed to assure reliability and repeatability of monitoring and measurement data. QC is defined as the routine application of procedures to obtain prescribed standards of performance in the monitoring and measurement process. The QAPP is consistent with guidelines set forth in the USEPA's *Requirements for Quality Assurance Project Plans for Environmental Data Operations, EPA QA/R-5* (USEPA 1998) and *Guidance for Quality Assurance Project Plans, EPA QA/G-5* (USEPA 1998).

Water quality measurements were collected *in situ* using a Yellow Springs Instrument (YSI) 6600 EDS multi-parameter sonde along with a YSI 650 handheld unit. The parameters that were studied included: dissolved oxygen (DO), specific conductivity, salinity, temperature, turbidity, pH, and depth.

Prior to deployment in the field, a trained water quality technician would ensure probe/instrument accuracy by calibrating the sonde according to YSI protocols and specifications listed in *YSI Environmental Monitoring Systems Operations Manual*. Upon arrival in the field and prior to any other data collection, the technician would deploy the sonde for discrete sampling upstream of an assessed barrier. Care was taken to ensure accurate readings by approaching from downstream and/or being careful not to disturb upstream habitat (especially stagnant pools) as to avoid human induced increases in readings (i.e. turbidity). Procedures for deployment included a four-minute equilibration period consisting of deploying the sonde while in "Run" mode and allowing parameters such as DO & pH to stabilize, followed by an eight-minute sampling period.

The Tribe oversees all aspects of data recording, validation, transformation, transmittal, reduction, analysis, and tracking as prescribed in the Tribe's USEPA-approved QAPP. All data collected for sonde parameters (temperature, DO, turbidity, specific conductivity, pH, salinity) were uploaded using YSI's EcoWatch program, generated in electronic format, and managed using Microsoft Excel. Metadata generated from field notes and sample collection log sheets generated in the field are also converted to Microsoft Excel.

Table C-1 below summarizes results of water quality data collected by the Tribe as part of the USFWS Tribal Wildlife Grant Eel River Pacific Lamprey Restoration Project.

Table C-1. Summary of water quality data collected for Eel River Pacific Lamprey Restoration Project.

PAD #	Stream	Date	Time	Temp (°C)	Specific conductivity (µS/cm)	Salinity (ppt)	DO concentration		pH	Barometric pressure (mmHg)	Turbidity (NTU)	Depth of reading (m)
							(mg/L)	(%)				
Pilot survey	South Fork Eel River	9/27/2012	9:49	17.41	0.255	0.120	10.01	104.6	8.16	757.00	0.67	0.231
Pilot survey	Chadd Creek	9/27/2012	13:35	12.93	0.176	0.080	10.18	96.5	7.82	755.85	1.06	0.109
715457	Rohner Creek	10/9/2012	14:04	12.02	0.443	0.210	3.00	27.9	7.31	760.00	13.58	0.181
715459	Strongs Creek	10/11/2012	11:17	12.03	0.483	0.230	4.90	45.5	7.36	758.00	6.67	0.190
715460	Strongs Creek	10/25/2012	9:59	9.93	0.337	0.160	8.42	74.5	7.53	767.13	7.80	0.532
715481	Butte Creek	11/6/2012	11:27	8.79	0.173	0.080	9.93	85.5	7.44	700.00	0.60	n/a
736789	Oil Creek	3/21/2013	13:48	8.41	0.042	0.020	13.16	108.3	7.92	766.00	26.34	0.185
715449	Stitz Creek	6/5/2013	9:59	12.56	0.454	0.220	10.03	94.4	7.56	756.35	2.97	0.166
715472	Yager Creek	6/12/2013	11:06	10.21	0.108	0.050	10.58	94.2	7.99	706.00	0.59	0.235
715429	Strawberry Creek	6/17/2013	10:33	11.47	0.254	0.120	10.17	93.3	7.72	750.00	5.20	0.105
715474	Root Creek	6/18/2013	10:38	13.07	0.211	0.100	10.02	95.3	7.85	755.00	2.20	0.485
707157	Fish Creek	6/28/2013	10:52	14.76	0.231	0.110	10.51	103.7	7.65	758.00	0.66	0.445
707096	Ten Mile Creek	7/3/2013	11:28	17.52	0.199	0.090	1.96	20.5	6.57	717.94	2.26	0.548
711992	Poison Oak Creek	7/12/2013	11:28	14.87	0.150	0.070	9.56	94.5	7.59	756.00	0.30	0.107
713221	Mountain Creek	7/18/2013	11:01	15.49	0.181	0.090	8.56	85.8	7.81	728.00	1.78	0.150
715476	Mill Creek	7/22/2013	10:55	14.45	0.177	0.080	9.70	95.1	8.11	730.06	0.91	0.358
706954	Cedar Creek	7/25/2013	11:28	17.87	0.224	0.110	9.03	95.2	8.15	739.00	0.24	0.438
705988	Mud Creek	8/8/2013	11:52	14.84	0.293	0.140	9.95	98.4	8.15	727.00	0.69	0.183
706962	Haehl Creek	8/20/2013	11:05	17.14	0.245	0.120	2.62	27.2	7.15	724.00	7.16	0.375
715526	Rattlesnake Creek	8/21/2013	11:14	19.47	0.354	0.170	8.83	96.2	8.01	730.00	0.37	0.500
707109	Foster Creek	8/21/2013	12:14	16.99	0.297	0.140	5.80	60.0	7.54	729.97	0.25	0.582
707115	Red Mountain Creek	8/21/2013	15:44	18.40	0.325	0.160	9.28	98.9	7.88	744.00	0.20	0.360
705816	Francis Creek	9/11/2013	9:22	15.97	0.679	0.330	7.49	76.0	7.47	761.00	2.13	0.839
NIP	Bear Creek	10/23/2013	10:12	10.70	0.244	0.120	10.84	97.7	7.56	757.00	0.00	0.231

Appendix D

Migration Flows Predicted for Fully Assessed Study Sites

Table D-1. Upper and lower migration flows predicted for fully assessed study sites based on nearby USGS gage data and drainage areas.

PAD ID	Stream	Drainage area at site (km^2)	Annual rainfall at site (in)[2]	USGS gage used	Drainage area at gage (km^2)	Annual rainfall at gage (in)[2]	Migration flows at gage		Migration flows at study site[5]	
							Low[3]	High[4]	Low	High
736751	Harper Cr.	3.9	62	Bull Cr.	73	63	6.7	679.0	0.4	36.7
713221	Mountain Cr.	4.0	62	Bull Cr.	73	63	6.7	679.0	0.4	37.1
715485	Poison Oak Cr.	4.2	49	Willits Cr.	10	57	0.4	54.0	0.2	23.7
711992	Poison Oak Cr.	4.2	49	Willits Cr.	10	57	0.4	54.0	0.2	23.7
715429	Strawberry Cr.	4.6	54	Bull Cr.	73	63	6.7	679.0	0.4	43.4
705815	Russ Cr.	8.4	44	Little River	105	51	13.0	693.3	1.0	55.7
715457	Rohner Cr.	8.5	44	Little River	105	51	13.0	693.3	1.1	56.2
715027	Goforth Cr.	9.9	51	Willits Cr.	10	57	0.4	54.0	0.4	55.4
715476	Mill Cr.	10.1	62	Cahto Cr.	13	65	0.4	92.0	0.3	70.7
707107	Elk Cr.	10.2	70	Elder Cr.	17	78	2.2	141.0	1.3	85.4
715449	Stitz Creek	10.2	53	Little River	105	51	13.0	693.3	1.3	67.4
705816	Francis Cr.	10.6	42	Little River	105	51	13.0	693.3	1.3	70.4
NIP[1]	Cuneo Cr.	11.3	70	Bull Cr.	73	63	6.7	679.0	1.0	105.2
707157	Fish Cr.	11.8	53	Little River	105	51	13.0	693.3	1.5	77.7
707096	Tenmile Cr.	12.2	66	Cahto Cr.	13	65	0.4	92.0	0.4	85.3
715472	Yager Cr.	16.7	68	Bull Cr.	73	63	6.7	679.0	1.5	156.1
715481	Butte Cr.	20.1	66	Cahto Cr.	13	65	0.4	92.0	0.6	140.5
715459	Strongs Cr.	24.5	44	Little River	105	51	13.0	693.3	3.0	162.1
707115	Red Mountain Cr.	31.1	68	Elder Cr.	17	78	2.2	141.0	4.1	260.7
715460	Strongs Cr.	31.2	44	Little River	105	51	13.0	693.3	3.9	206.4
707091	Long Valley Cr.	31.5	63	Cahto Cr.	13	65	0.4	92.0	1.0	219.5
706954	Cedar Cr.	38.3	68	Elder Cr.	17	78	2.2	141.0	5.0	320.8

[1] NIP = not in PAD.
[2] Mean annual precipitation estimate for 1981–2010 for each location from PRISM Climate Group, Oregon State University (http://prism.oregonstate.edu).
[3] Low-passage flows based on 90% exceedance at gage during core December–July migration period.
[4] High-passage flows based on 5% exceedance at gage during core December–July migration period.
[5] Assumes discharge and exceedance flows are proportional to drainage area.

Appendix E

Results of Passage Evaluations of Fully Assessed Study Sites and Supporting Information

Table E-1. Summary of site location and channel characteristics and results of passage evaluations of fully assessed study sites. Appendix F provides additional detailed site-specific data and rationale for passage designations.

PAD ID	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	FishXing model run?	Migration flows evaluated (cfs)	Range of passable flows (cfs)[1]	Passage designation	Barrier type
715457	Rohner Cr.	Main St.	Strongs Cr.	Lower Eel	10/9/2012	8.5	2.8	Yes	1.1–56.2	All	Non-barrier	None
715459	Strongs Cr.	S. Fortuna Blvd.	Eel River	Lower Eel	10/11/2012	24.5	7.6	Yes	3–162.1	All	Non-barrier	None
715460	Strongs Cr.	Hwy 101	Eel River	Lower Eel	10/25/2012	31.2	8.2	Yes	3.9–206.4	8.1–181.8	Partial barrier	Depth, velocity
715449	Stitz Cr.	Shively Rd.	Eel River	Lower Eel	6/5/2013	10.2	0.0	No	1.3–67.4	None	Total barrier	Perched outlet
713221	Mountain Cr.	Alderpoint Rd.	Larabee Cr.	Lower Eel	7/18/2013	4.0	0.0	Yes	0.4–37.1	0.4–4.8	Partial barrier	Velocity
715476	Mill Cr.	Alderpoint Rd.	Larabee Cr.	Lower Eel	7/27/2013	10.1	0.0	Yes	0.3–70.7	7.4–12.6	Partial barrier	Depth, velocity
705816[2]	Francis Cr.	Port Kenyon Rd.	Eel River	Lower Eel	9/11/2013, 1/14/2014	10.6	6.2	No	1.3–70.4	Unknown; likely passable at most flows	Unknown	Possible velocity
705815	Russ Cr.	Centerville Rd.	Eel River	Lower Eel	10/16/2013	8.4	3.8	No	1–55.7	Unknown; likely barrier at lower flows	Partial barrier, potential total barrier	Perched outlet, possible velocity
715481	Butte Cr.	Hidden Valley Rd.	Little Van Duzen River	Van Duzen	11/6/2012	20.1	2.1	Yes	0.6–140.5	Unknown	Partial barrier	South = perched outlet North = perched outlet, depth
715472	Yager Cr.	Redwood House Rd.	Van Duzen River	Van Duzen	6/12/2013	16.7	9.4	Yes	1.5–156.1	1.5–116	Partial barrier	Depth, velocity
715429	Strawberry Cr.	HRC Road 4	Yager Cr.	Van Duzen	6/17/2013	4.6	0.0	Yes	0.4–43.4	None	Total barrier	Perched outlet, velocity
707107	Elk Cr.	Hwy 101	Rattlesnake Cr.	South Fork Eel	3/22/2013	10.2	1.2	Yes	1.3–85.4	Likely none	Total barrier	Perched outlet, possible velocity
736751	Harper Cr.	Bull Cr. Flats Rd.	Bull Cr.	South Fork Eel	5/21/2013	3.9	0.0	Yes	0.4–36.7	None	Total barrier	Perched outlet

PAD ID	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	FishXing model run?	Migration flows evaluated (cfs)	Range of passable flows (cfs)[1]	Passage designation	Barrier type
NIP[3]	Cuneo Cr.	n/a; just d/s of Bull Cr. Flats Rd. bridge.	Bull Cr.	South Fork Eel	5/21/2013	11.3	0.6	No	1–105.2	Likely barrier at most flows	Partial barrier, potential total barrier	Drop / obstruction
707157	Fish Cr.	Avenue of the Giants	South Fork Eel River	South Fork Eel	6/28/2013	11.8	0.3	Yes	1.5–77.7	5.1–44.0	Partial barrier	Velocity, depth
707096	Tenmile Cr.	Hwy 101	South Fork Eel River	South Fork Eel	7/3/2013	12.2	3.7	Yes	0.4–85.3	South = 21.9–85.3 North = 37.4–85.3	Partial barrier	South = perched outlet North = depth
706954	Cedar Cr.	Hwy 101	South Fork Eel River	South Fork Eel	7/25/2013	38.3	5.5	Yes	5–320.8	Unknown, but likely passable at most flows	Partial barrier	Velocity, obstacle
707115	Red Mountain Cr.	Hwy 101	South Fork Eel River	South Fork Eel	8/21/2013	31.1	1.4	Yes	4.1–261	All	Non-barrier	None
711992	Poison Oak Cr.	Dyerville Loop Rd.	Eel River	Middle Main Eel	7/12/2013	4.2	0.0	No	0.2–23.7	All	Non-barrier	None
715485	Poison Oak Cr.	Dyerville Loop Rd.	Eel River	Middle Main Eel	7/12/2013	4.2	0.0	Yes	0.2–23.7	0.2–23.7	Non-barrier	None
707091	Long Valley Cr.	Hwy 101 (road-fill)	Outlet Cr.	Upper Main Eel	8/19/2013	31.5	10.8	Yes	1–219.5	47.5–86.2	Partial barrier	Perched outlet, velocity
715027	Goforth Cr.	Hwy 162	Middle Fork Eel River	Middle Fork Eel	8/20/2013	9.9	0.0	Yes	0.4–55.4	6.8–19.0	Partial barrier	Depth, velocity

[1] Numerical values based on FishXing model results.
[2] Site slated to be replaced with bridge in 2014.
[3] NIP = Not in PAD.

Appendix F

Site-specific Data and Rationale for Passage Designations of Fully Assessed Sites

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715457	Rohner Creek	Strongs Creek	Lower Eel	10/9/2012	Main St.	40.59815	-124.14988

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	12.1	12.3	145.2	0.17%	Yes, minor	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
70°	Wingwall <30°	At stream grade	No	No	Pool/run tailout	Good

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Continuous throughout structure	Gravel, silt, concrete	<1	<1	Attachment points are briefly interrupted at seam in the middle of the culvert that breaks continuous concrete walls.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
8.5	2.8	12.3

Additional site comments

Multi-angled box culvert under Main Street with very low gradient. Gentle right turn inside culvert (looking downstream). Several beams running through culvert's roof; storm drain entering from left bank near inlet. Minor slope break apparent from long profile survey.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Non-barrier	None	1.1–56.2	All	Crossing predicted passable at all flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Model results indicate crossing is passable at 100% of flow range evaluated. Even at highest flow evaluated, modeled velocities within culvert are lower than Pacific lamprey prolonged swimming speed (0.86 m/s).
Field evaluation observations and data	Culvert adequately sized compared with bankfull width, has relatively low gradient, and ample lamprey attachment points within. During the 10/9/2012 (low flow) evaluations, water depth within parts of the culvert (and also nearby natural channel) were shallow enough to restrict passage. However, during the core Dec–July passage period there is likely sufficient water depth to permit passage.
Ammocoete surveys	No Pacific lamprey ammocoetes located upstream or downstream of crossing or other sites in Rohner or Strongs Creeks. Relatively high densities of *Lampetra* ammocetes upstream of site.
PAD	No relevant information provided.
Other evaluations	None

Additional potential barriers in stream

Rohner Creek flows through the city of Fortuna and is crossed by numerous other roads, most of which are not listed in the PAD. Downstream of the Main Street crossing, we photo documented PAD ID 715452, an open-bottom arch culvert under Smith Lane, the 12th Street crossing, and the HWY 101 Crossing. The Smith Lane and HWY 101 crossings are unlikely to be barriers to lamprey passage. The 12th Street crossing, however, appears to present a significant obstacle to lamprey passage and may be a total barrier at most flows due to the presence of a channel-spanning, concrete tailwater control weir with a 90° angle and 2-3' drop, a perched 90° lip at the box culvert outlet, and complex internal baffles with 90° edges. This site also likely presents a passage obstacle to salmonids and should probably be replaced with a bridge. An examination of Google Earth indicates that Rohner Creek is crossed by several other public and private crossings upstream of Main Street that require passage evaluation.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715459	Strongs Creek	Eel River	Lower Eel	10/11/2012	S. Fortuna Blvd.	40.58004	-124.14706

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Conducted, but not usable	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	20.0	11.5	155.5	0.28%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
42°	Projecting wingwall (30–45° on river left; continuous with culvert wall on river right); inlet apron	Cascade over rock	No	No	Pool tailout	Good condition; no apparent structural damage

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in culvert	Concrete, silt, boulder	<1	<1	Continuous concrete w/ fine layer of silt/clay and leaf litter.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
24.5	7.6	21.3

Additional site comments

Where the concrete outlet meets the stream bed on river right, there is a small, 90° angle drop of ~4". The outlet is essentially flush with streambed on river left. Wingwall on river right of culvert inlet is continuous with culvert wall. Large pool present just upstream. Just downstream of culvert outlet there is a short, high-gradient riffle/cascade through small boulders.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Non-barrier	None	3.0–162.1	All	Passable flows predicted using FishXing.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

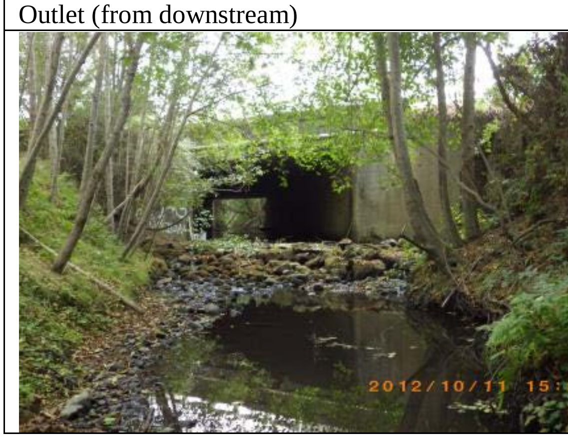
Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Model results indicate crossing passable at 100% of migration flows. The tailwater control cross-section could not be used in analysis, thus the model was run using the constant tailwater control approach and conservative assumptions about water surface elevations. To model the lower end of migration flows, the water surface elevation measured just downstream of outlet during the 10/11/2012 survey was used. At higher flows during the migration period, the water surface elevation of the outlet pool would rise at least 1.0 ft based on site photos. Model results indicate that water velocities occurring near the inlet at the highest migration flows may approach, but not reach, the Pacific lamprey maximum burst swimming speed (2.7 m/s). Since conservative values were used to parameterize the model, this crossing is unlikely to be a migration barrier.
Field evaluation observations and data	Culvert adequately sized compared with bankfull width, has a relatively low gradient, and ample concrete attachment points to allow for burst-and-attach swimming. Boulders at the upstream end of riffle below outlet are expected to help backwater culvert, moderating velocities at higher flows; however the steepness of the riffle could deter passage at very high and low flows.
Ammocoete surveys	No Pacific lamprey ammocoetes were located upstream or downstream of the crossing or at other sites in Strongs Creek during limited sampling of high quality rearing habitat. Relatively high densities of *Lampetra* ammocetes were captured.
PAD	No relevant information provided.
Other evaluations	None

Additional potential barriers in stream

Strongs Creek flows through the city of Fortuna and is crossed by numerous other roads, several of which are not listed in the PAD. Downstream of the S. Fortuna Blvd. crossing, we evaluated passage at PAD ID 715460. We also photo documented bridge crossings downstream at Eel River Dr. and Riverwalk Dr. and determined they were likely not barriers at migration flows based on professional judgment. An examination of Google Earth indicates that Strongs Creek is crossed by several other public and private crossings upstream (including PAD ID 715455) that require future passage evaluation.

Crossing photographs

Outlet (from downstream)	Inlet (from culvert looking upstream)
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715460	Strongs Creek	Eel River	Lower Eel	10/25/2012	Hwy 101	40.58101	-124.15115

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	Conducted using data from Lang (2005)	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	25.1 (outlet) 38.0 (inlet)[1]	12.6	154[1]	1.1%[1]	No	No

[1] Data from Lang 2005

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
50°	Wingwall (30–45°on river right; >45° on river left)	At stream grade	No	No	Pool tailout	Overall good; concave base

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Discontinuous layer beginning at 127' and ending at 152'	Concrete, sand, gravel, silt	<1	<1	Within culvert, attachment points are continuous as culvert is entirely made of concrete

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
31.2	8.2	19.7

Additional site comments

Large amount of woody debris near inlet. Culvert is comprised entirely of concrete and has non-uniform geometry with narrowing walls and wingwalls at various angles. Railroad trestle ~50' upstream does not pose a barrier to fish passage.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Depth, velocity	3.9–206.4	8.1–181.8	Overall, the site is expected to be passable across most migration flows. FishXing predicts a depth barrier below 8.1 cfs and a velocity barrier above 181.8 cfs. Field observations indicat site is unlikely a barrier at low flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Passage was modeled with FishXing using data from Lang (2005) and assumptions about tailwater water surface elevations at different stream flows based on photos from Lang (2005) and the field visit during low flows. For this reason, and due to non-uniform geometry of culvert, model results should be considered preliminary. The model predicts water depths <0.1 ft at flows <8.1 cfs and thus the site could impede or slow lamprey passage. FishXing predicts water velocities exceed the Pacific lamprey maximum burst swimming speed (2.7 m/s) at flows >182 cfs.
Field evaluation observations and data	The culvert is adequately sized compared with the bankfull width and has ample concrete attachment points to allow for burst-and-attach swimming. The concave bottom of the culvert was observed to concentrate flow to the culvert center, increasing depth during 10/25/2012 (low flow) field surveys.
Ammocoete surveys	No Pacific lamprey ammocoetes were located at crossing or at other sites in Strongs Creek. Relatively high densities of *Lampetra* ammocetes were captured.
PAD	Lists information from Lang (2005)
Other evaluations	With respect to salmonid passage, Lang (2005) stated: "The culvert is predicted to predominately be a depth barrier using conservative fish passage design criteria. Fish are likely passing this culvert better than predicted. However, passage could be improved by the addition of baffles or weirs or by minimally backwatering the culvert outlet to increase water depths at fish migration flows."

Additional potential barriers in stream

Strongs Creek flows through the city of Fortuna and is crossed by numerous other roads, several of which are not listed in the PAD. Upstream of HWY 101, we evaluated passage at PAD ID 715459.We also photo documented bridge crossings at Eel River Dr. and Riverwalk Dr. and determined they were likely not barriers at migration flows based on professional judgment. An examination of Google Earth indicates that Strongs Creek is crossed by several other public and private crossings upstream (including PAD ID 715455) that require future passage evaluation.

Crossing photographs

Inlet looking downstream towards outlet

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715449	Stitz Creek	Eel River	Lower Eel	6/5/2013	Shively Rd.	40.46488	-124.05297

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	No	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Structural steel plate with 1.2 ft thick concrete base	2.67 X 1.5 X 1.43	7.0	7.6	119.8[1]	2.4%[1]	No	Large concrete ledge d/s of outlet ~10 ft above stream grade

[1] Data from Ross Taylor & Associates (2005)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Projecting	Free-fall onto concrete	No	No	Pool tailout	Fair

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in culvert	Concrete	2.5	<1	Smooth, flat concrete bottom throughout

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
10.2	0.0	30.0

Additional site comments

The culvert outlet is perched above approximately 4 ft about concrete ledge/apron, which itself is approximately 10 ft above the natural elevation of the downstream channel. Water falls off this concrete apron onto vertically piled riprap mixed with large pieces of wood (see photograph).

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)	Range of passable flows predicted (cfs)	Notes
Total barrier	Perched outlet	1.3–67.4	None	Severely perched outlet is total barrier to Pacific lamprey passage.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Barrier
FishXing analysis	FishXing analysis not utilized due to definitive perched outlet barrier.
Field evaluation observations and data	Culvert outlet is clearly perched ~4 ft above water surface elevation at all migration flows. An additional drop onto riprap / wood pile exists below culvert outlet pool. This drop is also likely a barrier at most flows. The steep-sloped and undersized culvert also likely constitutes a velocity barrier at moderate to high flows.
Ammocoete surveys	No ammocoetes were found in Stitz Creek upstream or downstream of the crossing. However, several *Lampetra* ammocoetes and a single Pacific lamprey ammocoete were found where Stitz Creek meets a high flow side channel, which was disconnected from the Eel River on the survey date. We believe all individuals were likely deposited by the Eel River during higher flows.
PAD	Lists information provided by Ross Taylor & Associates (2005).
Other evaluations	Ross Taylor & Associates (2005) rated crossing as total barrier to salmonid passage and medium-priority for replacement, also stating that "the current culvert is extremely under-sized and has caused a severe down-cutting of the downstream channel and aggradation has occurred upstream of the culvert.

Additional potential barriers in stream

PAD ID 712002, located approximately 300 m downstream, is a railroad trestle with narrow concrete footing that does not appear to be a total barrier, but could impede passage at higher flows. In addition the PAD lists two waterfalls of unknown Pacific lamprey passage status approximately 300 m and 600 m upstream, respectively.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
713221	Mountain Creek	Larabee Creek	Lower Eel	7/18/2013	Alderpoint Rd.	40.29437	-123.6500

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Conducted using data from RTA (2005)	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	2.67 X 1.5 X 1.43	8.5	7.3	80.4	1.31%[1]	No	No

[1] Data from Ross Taylor & Associates (2005)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Projecting	Slightly perched due to rusted out bottom, but installed at stream grade.	No	No	Pool tailout	Poor; bottom rusted through entire length.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in culvert, but bottom rusted through	Boulder, cobble, sand (below rusted out bottom)	<1	<1	Corrugations present; damage to corrugations may preclude attachment in 1–2 ft wide part of the bottom through length of culvert; however, bottom edges and sides of culvert are not rusted and may allow attachment at moderate flows. Small size of corrugations may impede burst and attach swimming behavior.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
4.0	0.0	17.2

Additional site comments

None.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Velocity	0.4–37.1	0.4–4.8	Passable flows were predicted using FishXing and conservative assumptions about lamprey attachment and swimming ability. Site may be passable at higher flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Ross Taylor & Associates (2005) long profile and tailwater cross section data were used to run FishXing model. Results should be viewed with caution since data were collected in 2004 and the channel may have changed since that time. The model predicts that water velocities within the crossing exceed the Pacific lamprey critical swimming speed (0.86 m/s) at stream flows greater than 0.9 cfs, but that burst swimming (without attachment) can be used to pass the culvert at stream flows below approximately 5 cfs. The model was parameterized using conservative assumptions that (1) lampreys cannot effectively attach to the rusted culvert bottom or small corrugations at higher flows/velocities and (2) exhaustion occurs after 10 s of burst swimming (without ability to attach and rest). These assumptions need to be tested experimentally. Due to the uncertainty in model assumptions, it is possible that some individuals may be able to pass through the culvert at higher stream flows than predicted.
Field evaluation observations and data	Rusted through culvert outlet and bottom likely makes it difficult for migrating lampreys to enter and pass culvert at low flows. The summer flows observed during the 7/18/2013 site visit were primarily below the rusted culvert bottom. At higher flows when culvert is backwatered by tailwater control, individuals can likely enter culvert, but may have difficulty attaching to small corrugations and rusted bottom. Culvert is undersized compared with channel width.
Ammocoete surveys	No ammocoetes were located in limited surveys upstream or downstream of the crossing; though fine sediment habitat was minimal in sampled reach.
PAD	Lists information provided by Ross Taylor & Associates (2005).
Other evaluations	Ross Taylor & Associates (2005) recommended ranking site as medium-priority for replacement due to it being a partial migration barrier to adult salmonids with good-quality habitat upstream. Recommends replacing with properly sized open-bottom arch set on concrete footings.

Additional potential barriers in stream

No additional PAD crossings or crossings visible in Google Earth are located in the main stem of Mountain Creek upstream or downstream.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715476	Mill Creek	Larabee Creek	Lower Eel	7/27/2013	Alderpoint Rd	40.388210	-123.74050

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	6 X 2 X 3.6	11.6	14.0	144.7[1]	10.35%[1]	No	No

[1] Data from Ross Taylor & Associates (2005)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
n/a	Projecting	At stream grade	Reinforced steel plate on entire length of bottom	No	Pool tailout	Fair, with exception of bottom rusting through in places

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in structure	n/a	<1	<1	Large corrugations present; bottom lined with reinforced steel plates

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
10.1	0.0	36.5

Additional site comments

Water flowing under culvert from outlet to 15 ft above outlet (no water in culvert).

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Depth, velocity	0.3–70.7	7.4–12.6	FishXing predicts depth barrier from 0.3–7.4 cfs and velocity barrier at flows >12.6 cfs. See notes in FishXing analysis below.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Ross Taylor & Associates (2005) long profile data were used to run FishXing model along with the constant tailwater approach. A range of constant pool surface elevations (starting with the elevation of tailwater control) were tested to simulate increasing stage with increasing flows. Each value predicted the same range of flows would be depth and velocity barriers due to the steep slope of culvert. It was assumed that burst-and-attach behavior was possible on steel plates. FishXing predicts a depth barrier from 0.3–7.4 cfs, assuming 0.1 ft is the minimum depth required for passage. Due to water flowing under the rusted culvert, the depth barrier may continue to occur at higher flows than predicted. A velocity barrier was predicted at flows >12.6 cfs, when velocities exceed the Pacific lamprey maximum burst swimming speed (2.7 m/s).
Field evaluation observations and data	The culvert has a very steep gradient, but has ample attachment points on steel plates. The steep slope may present a barrier at moderate flows. During 7/27/2013 surveys, water was flowing under the culvert from outlet to 15 ft upstream. Lack of water in this part of the culvert prevents passage at low flows.
Ammocoete surveys	No ammocoetes were located in limited surveys upstream or downstream of the crossing; fine sediment habitat was minimal in sampled reach.
PAD	Lists information provided by Ross Taylor & Associates (2005).
Other evaluations	RTA (2005) listed the crossing as a total barrier to all life stages of salmonids. Ranked as low priority for removal because likely located upstream of the reach accessible to anadromous salmonids due to steep channel slopes in two reaches below Alderpoint Road.

Additional potential barriers in stream

The PAD lists an 8 ft waterfall just downstream of Alderpoint Rd (PAD ID# 736847). It is unknown whether this site is a barrier to lampreys. No additional PAD crossings or crossings visible in Google Earth are located in Mill Creek.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
705816	Francis Creek	Eel River	Lower Eel	9/11/2013 1/14/2014 (revisited)	Port Kenyon Rd.	40.59335	-124.25840

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Partial data	No	No	No	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	Unknown, but likely 2.67 X 0.50	3 (each pipe)	3 (each pipe)	30[1]	n/a	No	Yes, three adjacent 3ft diameter pipes

[1] Data from Taylor (2000) and should be considered approximate due to changes at site.

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Apron	At stream grade	No	No	Pool tailout	Fair; undersized and embedded with fine sediment

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Each pipe is embedded with ~6” of fine sediment	Could not assess, but assume silts and sands	Unknown	<1	Corrugations present

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
10.6	6.2	13.6

Additional site comments

Crossing is comprised of three ~30-ft long, 3-ft diameter corrugated metal pipes. Several physical characteristics of site could not be measured or evaluated due to lack of access. Unable to access inlet and upstream, but crossing has a 2–3-ft wide concrete apron (v-shaped) at inlet. Large pool (20 x 15 ft) at outlet with max depth of 6 ft and soft clay banks. Overall, culverts appear to be undersized and will likely become plugged due to low-gradient and high sediment retention. Creek is channelized and has invasive grasses lining banks. Substrate consists of clay, silt, and sand with no gravel. While e-fishing, crew witnessed large number of pikeminnow both upstream and downstream of site, including one feeding on a larval lamprey. Stream is turbid and stagnant in places and water quality is likely an issue during warmer / drier months. Culvert slated to be replaced with a bridge in 2014 by a Humboldt County project funded through the Fisheries Restoration Grant Program. The project will also remove a hydraulic constriction to allow channel and estuary “flushing” effects at medium to high flows.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)	Range of passable flows predicted (cfs)	Notes
Unknown	Possible velocity at high flows	1.3–70.4	Unknown; likely passable at most flows	Could not access site for full evaluation, but may be a velocity barrier at high flows due to small size and high sediment retention.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Not conducted due to lack of access and long profile data.
Field evaluation observations and data	Culvert appears to be undersized and retains a high amount of sediment, but likely allows passage at low to moderate flows. Possibly becomes a velocity barrier at higher flows due to low capacity, however low gradient channel likely keeps velocities relatively low. May become easily plugged with debris and sediment due to small size, low-gradient, and high sediment load.
Ammocoete surveys	No access upstream. Did not detect Pacific lampreys, but captured *Lampetra* ammocoetes downstream and observed a pike minnow preying on an ammocoete while e-fishing.
PAD	PAD states: “The culvert is a migration/emigration barrier to adult and juvenile fish. The failing and plugged culvert affects hydrology, floodplain function, water quality and habitat conditions. Upstream stream flows through concrete ditch and numerous culverts through downtown Ferndale.”
Other evaluations	Taylor (2000) stated the crossing was an adequately-sized concrete box culvert that was nearly full of fine sediment. However, our site visit revealed that the concrete box culvert has been replaced with three corrugated plastic pipes that do not appear to be adequately-sized. Comparison of photos from Taylor (2000) to recent photos indicate the entire channel was moved to the east (toward river right), likely during installation of the new crossing. Taylor (2000) did not run FishXing because of sediment in culvert, but stated that it was probably a velocity barrier to salmonids at higher flows. Culvert slated to be replaced with a bridge in 2014 by a Humboldt County project funded through the Fisheries Restoration Grant Program.

Additional potential barriers in stream

No other Francis Creek crossings are listed in the PAD, but upstream Francis Creek flows through numerous culverts with unknown passage status in downtown Ferndale. Several other private crossings upstream of Ferndale are apparent based on examination of Google Earth imagery.

Crossing photographs

Outlet from downstream (pipes obscured by grass)	Inlet; showing stagnant water.
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
705815	Russ Creek	Lower Eel River	Lower Eel	10/16/2013	Centerville Rd.	40.58196	-124.31153

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Partial data	No	No	No	No	No

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Heigh t (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	12.0[1]	9.0[1]	33.8[1]	0.2%[1]	No	No

[1] Data from Taylor (2000)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Wingwall <30°	Free-fall into pool (90° angle corner)	No	No	Log weir	n/a

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in structure	n/a	<1	<1	Concrete bottom

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
8.4	3.8	n/a

Additional site comments

Access to stream was denied by owner; data collected was based on visual inspection from road. Could not see or measure all physical characteristics, but concrete apron with 90° perched lip at outlet appears to be a barrier at some flows.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)	Range of passable flows predicted (cfs)	Notes
Partial, potentially total	Perched outlet, possible velocity	1.0–55.7	Unknown	Perched outlet likely barrier at low flows, but likely becomes backwatered at higher flows. Culvert could be a velocity barrier at higher flows.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Not conducted for Pacific lamprey. FishXing analysis by Taylor (2000) suggests that it may be a velocity barrier for juveniles at higher flows; thus it has potential to be velocity barrier for Pacific lampreys at higher flows.
Field evaluation observations and data	Not enough information for full evaluation, but the site is likely a barrier to passage at low to moderate flows when culvert perch is more pronounced. Outlet may backwater from log weir at tailwater at moderate to high flows, which would likely allow lampreys to enter culvert and pass if water velocities allow. In addition, the ability of lampreys to climb around the vertical 90° step needs further evaluation to improve confidence in the passage status of this site.
Ammocoete surveys	Did not conduct due to lack of access.
PAD	Lists information provided by Taylor (2000).
Other evaluations	Taylor (2000) stated: "Passable for most adults and temporary barrier for all juveniles. FishXing determined that there's a lack of depth for adults at lower migration flows and a potential velocity barrier at higher migration flows for juveniles. The slightly perched outlet may be a problem for juveniles too."

Additional potential barriers in stream

PAD ID 736838 is a private water diversion located upstream that according to the PAD is a "temporary small rock dam to facilitate water diversion that blocks downstream and upstream migration of juvenile salmonids at observed flows". Lamprey passage status at this site is unknown. No other potential barriers were evident in Russ Creek based on inspection of Google Earth imagery.

Crossing photographs

Outlet (from above)

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715481	Butte Creek	Little Van Duzen River	Van Duzen	11/6/2012	Hidden Valley Rd.	40.42928	-123.67326

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing	Multiple structures at site?
Pipe-arch	Annular CMP	7.5 X 2.3 X 4.4	13.3	3.4	75.70 (South) 76.20 (North)	0.86% (South) 1.10% (North)	None	Two pipe-arch culverts: South (primary) and North (secondary)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
50°	South = projecting; North = projecting	South = concrete outlet apron with 90° lip about ~8” above water surface. North = corrugated bottom ~1–2” above stream bottom elevation.	No	No	Pool tailout	Both culverts too small to safely inspect inside, but overall condition appears to be good. South has peeled up corrugated metal lip ~20 ft from outlet.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
South = shallow, discontinuous layer of substrate present primarily from inlet to ~20 ft inside. North = discontinuous layer of substrate mainly present at inlet; substrate depth level 0.8 at inlet and 0' at outlet	South = cobble, gravel, sand North = cobble, sand, boulder	South = ~2' North = ~2'	South = ~5' North = 0'	South = Concrete bottom throughout. Small substrate u/s of inlet and d/s outlet may make attachment difficult. North = large corrugations present.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
20.1	2.1	43.4

Additional site comments

Crossing consists of two pipe-arch culverts. Inside the South culvert there is a raised metal lip ~20 ft from outlet. This lip doesn't appear to be a lamprey barrier as individuals can pass toward culvert edges. The inlet of the South culvert is further upstream than the North culvert and thus at higher elevation.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	South = perched outlet North = perched outlet, depth	0.6–140.5	Unknown. South: >105 cfs if velocity suitable; North: >2.0 cfs if depth and velocity suitable	FishXing could only be used to evaluate flows at which culvert outlets backwater, but not depths and velocities; thus range of passable flows unknown.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing only used to evaluate stream flows at which the outlet of each culvert backwaters (allowing lamprey entry) based on surveyed outlet elevations and the tailwater cross section. Depth and velocity within each culvert not possible to accurately model since inlet of South (primary) culvert is ~20 ft further upstream than North inlet; this staggered placement causes the South culvert to receive more water (and the North less) than predicted by the model. The model predicts that the perched South culvert outlet backwaters at flows greater than 105 cfs; however, it is unknown whether velocities at this flow would be below the maximum swim speed of Pacific lamprey. It is also possible that some lampreys can scale the relatively short 90° concrete lip of the South culvert at flows lower than 105 cfs. The North culvert outlet, which is approximately 1 ft lower elevation, is predicted to backwater at flows greater than 2.0 cfs; however, field observations indicate the North culvert likely does not receive sufficient water depth to allow passage until lightly higher flows. Overall, the model indicates that upstream passage is possible at the crossing at moderate, and possibly high, migration flows.
Field evaluation observations and data	The 90° lip of the concrete outlet apron on the South culvert was approximately 8" above the water surface during 11/6/2012 field surveys (moderately low flows). It is unknown whether lampreys can scale the vertical surface and enter before the outlet backwaters, but the outlet drop is expected to be, at minimum, a significant passage obstacle at the South culvert. The bottom of the North culvert was slightly perched (1–2") above the adjacent stream bed during the field visit, which may be an obstacle to lamprey passage at lower flows. The North culvert was essentially dry at the surveyed flows and presents a depth barrier until it receives sufficient water. The North culvert is expected to receive water during winter base flows when most lamprey movement occurs. Both structures are relatively low gradient and have ample attachment points within.
Ammocoete surveys	Pacific lamprey ammocoetes were detected during limited surveys both upstream and downstream of the crossing, indicating passage is possible at some range of flows.
PAD	A 2003 evaluation by California Department of Fish and Wildlife listed the crossing as "Not a barrier" to salmonids based on professional judgment.
Other evaluations	No other evaluations have been carried out to our knowledge.

Additional potential barriers in stream

A road crossing approximately 1.3 miles upstream is listed in the PAD (ID 723653); a rock weir has been installed below this site to improve salmonid passage. Photo documentation of this site indicates that this site is most likely not a barrier to salmonids, but further evaluation is needed. Google Earth indicates several other private crossings may be present upstream of PAD ID 715481 in tributaries to Butte Creek.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715472	Yager Creek	Van Duzen River	Van Duzen	6/12/2013	Redwood House Rd.	40.54411	-123.91543

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Pipe-arch	Annular CMP	6 X 2 X 3.6	16.0	8.0	66.4	1.57%	Yes, due to debris jammed under culvert	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
80°	Projecting	At stream grade	No	No	Pool tailout	Very poor. Bottom rusted through & water flowing under culvert. Debris jammed under culvert causing humps where water is forced toward river left in culvert.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in culvert	n/a	4	<1	Significant damage to corrugations on center of culvert bottom, but edges of bottom are not rusted through and would presumably allow attachment when wetted during moderate to high migration flows.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
16.7	9.4	43.1

Additional site comments

Culvert is failing and needs to be replaced ASAP. Starting about 4 ft from the culvert outlet, the bottom is “humped-up” and raised ~0.5–2 ft above the water surface elevation, likely preventing passage at low flows. Water appears to be running almost entirely beneath, rather than through, culvert. The outlet is in a large, deep, low-velocity pool with a distinct tailwater control. Site is located in reach of upper mainstem of Yager Cr. also known as South Fork Yager Cr., which is upstream of the confluence with the much larger North Fork Yager Cr. watershed.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Depth, velocity	1.5–156.1	1.5–116	Field observations indicate likely barrier at low migration flows due to damage.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing model results should be viewed cautiously due to misshapen state of culvert and uncertainties in parameterizing the channel slope downstream of the tailwater control. Nevertheless, the model indicates that the culvert is not passable at flows higher than approximately 115 cfs, when velocities exceed the Pacific lamprey maximum burst swimming speed (2.7 m/s). The model run assumed that burst-and-attach behavior is possible on the large culvert corrugations. FishXing does not predict a depth barrier at low flows, but field observations indicate that the damaged culvert bottom creates a barrier at low flows and thus the model likely overestimated percent of passable flows.
Field evaluation observations and data	The culvert has a relatively gentle slope with ample attachment points. Lampreys could enter the culvert outlet at the relatively low flows present during the 6/12/2013, but the “humped-up” bottom that starts approximately 4 ft from the outlet would not allow passage through the culvert at these flows. It is unknown how much flow would be required to allow migration past the raised bottom, which, along the left side of the culvert, was approximately 0.5 ft above the water surface elevation of the outlet pool on the survey date. It appears that passage would be possible at moderate flows due to presence of tailwater control. It is possible that lampreys could cross under the raised portions of the culvert during low flows, but this potential passage route could change over time depending on bottom damage and sediment and debris accumulation.
Ammocoete surveys	No ammocoetes were located during limited sampling immediately upstream or downstream of the crossing. Several suitable fine sediment habitat patches were sampled.
PAD	None relevant
Other evaluations	To our knowledge no other systematic passage evaluations have been done at this site.

Additional potential barriers in stream

The PAD lists another crossing of mainstem Yager Cr. by Redwood House Rd. (PAD ID 715471) approximately 4 miles upstream. Google Earth indicates that this site may not actually be a crossing, but its status should be evaluated. The PAD also lists two high-gradient natural features approximately 5 miles downstream in mainstem Yager Cr. that are considered potential migration obstacles to salmonids. Evaluation of these sites for lamprey passage was beyond the scope of this study, but they are not likely to be barriers since steelhead have been observed upstream according to the PAD.

Crossing photographs

Outlet	Inlet (looking d/s towards outlet)
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715429	Strawberry Creek	Yager Creek	Van Duzen	6/17/2013	HRC Road 4	40.57996	-123.97424

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	2.25 X 0.5 X 1.23	5.8	6.0	61.3	12.01%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Projecting	Free-fall into pool	Wood, spaced approx. 6 ft apart throughout length of culvert	No	Boulder weir	Overall good condition.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Minimal amount of small cobble behind some baffles	n/a	<1	<1	Corrugations are small and could make attachment at high velocities difficult. Wood baffles on both sides approx. 6 ft apart could allow for attachment, but have 90° angled corners.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
4.6	0.0	14.9

Additional site comments

This culvert contains 10 rows of paired wooden baffles (10 on left side of culvert and 10 on the right) spaced approximately 6 ft apart. The outlet is perched ~0.8 ft above stream bed elevation and ~0.3 ft above water surface elevation of outlet pool.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Total barrier	Perched outlet, velocity	0.4–43.4	None	Evidence from FishXing and field evaluations indicate the site is a perched outlet barrier at flows lower than 32 cfs and a velocity barrier at moderate to high flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Likely total barrier due to perched outlet, but initially categorized as indeterminate due to potential to backwater during high flows.
FishXing analysis	FishXing model results should be viewed cautiously due to wood baffles and uncertainties in lamprey attachment ability and burst swimming exhaustion time. Baffles were accounted for in the model by using a high (0.050) bottom roughness coefficient. FishXing predicts that the tailwater pool backwaters into the perched outlet at flows higher than 31.9 cfs; thus we conservatively assume most lampreys cannot enter the culvert at lower flows. Regardless of the flow level where lampreys can begin to enter the culvert, FishXing predicts that water velocities exceed the Pacific lamprey critical swimming speed (0.86 m/s) at flows >0.5 cfs. Assuming that (1) attachment to the small corrugations is not possible and (2) exhaustion occurs after 10 s of burst swimming, the model predicts that lampreys can pass the culvert at stream flows below approximately 1.0 cfs using burst swimming without attachment (if they could enter the perched outlet at those flows). If burst-and-attach behavior were possible, the model predicts successful passage at flows less than 12 cfs. Overall, the model indicates that the site is a total barrier to lamprey migration due to perched outlet at low flows and high velocities at moderate and high flows.
Field evaluation observations and data	Culvert perched ~0.8 ft above stream bed elevation and ~0.3 ft above water surface elevation of outlet pool during 6/17/2013 survey. Assume attachment to small corrugation difficult and burst-and-attach swimming behavior likely not possible at maximum burst speed. Culvert has potential to backwater at moderate to high flows due to boulders and wood in tailwater of outlet pool, but very steep gradient (12%) likely precludes passage at these flows.
Ammocoete surveys	No ammocoetes were located during limited sampling of fair quality ammocoete habitat immediately upstream or downstream of the crossing. Several Pacific lamprey ammocoetes were captured in Yager Creek near its confluence with Strawberry Creek.
PAD	In 1982 CDFW designated the crossing as a partial barrier to salmonids based on professional judgment.
Other evaluations	To our knowledge no other systematic passage evaluations have been done at this site.

Additional potential barriers in stream

With the exception of the very upper portion of the watershed, no other road crossings are apparent in Strawberry Creek based on examination of Google Earth imagery.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
707107	Elk Creek	Rattlesnake Creek	South Fork Eel	3/22/2013	Hwy 101	39.82651	-123.59310

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Partial	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	5 X 1 X 2.7	13.0	13.0	263.5	1.65%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
25°	Wingwall <30°	Free-fall into jump pool created by weir / ladder.	Metal baffles (11) present throughout culvert. Series of weirs & fish ladder present at outlet.	Concrete ladder with sharp corners and 2–6" drops into pools.	Concrete/metal weirs	Good

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Discontinuous layer beginning at 0' and ending at 120' Substrate depth level 0.1' at inlet and 0' at outlet	Cobble, gravel, boulder	0	0	Corrugations continuous with 11 baffles interspersed within culvert for adequate resting areas. Baffles may deter burst-and-attach swimming.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
10.2	1.2	34.3

Additional site comments

The creek was at winter base flow during the 3/22/2013 evaluation.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Total barrier	Perched outlet, possible velocity	1.3–85.4	Likely none	Designation based primarily on professional judgment. It is possible that under certain flow conditions, lampreys may be able to scale ladder/weir and enter culvert.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate, but likely total.
FishXing analysis	The site is too complex to do a complete evaluation using FishXing; however the model was run to predict approximate water velocities within the culvert at migration flows to determine whether passage would be possible if lampreys could enter the culvert. A bottom roughness coefficient of 0.050 was applied to simulate presence of baffles. The model predicts that average water velocities near both inlet and outlet exceed Pacific lamprey critical swimming speed (0.86 m/s) at all migration flows. However, water velocity was not predicted to exceed the maximum burst swimming speed (2.7 m/s). Therefore, lampreys could, theoretically, successfully pass through culvert assuming they could reach and enter outlet, use burst-and-attach behavior, and navigate around metal baffles.
Field evaluation observations and data	Overall, the site appears to be a total barrier to lamprey passage at most, if not all flows. Both the outlet weirs and fish ladder represent a substantial obstacle to migration and possibly a total barrier to even reaching the culvert outlet. The 90° angles of the concrete steps of the fish ladder are slightly worn in places and it is possible some fish could reach the outlet via this route at moderate flows such as those observed on the survey date. At the observed flows, the outlet was perched approximately 0.15 ft (2 in) above the water surface elevation of the fish ladder pool. Even if lampreys could reach and then enter the slightly perched outlet, the relatively steep culvert slope and the presence of metal baffles with sharp angles would presumably make passage difficult at most flows.
Ammocoete surveys	No ammocoetes were located immediately upstream or downstream of the crossing during limited sampling of suitable ammocoete habitat. Pacific lamprey ammocoetes were documented in a separate survey of Rattlesnake Creek just downstream of its confluence with Elk Creek.
PAD	Indicates that the culvert is a total barrier to adult salmonids based on FishXing evaluation by Humboldt State University (HSU).
Other evaluations	HSU evaluated according to PAD, but date and details could not be located.

Additional potential barriers in stream

No additional PAD records exist for the watershed. Inspection of Google Earth imagery indicates the presence of at least one private road crossing upstream.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
736751	Harper Creek	Bull Creek	South Fork Eel	5/21/13	Bull Creek Flats Road	40.351028	-123.988045

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)[1]	Crossing slope (average)[1]	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	East = 10.0 West = 10.0	East = 10.0 West = 10.0	East = 27.2 West = 29	East = 0.52% West = 0.53%	No	Two adjacent, box culverts. East = primary on river left, West = secondary on river right

[1] Data provided by Ross Taylor

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
n/a	Headwall	Freefall into Pool. East culvert perched ~8–12” above stream bed. West perched 1–4” above channel substrate.	No	No	Pool tail	Sediment plugging outlet of west culvert; ~25% blockage.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
West culvert retains approximately 2–3 ft of substrate.	Gravels, cobble, boulder	0	0	Concrete bottom w/ continuous attachment points throughout.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
3.9	0.0	15–18 (estimate)

Additional site comments

Two adjacent, like-sized box culverts. East = primary on river left and West = secondary on river right. River right (west) culvert is extremely embedded and water only appears to flow through it during high flow events.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Total barrier	East = perched outlet West = depth	0.4–36.7	None	FishXing predicts that the east (primary) culvert is a perched outlet barrier at all migration flows and that the west culvert is a depth barrier at all flows. Field observations indicate that lamprey may be able to enter east culvert at higher migration flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

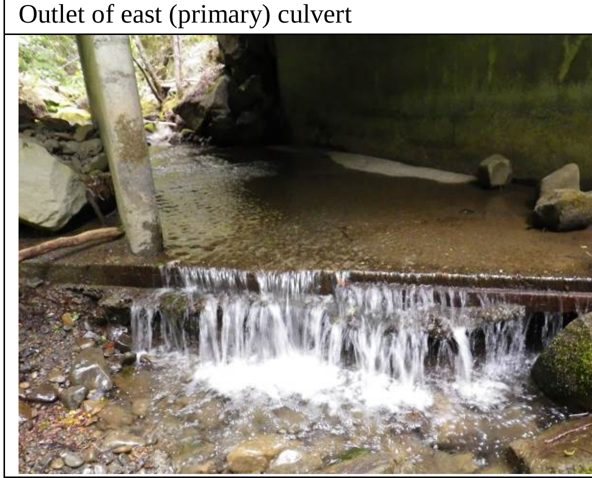
Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing was run using data provided by Ross Taylor & Associates from a 2009 survey. FishXing predicts that the east (primary) culvert is a perched outlet barrier at all migration flows. The model predicts that elevation of the outlet pool rises modestly at the highest passage flow (36.7 cfs), but the culvert outlet does not backwater enough to allow lamprey to enter. FishXing predicts the west culvert is a depth barrier at all flows. The inlet elevation of west culvert is 2.3 ft higher than right culvert, indicating it does not receive flow until water in the east culvert is >2.3 ft deep.
Field evaluation observations and data	The crossing is likely a barrier to migration at most migration flows due to perched concrete lip at outlet of east culvert and significant substrate and higher elevation of the west culvert. At higher flows, lampreys could possibly use boulders at edge of outlet on river left to climb into east culvert. It is also possible they could climb into the east culvert from the river right side of the channel during higher flows.
Ammocoete surveys	No ammocoetes were detected during limited surveys upstream and downstream of the crossing.
PAD	Indicates site is partial barrier to salmonid passage based on FishXing evaluation by RTA in 2009.
Other evaluations	Site surveyed by RTA in 2009 for salmonids as part of a State Park fish passage evaluation project. Right bay does not receive flow at the outlet until left bay is flowing above 2.3 feet deep. Results indicate that it is a partial barrier to salmonid passage.

Additional potential barriers in stream

No additional crossings are known to occur in the watershed.

Crossing photographs

Outlet of east (primary) culvert	West (secondary) culvert from outlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
Not in PAD	Cuneo Creek	Bull Creek	South Fork Eel	5/21/13	n/a; just d/s of Bull Creek Flats Rd. bridge.	40.333117	-124.027039

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	No	Yes	Yes

Site physical characteristics

Shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope	Slope breaks in crossing?	Multiple structures at site?
Irregular; abandoned concrete abutment	Concrete	None	n/a	n/a	n/a	n/a	n/a	n/a

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
n/a	n/a	n/a	No	n/a	n/a	n/a

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
n/a	n/a	n/a	n/a	n/a

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
11.3	0.6	30

Additional site comments

Abandoned concrete bridge abutment just downstream of the Bull Creek Flats Rd. (Mattole Road) bridge. Structure is irregularly shaped and channel-spanning. Stream has high quality spawning habitat and potential for restoration. Structure could be easily removed or modified with lamprey ramps to improve passage.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier, possibly total barrier	Drop / obstruction	1.0–105.2	Likely none	Based on professional judgment, site likely a barrier, or major obstacle to lamprey migration.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Site not suitable for FishXing analysis.
Field evaluation observations and data	At the moderate stream flows observed during the 5/21/13 field visit (and possibly across the range of migration flows), the site appears to be a total lamprey passage barrier. At the least, it is a major obstacle to passage. The concrete structure spans the active channel and is elevated approximately 1.5–4 ft above the streambed. Most of the structure has a sharp 90° angle edge where water pours over, which would likely deter lamprey passage. There are a couple of locations where the angle of the edge is slightly more rounded due to erosion. It is possible that parts of the site began to backwater at the higher end of migration flows, but water velocities are likely to be too high to allow lampreys to climb the structure and round the sharp corners at high flows. The ability of lampreys to climb and traverse vertical 90° corners needs further evaluation to improve confidence in designating passage status of this site.
Ammocoete surveys	Ammocoetes not detected upstream or downstream of site during limited sampling of mostly marginal habitat. One high quality habitat patch just downstream did not contain ammocoetes. Pacific lamprey ammocoetes were detected in Bull Creek near the Cuneo Creek confluence.
PAD	This site is not in the PAD.
Other evaluations	There have been no other evaluations of this site to our knowledge.

Additional potential barriers in stream

PAD ID 736752, the Bull Creek Flats Rd. (Mattole Road) bridge crossing, is located just upstream and is not a barrier. No additional PAD crossings or other crossings visible in Google Earth are located in the mainstem of Cuneo Creek.

Structure photograph

Concrete structure downstream of Mattole Road Bridge (PAD ID 736752).

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
707157	Fish Creek	South Fork Eel River	South Fork Eel	6/28/2013	Avenue of the Giants	40.22266	-123.80128

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	6.0	7.6	114 (184 including wingwalls at outlet and inlet)	9.05%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
70°	Wingwall <30°	At stream grade	13 concrete & metal baffles present within and 2 at culvert inlet	No	Pool tailout	Overall good; erosion occurring on outside of inlet wing walls

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Discontinuous layer of substrate from 0–20 ft from inlet	Silt, Gravel, Sand	<1	<1	Smooth, flat concrete throughout with substrate behind baffles and in pools.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
11.8	0.3	20.8

Additional site comments

Baffles do not span entire width of culvert and have small, steps with more rounded edges on river right that lamprey can most likely navigate. Baffles increase water depth at low flows. Both the outlet and inlet have projecting straight wingwalls, which are essentially an extension of the culvert (46 ft downstream of outlet and 24 ft upstream of the inlet). The culvert itself is steep, but the outlet apron is nearly flat. Very little water was present in the channel during the 6/28/2013 survey (running sub-surface for significant lengths). Marijuana cultivation, and presumably illegal diversion, appears to be a significant factor in the headwaters based on an inspection of Google Earth.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Velocity	1.5–77.7	5.1–44.0	FishXing predicts a potential depth barrier at flows lower than 5.1 and a velocity barrier at flows greater than 44.0 cfs.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing results for this site should be viewed with caution due to complexity (long wingwalls extending from culvert) and presence of baffles. Baffles were accounted for in the model by using a bottom roughness coefficient of 0.050. The model predicts that water velocities in the culvert exceed the Pacific lamprey critical swimming speed (0.86 m/s) at flows >5.1 cfs, but do not exceed the maximum burst swimming speed (2.7 m/s) until flows reach 44.0 cfs; thus individuals could theoretically pass at flows <44.0 cfs assuming burst-and-attach behavior is possible. FishXing indicates that water depth may become too shallow for passage at flows <5.1 cfs, but field observations indicate that passage is likely possible at lower flows.
Field evaluation observations and data	Culvert may be a barrier at high flows due to small size and steep slope. Continuous concrete attachment surface is present along river right edge of culvert, but small (1–2") steps and an uneven bottom may create turbulence and make burst-and-attach swimming more difficult at water velocities lower than the maximum burst swimming speed. The baffles increase water depth and likely improve passage at low flows.
Ammocoete surveys	No ammocoetes were located immediately upstream or downstream of the crossing during limited sampling of marginal habitat. Stream was primarily subsurface or isolated pools on survey date.
PAD	Lists information from Lang (2005)
Other evaluations	Lang (2005) evaluated this site for CalTrans as part of District 1 Pilot Fish Passage Assessment and deemed it a partial barrier to salmonids. It was ranked top priority site for remediation in District 1. The report states: "Culvert has a steep slope (7.6%) and even with baffles is a partial barrier to adult salmonids and most likely a complete barrier to resident and juvenile salmonids. The culvert slope needs to be substantially reduced to improve passage."

Additional potential barriers in stream

No additional PAD crossings occur in Fish Creek. Google Earth imagery indicates at least one potential private crossing upstream of where the stream forks.

Crossing photographs

Outlet (showing low wingwalls and buried apron)

Inlet (showing wingwalls and baffles)

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
707096	Tenmile Creek	South Fork Eel River	South Fork Eel	7/3/2013	Hwy 101	39.64707	-123.47631

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	10.0 (South) 10.0 (North)	7.0 (South) 7.0 (North)	70.0 (South) 70.0 (North)	0.46% (South) -1.13%[1] (North)	No	Yes; two adjacent box culverts

[1] Negative slope is due to retention of ~1.2 ft of sediment at outlet of North culvert.

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Wingwall <30°	South = free-fall into pool; North = at grade of high flow gravel bar.	No	No	Pool tailout	Culvert in good shape, but outlet wingwalls broken and in creek

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in South bay; Substantial retention in North, with ~1.2 ft at outlet and minimal substrate at inlet.	Gravel, Cobble, Sand	<1	<1	South bay has smooth, flat concrete throughout. North bay has natural streambed or concrete with suitable attachment points throughout.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
12.2	3.7	34.6

Additional site comments

The concrete outlet wingwalls have broken on both sides and fallen into channel immediately downstream of outlet, possibly influencing water surface elevation of tailwater pool during higher flows and increasing the potential of South bay of culvert to backwater.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	South = perched outlet North = depth	0.4–85.3	South = 21.9–85.3 North = 37.4–85.3	Lampreys may be able to enter perched outlet by climbing or swimming at flows lower than predicted by FishXing.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing results should be viewed with caution due to the complexity of the site (2 culvert bays and broken wingwalls in channel). For the South bay, the model predicts that the 90° perched outlet will begin to backwater at flows higher than 21.9 cfs. We conservatively assume that lampreys cannot enter the culvert at flows lower than 21.9 cfs. The model predicts that water velocities will remain below the maximum burst swimming speed (2.7 m/s) at all migration flows, and thus lampreys can pass once they are able to enter the South outlet. For the North bay, the model predicts that water depth at gravel bar at the outlet will be below the minimum depth criteria of 0.1 ft until flows reach 37.4 cfs, when lampreys could presumably begin to enter the culvert. The model also predicts that water velocities are well below maximum burst swimming speed in North bay at all migration flows and thus passage would be possible once lampreys can enter.
Field evaluation observations and data	The perched outlet drop at the South bay is expected to be a barrier to lamprey migration at the low flows occurring (7/3/2013 survey). The South bay is low gradient and has ample attachment points and would likely be passable if the outlet backwatered enough for lampreys to enter at higher flows. The broken concrete outlet wingwalls in the channel downstream of outlet may influence water surface elevation of the tailwater during higher flows, possibly backwatering the outlet and allowing lampreys to enter at lower flows than predicted by FishXing. The North bay has over 1 ft of gravel substrate at the inlet that blocks passage at low flows. If water velocities remain low enough when the water level exceeds the gravel bar at the outlet, then lampreys could presumable enter and pass the North bay. Overall, the site appears to block passage at low migration flows and likely allows passage at moderate to higher migration flows.
Ammocoete surveys	No ammocoetes were detected during sampling of a relatively high amount of suitable habitat upstream and downstream of the crossing.
PAD	The PAD indicates that site partial barrier to salmonids based on professional judgment by HSU in 2005. The PAD states that CalTrans has a project to incorporate a low flow channel to be completed in 11/1/2012. No work had been done as of our survey date. CalTrans should consider lamprey passage when retrofitting this site.
Other evaluations	HSU evaluated the site in 2005 based on professional judgment according to the PAD.

Additional potential barriers in stream

The PAD does not list additional crossings of the mainstem of Tenmile Creek. However, a cursory inspection of Google Earth imager indicates that there are numerous additional crossings both upstream and downstream of PAD ID 707096, both private and public. Most of these appear to be either bridges or low water crossings, but they should be investigated further. Marijuana cultivation in the watershed is extremely intensive (and spatially extensive) and likely exacerbates seasonal passage barriers due to reduced stream flows.

Crossing photographs

Outlet; South bay on right.	Inlet; South Bay on left.
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
706954	Cedar Creek	South Fork Eel River	South Fork Eel	7/25/2013	Hwy 101	39.84793	-123.70213

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Width (ft)	Height (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Concrete bottom arch	Concrete	None	22.0	20.0	828[1]	1.8%[1]	Yes, associated with weirs	No

[1] Data from Lang 2005

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
~60–70°	Wingwall < 30°	Outlet apron at stream grade then cascade over rock at end of wingwall; Fish ladder on river right	25 concrete weirs spanning culvert width	Denil style fish ladder. 14 pairs of ¼" steel plate baffles attached to stepped concrete	Pool tailout	Overall good; minor cracks in concrete seams.

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Discontinuous layer of substrate in structure; Substrate builds up in pools behind steel weirs with concrete patches between	Sand, boulder, cobble; Culvert has concrete bottom but substrate is present at intervals	<1	<1	Natural streambed & concrete throughout with ample attachment points.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
38.3	5.5	n/a

Additional site comments

Concrete outlet apron is elevated and drops abruptly over steep concrete and boulder cascade into large outlet pool. Culvert has dog-leg within.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)	Range of passable flows predicted (cfs)	Notes
Partial barrier	Velocity, obstacle	5.0–320.8	Unknown, but likely passable at most flows	FishXing indicates that culvert may be a velocity barrier at highest migration flows. Elevated outlet apron is likely greatest obstacle to passage at lower migration flows.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Not possible to predict passage at elevated outlet apron or model water surface elevation at outlet / entry into culvert using FishXing due to site complexity. However, model was run using constant tailwater elevation approach and data from Lang (2005) to predict velocities within culvert across migration flows. Assuming water surface elevation changes little with increasing flow (model parameterized with constant tailwater water surface elevation 0.5 ft higher than outlet elevation), the model indicates water velocities near culvert outlet exceed maximum burst swimming speed of Pacific lampreys (2.7 m/s) at flows greater than 244 cfs. However, assuming a moderate backwater (1.5 ft higher than outlet elevation) occurs at higher migration flows due to the small boulders on outlet apron and fish ladder infrastructure, water velocities remain below 2.7 m/s at the outlet at all migration flows. Water velocities predicted upstream of outlet remain well below 2.7 m/s at all migration flows regardless of tailwater elevation. Although there is some uncertainty in upper passable flow due to site-complexity and unknown effect of tailwater control, overall the model indicates passage possible at most migration flows.
Field evaluation observations and data	The elevated outlet apron likely creates the greatest obstacle to lamprey passage at site; however, when sufficient water is flowing over rock/concrete drop, lampreys can likely climb feature to reach culvert outlet. At higher flows, lampreys can likely climb via multiple routes, but velocities may become too high at highest migration flows. The steep fish ladder below outlet on river right is unlikely to permit passage due to sharp-angled steel plates. Within culvert, weirs slow water velocity and create resting areas, and although they span entire width, lampreys can likely pass over relatively rounded edges and also where baffles meet culvert walls. Overall, field observations indicate that lampreys likely have little difficulty passing through culvert during relatively low flows and can likely pass at relatively high migration flows due to large culvert size and presence of weirs.
Ammocoete surveys	Pacific lamprey ammocoetes detected both upstream and downstream of the crossing, indicating successful passage.
PAD	Lists information from Lang (2005)
Other evaluations	Lang (2005) surveyed site in July 2002 and indicated that adult anadromous salmonids can likely pass via fish ladder, but that resident and juvenile passage is limited.

Additional potential barriers in watershed

The remnants of an old hatchery structure (PAD ID 737364) are located ~0.75 river miles downstream of the Hwy 101 crossing. Based on photos and observations, we expect that this channel spanning concrete structure and associated low waterfall likely causes a delay in migration but would be passable at most migration flows. With the exception of the Hwy 271 bridge, no other crossings are evident in Cedar Creek based on inspection of Google Earth imagery.

Crossing photographs

Outlet	Inside culvert, looking upstream
	

Location Information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
707115	Red Mountain Creek	South Fork Eel River	South Fork Eel	8/21/2013	Hwy 101	39.92968	-123.76100

Work Performed at Site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Conducted, but not usable	Yes	Yes	Yes

Crossing Physical Characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Open-bottom arch	Concrete	None	20.0	20.0	514	0.53%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
45°	Wingwall <30°	At stream grade	8 concrete baffles approx. 6 ft. long X 18 in wide; 7 reinforced boulder piles	No	Concrete baffle and small boulders	Good condition

Substrate and Suitable Lamprey Attachment Points within Crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Substrate is continuous throughout structure	Silt, Gravel, Cobble	<1	<1	Natural streambed throughout crossing with suitable attachment points. Structure surface material with flat, smooth concrete walls and bottom side curb.

Channel Characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
31.1	1.4	31.8

Additional Site Comments

Considerable cobble and gravel present on the upstream side of baffles; silt on downstream side.

Passage Designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Non-barrier	None	4.1–260.7	All	Passable flows predicted using FishXing.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

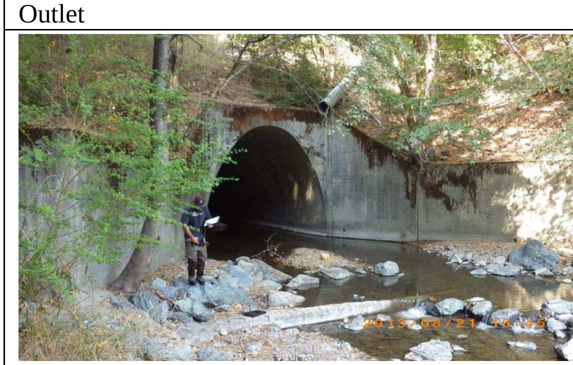
Evidence for Passage Designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	Model results indicate the crossing is passable at 100% of the flows evaluated. The measured tailwater control cross-section could not be used in the analysis, thus the model was run using the constant tailwater control approach. To model the lower range of migration flows, the water surface elevation of the outlet pool measured during the 8/21/2013 survey was used. For higher migration flows, it was conservatively assumed that water surface elevation of the outlet pool would rise at least 0.5 ft during higher flows based on site photos. To help account for reduced velocities from internal baffles and boulders, a bottom roughness coefficient of 0.40 was applied. Model results indicate that water velocities occurring at the upper end of migration flows remain below the Pacific lamprey maximum burst swimming speed (2.7 m/s). Since conservative values were used to parameterize the model, this crossing is unlikely to be a migration barrier at the migration flows evaluated.
Field evaluation observations and data	The open bottom arch culvert has a natural stream bed, relatively low gradient, and internal baffles across part of the channel that reduce velocity at higher flows. During late-summer field surveys, there was sufficient water depth to provide passage. There are ample attachment points present through the crossing to allow for burst-and-attach swimming.
Ammocoete surveys	Pacific lamprey ammocoetes were located upstream of the crossing.
PAD	In 2010, a corrugated "U" shaped culvert was replaced with the existing culvert by Caltrans.
Other evaluations	None

Additional Potential Barriers in stream

The PAD lists two potential temporal barriers to fish passage (PAD IDs 712847 and 712848) that occur approximately 0.5 and 1.0 miles upstream of the HWY 101 crossing. Both are listed as recreational summer dams and it is not clear whether these sites still exist, if they are constructed each year, and how long they remain in place. If only present during summer, these sites are expected to have minimal impact on Pacific lamprey passage, since movement occurs primarily from December through July. However, since Red Mountain Creek is a relatively large watershed with good habitat potential for lampreys and salmonids, these sites should be further investigated to verify they do not constitute significant barriers.

Crossing Photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
711992/ 758572	Poison Oak Creek	Eel River	Middle Main Eel	7/12/2013	Dyerville Loop Rd.	40.33809	-123.89988

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	No	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Open-bottom arch	Concrete	None	8.6	3.5	43.4[1]	-1.75%[1]	No	No

[1] Data from Ross Taylor & Associates (2011)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Wingwall < 30°	At stream grade	No	No	Pool tailout	Overall good, but embedded with sediment and appears to be undersized

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Substrate is continuous throughout structure.	Gravel, sand, cobble	<1	<1	Natural streambed throughout crossing with ample suitable attachment points

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
4.2	0.0	25.5

Additional site comments

Crossing is listed in the February 2013 PAD as both PAD ID 711992 and PAD ID 758572, which was added to the database in following evaluation by RTA (2011). The railroad crossing is immediately upstream of the Dyerville Loop Rd. crossing (PAD ID 715485). There is a substantial amount of substrate throughout crossing, reducing flow conveyance capacity and water velocity at higher flows.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Non-barrier	None	0.2–23.7	All	Designation based on professional judgment and RTA (2011)

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing was not run for this site.
Field evaluation observations and data	Because the culvert is heavily embedded with sediment, water velocities may present passage problems during very high flows; however based on field evaluations and RTA (2011), the site is not likely a barrier to lamprey migration at most lamprey migration flows.
Ammocoete surveys	No ammocoetes were detected during limited sampling upstream and downstream of crossing.
PAD	Cites 1997 evaluation by CDFW and states: "Xing is 85% plugged with gravel/fines."
Other evaluations	RTA (2011) evaluated site ("NWPRR-236.08") as part of their railroad evaluation and concluded that the site provides unimpeded passage for all age classes of salmonids.

Additional potential barriers in watershed

The PAD lists Dyerville Loop Rd. crossing (PAD ID 715485), which is immediately downstream of the railroad crossing. Google Earth imagery indicates a private timber road crossing exists approximately 1.75 miles upstream. This crossing should be evaluated, but is likely upstream of the historical lamprey distribution.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715485	Poison Oak Creek	Eel River	Middle Main Eel	7/12/2013	Dyerville Loop Rd	40.33835	-123.89981

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	No	No	Yes	Yes	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Open-bottom arch	Annular CMP	2 1/2 X 1/2	7.4	7.0 (excluding sediment)	71.2	-0.17%	No	No

[1] Data from Ross Taylor & Associates (2005)

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
90°	Projecting	At stream grade	No	No	Pool tailout	Poor condition; undersized, some structural damage; blockage from sediment

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Substrate is continuous throughout structure with depth at inlet and outlet > 1.5 ft. Nearly 75% retention.	Cobble, gravel, sand	Unknown; access limited due to private property	<1	Natural streambed throughout crossing with ample suitable attachment points; Small corrugations of culvert sides.

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
4.2	0.0	n/a

Additional site comments

The Dyerville Loop Rd. crossing is just downstream of the railroad crossing (PAD ID 711992).

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)	Range of passable flows predicted (cfs)	Notes
Non-barrier	None	0.2–23.7	0.2–23.7	Used data from RTA (2005) to run FishXing.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing predicts that velocities in the culvert remain below the Pacific lamprey maximum burst swimming speed (2.7 m/s) at all migration flows evaluated. Results indicate that water depth at the outlet may be below the 0.1 ft minimum depth criteria at migration flows below 2.0 cfs, but field observations during the low flow period indicate that depths are suitable.
Field evaluation observations and data	The crossing is low gradient, has ample attachment points, and water depths were suitable at low flows. Because the culvert is heavily embedded with sediment, water velocities have potential to hinder passage during high flows. However, based on field evaluations we conclude the site is unlikely to be a barrier to lamprey migration at most flows.
Ammocoete surveys	No ammocoetes were detected during limited sampling upstream of the crossing.
PAD	Repeats information from RTA (2005)
Other evaluations	RTA (2005) state: "FishXing determined that the current crossing provides unimpeded passage for adult salmonids and partial passage for juvenile salmonids. However, from a road maintenance point-of view the current crossing is due for replacement; the culvert is in poor condition and both the culvert and road prism are over-topped on less than a five-year storm flow."

Additional potential barriers in watershed

The railroad crossing (PAD ID 711992) is immediately upstream of the Dyerville Loop Rd. crossing. Google Earth imagery indicates a private timber road crossing exists approximately 1.75 miles upstream. This crossing should be evaluated, but is likely upstream of the historical lamprey distribution.

Crossing photographs

Inlet (outlet not accessible)

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
707091	Long Valley Creek	Outlet Creek	Upper Main Eel	8/19/2013	Hwy 101 / Road Fill	39.57969	-123.44275

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	No	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size (inches, W X H X diagonal)	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Circular	Annular CMP	6.5 X 2.5 X 4.1	19.3	17.3	449.8	0.68%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
0°	Projecting	Free-fall into pool	No, but tailwater control weir present.	No	Pool tailout at observed low flows, but “v-notch” weir likely controls at higher flows.	Overall fair-good condition; Rusted through in narrow slits in a few places

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
Thin, discontinuous layer of substrate in bottom	Silt, Sand, Gravel	<1	<1	Large corrugations

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
31.5	10.8	44.2

Additional site comments

HWY 101 does not actually cross the creek, but stream crosses under a large amount of fill adjacent to the highway that is associated with its construction. Flow was very low, with stagnant water and grass growing in the active channel during the late-summer (8/19/2013) survey. The crossing is very long (450 ft) and has 2 minor doglegs within. The culvert outlet was perched approximately 4” above the water surface elevation of the tailwater at the observed low flows (8/19/2013). There is a concrete tailwater control weir with a “V-notch” approximately 30 ft downstream of the outlet that was presumably designed to backwater and slow velocities at the outlet. During the observed flows, the outlet pool water surface elevation was controlled by the downstream pool tail, but the weir likely affects water surface elevation and velocities near the outlet at higher flows. Long Valley Creek has potential to be an excellent lamprey stream due to large size and significant amount of low gradient habitat.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Perched outlet, velocity	1.0–219.5	47.5–86.2	FishXing predicts site is a perched outlet barrier at low to moderate migration flows and velocity barrier at higher flows.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	FishXing predicts the perched outlet will backwater at flows higher than 47.5 cfs, and we conservatively assume that lampreys cannot enter culvert at lower flows. The model predicts water velocities will exceed maximum burst swimming speed (2.7 m/s) at flows higher than 86.2 cfs. We assume burst-and-attach behavior is possible on the large corrugations, but it is uncertain whether the maximum burst speed can be reached in corrugated culverts. Results should be viewed with caution due to uncertain effects of the culvert doglegs and V-notch weir just downstream of outlet. The weir might backwater culvert outlet at lower flows than predicted by the model based on downstream tailwater control cross-section at pool tail. The weir also likely slows water velocities at outlet, which is where highest velocities are predicted to occur. For these reasons, FishXing may underestimate range of flows that are passable.
Field evaluation observations and data	Outlet is perched ~4” above water surface elevation at observed low flows and likely prevents lamprey from entering culvert. Crossing length (450 ft) may lower passage success, but large corrugations would presumably allow attachment. Estimated bankfull width is over twice culvert diameter. High water velocities at outlet of tailwater control weir V-notch could be a passage obstacle at higher flows and prevent lampreys from reaching culvert outlet.
Ammocoete surveys	Sampling could not be conducted due to issue with E-fisher breaking electrical circuit in Long Valley Creek, which was likely related to high conductivity of stagnant, murky water. E-fisher worked fine in adjacent streams. Pacific lampreys have yet to be documented in Long Valley Creek, but are likely present due to relatively large and low-gradient channel.
PAD	Crossing was designated a partial barrier to salmonids based on professional judgment by CDFW.
Other evaluations	Evaluated by CDFW based on professional judgment according to the PAD.

Additional potential barriers in stream

Long Valley Creek parallels HWY 101 for approximately 6 miles and is crossed by it five times (PAD IDs: 707090, 707091, 707092, 707094, 707095). We photo documented PAD ID 707092, a bridge, and determined it had minimal impact on passage. We also photo documented PAD ID 707094, a bridge with baffles and concrete in the channel between abutments, and concluded it may impede passage at high flows, but is most likely passable at moderate flows. PAD IDs 707090 and 707095 are bridges and not expected to be barriers, but should be visited to confirm. In addition to the HWY 101 crossings, Google Earth imagery indicates there are at least three other bridge crossings that are not listed in the PAD. These sites are unlikely to be total barriers to lamprey migration but should be evaluated due to the high habitat potential of Long Valley Creek.

Crossing photographs

Outlet	Inlet
	

Location information

PAD ID	Stream name	Tributary to	Sub-basin	Survey date	Road name	Latitude (N)	Longitude (W)
715027	Goforth Creek	Middle Fork Eel River	Middle Fork Eel	8/20/2013	Hwy 162	39.71201	-123.34268

Work performed at site

Crossing physical characteristics	Long profile	Tailwater control cross-section	FishXing analysis	Ammocoete surveys	Habitat surveys
Yes	Yes	Yes	Yes	No water	Yes

Crossing physical characteristics

Crossing shape	Structure material	Corrugation size	Span (ft)	Rise (ft)	Length (ft)	Crossing slope (average)	Slope breaks in crossing?	Multiple structures at site?
Box	Concrete	None	10.0	11.1	89.6	5.42%	No	No

Skew from road	Inlet type	Outlet configuration	Baffles, weirs, or other internal structures	Fish ladder at outlet?	Tailwater control d/s of outlet	Crossing condition
75°	Headwall	Concrete apron gradually sloping and ending in ~1 ft drop at rip rap pile.	Lower elevation trough focuses water on river right (0.3–0.9 ft lower elevation than river left and 24 in wide)	No	Pool tailout, but rip rap may affect water elevation and velocity at outlet during higher flows.	Culvert in fair condition overall. Some erosion under concrete outlet apron. Right of culvert worn and rebar exposed

Substrate and suitable lamprey attachment points within crossing

Substrate retention	Dominant substrates in crossing (listed in order of abundance)	Distance from suitable attachment in crossing to suitable attachment:		Notes on attachment points within crossing
		Downstream of outlet (ft)	Upstream of inlet (ft)	
No substrate in structure	n/a	<1	<1	Smooth, flat throughout; Continuous concrete base and walls

Channel characteristics

Contributing drainage area at site (km^2)	Length of channel upstream with gradient <2% (km)	Bankfull channel width (mean; ft)
9.9	0.0	27.3

Additional site comments

Stream was extremely dry during late summer site visit, with only a trickle flowing through culvert and a few isolated depressions with water. Large cobble and small boulder substrate accumulating in front of edge of inlet. Very high-gradient channel with cobble and boulder substrates both upstream and downstream.

Passage designation

Designation	Barrier type	Migration flows evaluated (cfs)[1]	Range of passable flows predicted (cfs)	Notes
Partial barrier	Depth, velocity	0.4–55.4	6.8–19.0	FishXing predicts a depth barrier at flows <6.8 cfs and a velocity barrier at flows >19.0 cfs.

[1] High and low migration flows were defined as the 5% and 90% exceedance flows, respectively, during the core Pacific lamprey migration period of December through July.

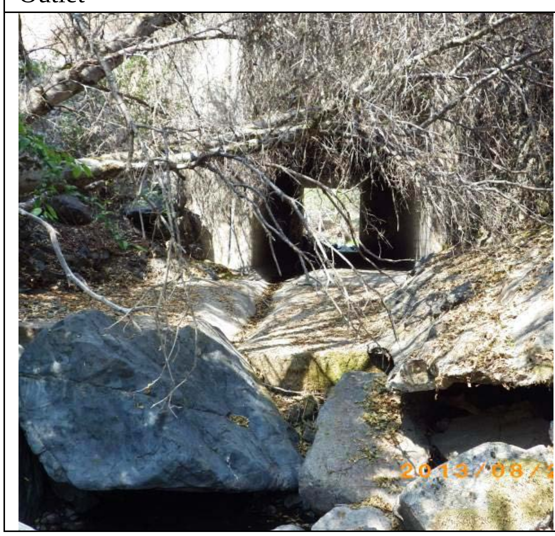
Evidence for passage designation

Source	Summary, rationale, and assumptions
Initial passage filter	Indeterminate
FishXing analysis	The model predicts a depth barrier at flows <6.8 cfs; however, the lower elevation trough on river right concentrates flow and increases water depth, allowing lampreys to pass at lower flows than predicted. The model predicts a velocity barrier at flows > 19.0 cfs when velocities exceed the maximum burst swimming speed (2.7 m/s). When interpreting model results, it was assumed that lampreys could ascend the concrete apron and reach the outlet. Model results should be viewed with caution due to the presence of the trough, apron drop, and unknown effects of the rip-rap and boulders downstream of the culvert apron on water velocities.
Field evaluation observations and data	High gradient, relatively narrow culvert is expected to present a velocity barrier at high flows. Lampreys can attach to concrete bottom throughout culvert. Lower elevation trough on river right concentrates flow at lower flows, increasing water depth and likely allowing lampreys to pass at lower flows than predicted by FishXing. Concrete apron below culvert ends in a ~1 ft drop at rip rap pile may be difficult to pass at some flows, but lamprey could likely climb around edges by attaching to riprap and other substrate.
Ammocoete surveys	Ammocoete surveys were not performed due to lack of water. Lampreys have not previously been documented in Goforth Creek.
PAD	Indicates CDFW visited the site in 1976 and designated an “Unknown” barrier status for salmonids.
Other evaluations	No other passage evaluations have been conducted at this site to our knowledge.

Additional potential barriers in stream

The PAD indicates that there is a significant waterfall (PAD ID 712927) that is considered the end of salmonid anadromy ~0.5 miles upstream. Field observations and GIS analysis also indicate that the reach upstream is extremely high-gradient and it is unlikely that lampreys would utilize it. Further upstream, Goforth Creek is crossed by Poonkinny Rd., a culvert that is not listed in the PAD.

Crossing photographs

Outlet	Inlet
	

Appendix G

Site Information and Rationale for Passage Designation of Partially Assessed Study Sites

Table G-1. Summary of site location and channel characteristics and results of passage evaluations of partially assessed study sites.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
715452	Rohner Cr.	Smith Lane	Strongs Cr.	Lower Eel	10/10/2012	10.9	3.7	Non-barrier	None	Open bottom arc culvert with natural streambed substrate and relatively low gradient.
NIP	Rohner Cr.	12th St.	Strongs Cr.	Lower Eel	10/10/2012	10.1	4.1	Partial barrier, potential total barrier	Perched outlet, possible velocity	Extremely complex concrete box culvert with three like-sized bays. Outlet of each bay is a 90° angle concrete step approximately 0.8 ft above water surface elevation during site visit. Center bay has a series of concrete velocity control weirs with sharp corners from inlet to outlet. A channel spanning concrete tailwater control weir with a 90° angle drop to streambed and V-notch in center is located ~20 ft d/s of outlet. Weir and V-notch were perched 1.5 ft and 3.0 ft, respectively, above water surface elevation on survey date. Culvert outlet likely backwaters at moderate flows due to presence of tailwater control weir, but weir and V-notch likely constitute a total barrier due to sharp angles at tops. Additionally, complex velocity control weirs inside main culvert likely impede passage during moderate to high stream flows. Overall, crossing is poorly designed for lampreys and is expected to prevent passage at most, if not all migration flows.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
NIP	Rohner Cr.	Hwy 101	Strongs Cr.	Lower Eel	10/10/2012	10.2	4.3	Non-barrier	None	Large bridge with natural bottom channel and negligible impact on lamprey passage conditions.
NIP	Strongs Cr.	Riverwalk Dr.	Eel River	Lower Eel	10/10/2012	31.3	8.8	Non-barrier	None	Large bridge with natural bottom channel and negligible impact on lamprey passage conditions.
705818	Barber Cr.	Grizzly Bluff Rd.	Eel River	Lower Eel	3/21/2013	4.9	3.0	Total barrier	Perched outlet	Concrete box culvert known as Barber Creek #1. Outlet is perched ~5ft above water surface elevation. Barber #2 upstream also a likely barrier based on RTA (2005).
736789	Oil Cr.	Blue Slide Rd.	Eel River	Lower Eel	3/21/2013	4.7	1.3	Total barrier	Perched outlet	Concrete box culvert with outlet perched ~3 ft above water surface during relatively high winter stream flows is total barrier to lamprey migration. Oil Cr. has a relatively small drainage area, but ample flow, significant low gradient habitat, intact riparian, and cool temperatures. A single *Lampetra* ammocoete was located downstream during limited sampling and CDFW also documented ammocoetes (SWS 2011). Remediation would also benefit salmonids as CDFW inventory found coho below crossing and steelhead found upstream.
715477	Knack Cr.	Alderpoint Rd.	Larabee Cr.	Lower Eel	7/18/2013	2.6	0.0	Total barrier	Perched outlet	Corrugated metal pipe with outlet perched approximately 15 ft above stream grade. Small, high gradient stream with little suitable habitat; low priority for remediation.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
736846	Little Burr Cr.	Alderpoint Rd.	Burr Cr.	Lower Eel	7/18/2013	4.1	0.0	Total barrier	Perched outlet	Corrugated metal pipe with outlet perched approximately 6 ft above stream grade constitutes a total barrier to lamprey migration. Small, high gradient stream with little suitable habitat.
NIP	Dean Cr.	Sequoia Rd., Rio Dell	Eel River	Lower Eel	3/27/2013	3.0	0.0	Unknown	n/a	Large open-bottom arch culvert with concrete abutments extending into and constricting natural channel. Unlikely to be lamprey barrier at low to moderate flows, but could create a velocity barrier at higher flows.
715448	Dean Cr.	Hwy 283 / Wildwood Ave.	Eel River	Lower Eel	10/16/2013	3.6	0.0	Total barrier	Perched streambed	Footings from Eagle Prairie Bridge consist of large boulders embedded in concrete that extends into stream bed, creating scour and 9 ft waterfall just upstream of confluence with Eel River. Falls considered a total barrier to lamprey passage because erosion has caused large boulder to be undercut and perched above stream channel with no obvious routes for climbing. Humboldt Redwood Company has plans to remediate site.
NIP	Bear Cr.	HRC logging road	Eel River	Lower Eel	10/23/2013	20.1	0.6	Non-barrier	None	Private logging road bridge is definite non-barrier. Ammocoete distribution surveys were performed both u/s and d/s of crossing, but no ammocoetes were detected in limited suitable habitat sampled.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
723653	Butte Cr.	Hidden Valley Rd.	Little Van Duzen River	Van Duzen	11/6/2012	12.3	0.4	Unknown, likely minimal impact	n/a	Open-bottom arch culvert recently treated to improve passage for salmonids by building boulder weir for hydraulic control. Weir could be migration obstacle for lampreys at some flows, but overall, site does not appear to be a barrier.
NIP	Swift Cr.	Spur Rd., off Hidden Valley Rd.	Butte Cr.	Van Duzen	11/6/2012	2.1	0.0	Non-barrier	None	Adequately-sized open-bottom arch culvert with natural stream bed not a barrier based on professional judgment.
715462	Blanton Cr.	Yager-Lawrence Mainline	Yager Cr.	Van Duzen	6/17/2013	8.4	0.0	Non-barrier	None	Bridge crossing over natural channel, not a barrier. Decent size stream with ample water during assessment, but little low gradient habitat.
715474	Root Cr.	Private timber road (HRC)	Van Duzen River	Van Duzen	6/18/2013	13.3	1.1	Non-barrier	None	Steel plate bridge over natural channel that appears to be removed seasonally; not a barrier. Excellent habitat and numerous *Lampetra* ammocoetes detected.
737364	Cedar Cr.	n/a; remnant of hatchery structure near confluence with SF Eel	South Fork Eel River	South Fork	7/25/2013	39.4	6.1	Unknown, likely obstacle	n/a	Concrete remains of old hatchery structure creates waterfall at low flows. Site can likely be climbed by lampreys at most flows, but likely creates an obstacle, slowing migration times. Definitely not total barrier since Pacific lampreys found upstream. Although not total barrier, removal of site is expected to improve lamprey and salmonid passage and would be worthwhile due to the large amount of high quality habitat upstream.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
706987	Rattlesnake Cr.	Hwy 101	South Fork Eel River	South Fork	8/21/2013	88.0	16.2	Unknown, likely minimal impact	n/a	Large 2-bayed concrete arch culvert with concrete bottom likely has minimal impact on fish passage at most flows, though could present a velocity barrier at the higher end of migration flows. Pacific lamprey ammocoetes collected upstream indicating successful passage. Culvert was being modified during site visit to include low flow channel. Site should be re-evaluated following completion of modifications to ensure no impact on lamprey passage.
707109	Foster Cr.	Hwy 101	Rattlesnake Cr.	South Fork	8/21/2013	22.8	4.1	Non-barrier	None	There was no indication of road crossing or other potential barrier near confluence as listed by PAD. There is a bridge not listed in the PAD ~1,800 ft upstream that is ~70 ft above natural channel and not a barrier to fish migration. Stream has good habitat, but Google Earth suggests significant impacts of marijuana cultivation in upper watershed.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
715526	Rattlesnake Cr.	Trash rack just upstream of Hwy 101	South Fork Eel River	South Fork	8/21/2013	88.0	16.0	Unknown, likely non-barrier	n/a	Out-of-commission debris rack with poured cement foundation that slopes downstream. Does not appear to be a barrier when adequate flows are present. Likely a migration obstacle at some flows and could prevent passage at low flows. Pacific lamprey ammocoetes documented upstream.
706963	Hollow Tree Cr.	n/a; concrete sill at old hatchery site	South Fork Eel River	South Fork	n/a	94.0	24.7	Non-barrier	None	Site was not visited but concrete sill associated with old hatchery site was removed in summer 2012 and photos showing remediated channel were provided (T. Tollefson, CDFW, pers. comm. 7/3/2013). Due to large size of watershed and high quality habitat, remediation of this potential low flow barrier was highly warranted.
705826	Frenchman Cr.	Harris Rd.	Eel River	Middle Main	8/8/2013	3.3	0.0	Unknown, likely partial	n/a	Two small corrugated metal pipes, with secondary pipe perched 1.5 ft. Crossing likely a velocity barrier at moderate to high migration flows, but requires additional evaluation.
705988	Mud Cr.	Zenia-Bluff Rd.	South Dobbyn Cr.	Middle Main	8/8/2013	19.4	0.1	Non-barrier	None	Culvert has been replaced by bridge over natural channel. Large stream, but little low gradient habitat. No ammocoetes found in limited sampling of fair quality habitat.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
713224	Carter Cr.	Alderpoint Rd.	Eel River	Middle Main	8/8/2013	6.0	0.0	Unknown, likely non-barrier	n/a	Concrete box culvert in poor condition. Stream enters inlet at sharp angle and may be velocity barrier at high flows. Overall site not expected to be a barrier at most flows.
705896	Ryan Cr.	Ryan Cr. Rd.	Outlet Cr.	Upper Main	8/19/2013	5.8	1.8	Non-barrier	None	New open-bottom arch culvert with natural streambed. Culvert replaced as part of mitigation for Willits bypass project. Refer to RTA (2013) for more information. Ross Taylor documented Pacific lamprey spawning in Ryan Cr.
707085	South Fork Ryan Cr.	Hwy 101	Ryan Cr.	Upper Main	8/19/2013	3.6	1.0	Unknown	n/a	Circular concrete culvert that appears to not be a barrier at low to moderate flows but could present a velocity barrier at higher flows because it is undersized. Culvert slated to be replaced with arched culvert with natural streambed bottom as part of the Willits Bypass project.
707086	North Fork Ryan Cr.	Hwy 101	Ryan Cr.	Upper Main	8/19/2013	2.1	0.6	Total barrier	Perched outlet	Concrete culvert perched ~3 feet above water surface elevation during summer low flows. Photo from PAD indicates outlet does not backwater during high flows and thus is a total barrier to lamprey migration. Small stream, but low gradient habitat could potentially support Pacific lampreys.
707092	Long Valley Cr.	Hwy 101	Outlet Cr.	Upper Main	8/19/2013	31.1	10.5	Non-barrier	None	Bridge with little impact on natural channel in a low-gradient reach is expected to have negligible influence on lamprey passage.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
707094	Long Valley Cr.	Hwy 101	Outlet Cr.	Upper Main	8/19/2013	21.6	7.2	Unknown, likely partial	n/a	Hwy 101 bridge crossing high-gradient reach. There is concrete in the channel between abutments, with a series of baffles / weirs on concrete surface. Site likely passable under moderate flow conditions, but may be migration barrier at higher flows due to high velocities and presence of weirs. Site too complex for standard evaluation, but warrants a return visit to evaluate conditions during higher stream flows.
712813	South Fork Ryan Cr.	Hamman Driveway	Outlet Cr.	Upper Main	8/19/2013	3.1	0.9	Non-barrier[1]	None	Current site slated to be replaced with open-bottom arch culvert with natural streambed. Perched and undersized corrugated metal pipe was in process of being replaced during 8/19/13 site visit. A follow-up site visit to verify new crossing does not present passage problems for lampreys would be valuable.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
713110	Reeyes Canyon Cr.	Hwy 101	Outlet Cr.	Upper Main	8/19/2013	5.1	2.4	Unknown, likely partial	n/a	Concrete box culvert with two bays. Right culvert outlet is perched approximately 1 ft and left is in poor condition. Likely allows passage at moderate flows, but possible barrier at high and low flows. Need more info to assess passage. Stream appears to have fair habitat potential with flowing water in dry summer and low gradient habitat upstream. Marijuana cultivation and roads in upslope areas likely have negative impact on stream.
706962	Haehl Cr.	E. Hill Rd.	Outlet Cr.	Upper Main	8/20/2013	12.7	7.0	Non-barrier	None	PAD 707962 is listed as a fish passage facility at or near the bridge on E. Hill Rd. approximately 600 ft west of Beachtel Rd. No passage facility was observed in this area, but a bridge over natural channel is present and does not impede lamprey passage.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
758555	Haehl Cr.	Railroad bridge in Willits	Outlet Cr.	Upper Main	8/20/2013	12.7	7.0	Total barrier	Perched outlet	Railroad crossing with concrete slab foundation perched ~3 ft above water surface during low flows. Haehl Cr. is heavily altered by human activity, but has good potential for Pacific lamprey due to relatively large size and extent of low gradient habitat. RTA (2011) evaluated site and determined it was passable by adult salmonids, but presents passage problems for juveniles. Severity of perch has potential to worsen if channel head-cuts. A series of other likely migration barriers exist, starting approximately 2 mi upstream of crossing in upper Haehl Cr. (RTA 2011). These sites need to be visited to evaluate lamprey barrier status and the extent of suitable lamprey habitat upstream.
707075	Bloody Run Cr.	Hwy 162	Outlet Cr.	Upper Main	8/20/2013	24.3	0.5	Non-barrier	None	Bridge over natural channel. Just d/s is a railroad crossing that is an open-bottomed concrete arch culvert that appears to be properly sized. Relatively large watershed, but very little water during late summer. Google Earth suggests moderate to high level of marijuana cultivation in watershed.

PAD	Stream	Road name	Tributary to	Sub-basin	Assessment date	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Passage designation	Barrier type	Notes and rationale for passage designation
713155	Trib to Outlet Cr.	Hwy 162	Outlet Cr.	Upper Main	8/20/2013	2.3	0.3	Unknown	n/a	Corrugated metal pipe at grade, likely not a passage barrier at most flows. No water in channel during 8/20/13 site visit. Stream likely does not support lampreys and low-priority for full evaluation. PAD indicates partial barrier to salmonids.
718572	Corral Cr.	Hwy 162	Outlet Cr.	Upper Main	8/20/2013	3.1	0.0	Non-barrier	None	Natural bottom bridge crossing. Just downstream is a 5-ft concrete pipe that may be present passage problems, but stream is small, goes dry in the summer, and has little habitat potential. Low priority for assessment.

[1] To be treated with open-bottom arch culvert.

Appendix H

Initial Ranking Scores and Justification for Final Ratings of Barrier Remediation Priority

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
Large steams														
707091	Long Valley Cr.	Hwy 101 (road-fill)	Partial barrier	Perched outlet, velocity	18%	6	31.5	7.9	10.8	5.4	19.3	High	ns	Extent of Barrier score decreased from 12 to 6 since field observations indicate FishXing likely underestimated range of passable flows. Overall, site High Priority for remediation due to large size and significant low gradient channel upstream. An extremely large volume of fill would need to be removed to replace with new culvert, but passage may be improved by adding lamprey ramp (Moser 2011) to allow fish to enter outlet at lower passage flows. Site may also benefit from placement of rounded baffles or other lamprey-friendly resting structures within very long corrugated culvert.
715472	Yager Cr.	Redwood House Rd.	Partial barrier	Depth, velocity	74%	6[2]	16.7	4.2	9.4	4.7	14.9	High	None	Extent of Barrier score was increased from 3 to 6 since field observations indicate site a barrier at low migration flows (in contrast to FishXing results) due to damaged bottom. In addition, extent to which site is a barrier could change following high flow events if culvert is further damaged or plugged with debris. Culvert is failing and needs to be replaced as soon as possible. Overall, habitat quantity and quality in South Fork Yager Cr. upstream of crossing is relatively high.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
706954	Cedar Cr.	Hwy 101	Partial barrier	Velocity, obstacle	UK	3	38.3	9.6	5.5	2.7	15.3	Medium	ET, UK	Extent of Barrier score of 3 was assigned based on professional judgment. While Pacific lampreys can likely navigate past crossing at most migration flows (ammocoetes were detected upstream), the elevated outlet apron likely presents a migration obstacle and may be a barrier at lower migration flows. Cedar Cr. has excellent water quality, ample summer stream flows, and a significant amount of high quality habitat upstream. For this reason, stream is likely important to overall population of the South Fork Eel River and improving lamprey passage at site would be valuable.
715481	Butte Cr.	Hidden Valley Rd.	Partial barrier	South = perched outlet North = perched outlet, depth	UK	6	20.1	5.0	2.1	1.0	12.1	Medium	ET	Extent of Barrier score of 6 was assigned based on overall evidence from FishXing and field observations that passage is possible at moderate, and possibly high, migration flows. Successful passage was verified by detection of Pacific lamprey ammocoetes upstream. Site ranked as Medium priority for remediation since it is a barrier at the lower end of migration flows and a moderate amount of fair-to-good quality habitat is upstream. Passage could be improved through addition of lamprey ramp (Moser 2011) at perched outlet apron of South bay of culvert to allow entry at low migration flows.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
715460	Strongs Cr.	Hwy 101	Partial barrier	Depth, velocity	86%	0	31.2	7.8	8.2	4.1	11.9	Low	LS	Model results and field observations indicate site is passable at most migration flows. For this reason, it is ranked as low priority for remediation. Strongs Creek appears to have high potential for Pacific lamprey spawning and rearing, but extensive surveys at this site and others only detected *Lampetra* ammocoetes.
Medium streams														
758555	Haehl Cr.	Railroad bridge in Willits	Total barrier	Perched outlet	0%	15	12.7	3.2	7.0	3.5	21.7	High	None	Perched concrete slab of railroad crossing is expected to be total lamprey migration barrier and perch has potential to worsen if channel head-cuts (RTA 2011). A significant amount of high quality habitat exists upstream; although it is limited by other possible migration barriers that are present in upper Haehl Cr. RTA (2011) ranked site as "Medium-Priority" for remediation since crossing currently provides passage for adult anadromous salmonids. There is potential to remediate site and other barriers in Haehl Cr. with Willits Bypass mitigation funds (RTA 2011).

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
NIP	Cuneo Cr.	n/a; just d/s of Bull Cr. Flats Rd. bridge.	Partial barrier, potential total barrier	Drop / obstruction	UK	12	11.3	2.8	0.6	0.3	15.1	High	None	Channel-spanning, perched concrete structure is expected to be barrier or major passage obstacle at most migration flows. Due to uncertainty as to whether lampreys may be able to ascend and pass feature at certain flows, Extent of Barrier score of 12 was assigned. Cuneo Cr. is a moderate size stream with limited low gradient channel upstream. However, site was ranked as High priority for remediation because watershed located entirely within Humboldt Redwoods State Park, has good summer water quality, and high potential for habitat restoration. Since there is no road fill, site could be remediated relatively easily by removing all or part of concrete structure. Installation of a lamprey ramp (Moser 2011) could provide a shorter term lamprey passage fix.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
715449	Stitz Cr.	Shively Rd.	Total barrier	Perched outlet	0%	15	10.2	2.6	0.0	0.0	17.6	Medium	None	Severely perched culvert is total barrier to both lampreys and salmonids. Ranked as Medium priority for remediation due to moderate stream-size and lack of low-gradient habitat upstream. Field observations indicated presence of relatively good ammocoete habitat near crossing and GIS analysis indicates considerable channel with 2–4% gradient. RTA (2005) indicates culvert is extremely under-sized and has caused a severe down-cutting of downstream channel and aggradation upstream. We recommend replacement with properly sized open-bottom arch culvert.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
NIP	Rohner Cr.	12th St.	Partial barrier, potential total barrier	Perched outlet, possible velocity	UK	12[2]	10.1	2.5	4.1	2.1	16.6	Medium	ns	Site likely total barrier to Pacific lamprey passage due to perched tailwater control weir, outlet apron, and internal weirs with sharp corners. Due to site complexity and uncertainty in whether passage is possible at a narrow range of flows, Extent of Barrier score was lowered from 15 to 12. Rohner Cr. has extensive low-gradient habitat and good potential to support Pacific lampreys despite flowing through an urban environment. Ammocoete surveys in Rohner Cr. indicated high densities of *Lampetra* ammocoetes, but Pacific lampreys not detected. Site rated as Medium priority due to extent of barrier, good habitat potential, and likelihood that it is also partial barrier to salmonids passage. Recommend remediating site by restoring natural channel below bridge, but partial remediation could be achieved by adding lamprey ramps (Moser 2011) at tailwater control weir and outlet apron.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
707107	Elk Cr.	Hwy 101	Total barrier	Perched outlet, possible velocity	0%	12[2]	10.2	2.6	1.2	0.6	15.1	Medium	None	Overall, site expected to be total barrier to lamprey passage due to outlet weirs, fish ladder, and perched outlet. However, Extent of Barrier score was lowered from 15 to 12 due to uncertainty in whether lampreys could enter perched outlet at higher migration flows. Site was rated as Medium Priority due to extent of barrier, moderate habitat potential, and listing as total barrier to adult salmonids in PAD. Ideal remediation would be replacement with bridge or properly sized open-bottom arch culvert; however this may not be feasible due to crossing under Hwy 101 and large amount of fill. Addition of a lamprey ramp (Moser 2011) at perched outlet may improve passage, but design and placement would need to avoid impacting salmonid passage.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
705815	Russ Cr.	Centerville Rd.	Partial barrier, potential total barrier	Perched outlet, possible velocity	UK	9	8.4	2.1	3.8	1.9	13.0	Medium	ns	Extent of Barrier score of 9 was assigned since perched concrete outlet apron with 90° step is expected to inhibit passage at low to moderate migration flows and culvert may be velocity barrier at high flows. A full FishXing evaluation is needed to improve understanding passable flows and potentially refine ranking. Russ Cr. is a relatively small stream, but has considerable low-gradient channel upstream. Therefore site rated Medium priority for remediation. Installation of a lamprey ramp (Moser 2011) could improve passage success at perched outlet.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
707096	Tenmile Cr.	Hwy 101	Partial barrier	South = perched outlet North = depth	South = 75% North = 57%	6	12.2	3.1	3.7	1.9	10.9	Medium	None	Despite relatively low initial ranking score, site designated as Medium priority for remediation and should be considered one of the higher priority medium stream-size sites due to relatively large drainage area and extent of low gradient channel upstream. Tenmile Cr. has excellent potential to support Pacific lampreys, but water quantity and quality appear to be limited by intensive marijuana cultivation in watershed. Decreased stream flows may also restrict window of time that perched outlet is passable. The PAD states that Caltrans has a project to incorporate a low flow channel by 11/1/2012. No work had been done as of survey date, but lamprey passage (including possible installation of a lamprey ramp; Moser 2011) should be considered when retrofitting site.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
707157	Fish Cr.	Avenue of the Giants	Partial barrier	Velocity, depth	51%	6	11.8	3.0	0.3	0.2	9.1	Medium	None	Despite relatively low initial ranking score, site was designated as Medium priority for remediation due to relatively large size and moderate upstream habitat potential. In addition, this site was ranked the top priority for remediation in Caltrans District 1 (Lang 2005). Habitat potential (and possibly fish passage) is limited by extremely low stream flows. Little water was present in channel during 6/28/2013 survey. Marijuana cultivation appears significant in headwaters based on an inspection of Google Earth, and associated illegal diversions are likely impacting stream flow.
715476	Mill Cr.	Alderpoint Rd.	Partial barrier	Depth, velocity	7.5%	12	10.1	2.5	0.0	0.0	14.5	Low	None	Despite high severity of barrier, the site was rated as Low priority for remediation due to lack of suitable upstream habitat. Reaches downstream and upstream of crossing are very high gradient and would provide minimal lamprey habitat.
715027	Goforth Cr.	Hwy 162	Partial barrier	Depth, velocity	22%	9	9.9	2.5	0.0	0.0	11.5	Low	ns	Site ranked Low Priority for remediation due to lack of upstream habitat potential. Goforth Creek is very high gradient and dominated by boulder and bedrock, with very low summer stream flows.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
Small streams														
705818	Barber Cr.	Grizzly Bluff Rd.	Total barrier	Perched outlet	0%	15	4.9	1.2	3.0	1.5	17.7	Low	ns	Despite its relatively high initial ranking score, site was designated as Low Priority for remediation due to small stream-size and relatively degraded upstream habitat. Due to considerable length of low-gradient channel upstream, however, site should be considered among the highest priority sites for remediation in the small stream-size category. Watershed entirely privately owned and managed for timber production and grazing, which limits habitat quality and restoration potential. Any plans for remediation at site should consider evaluation and remediation of Barber #2 (PAD 705821) just upstream, which may also be a migration barrier (RTA 2005).
736789	Oil Cr.	Blue Slide Rd.	Total barrier	Perched outlet	0%	15	4.7	1.2	1.3	0.7	16.8	Low	LS	Despite its relatively high initial ranking score, site was designated Low priority for remediation due to small stream-size. Because Oil Cr. has ample summer flows, moderate amount of low gradient channel, intact riparian, and cool water temperatures (and because remediation would also benefit salmonids), site is considered among highest priority sites for remediation in the small stream-size category. Remediation is complicated by large amount of road fill, thus a lamprey ramp (Moser 2011) may be the most feasible passage solution.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
715429	Strawberry Cr.	HRC Road 4	Total barrier	Perched outlet, velocity	0%	15	4.6	1.2	0.0	0.0	16.2	Low	None	Site was ranked Low priority for remediation due to small stream-size and high gradient channel upstream. Strawberry Creek has relatively intact riparian forest canopy and is expected to have good summer water quality, but, overall has limited potential to support Pacific lampreys.
736846	Little Burr Cr.	Alderpoint Road	Total barrier	Perched outlet	0%	15	4.1	1.0	0.0	0.0	16.0	Low	ns	Site ranked Low priority for remediation due to small stream-size and high gradient channel upstream. Little Burr Creek has little if any potential to support Pacific lampreys.
736751	Harper Cr.	Bull Cr. Flats Rd.	Total barrier	Perched outlet	0%	15	3.9	1.0	0.0	0.0	16.0	Low	None	Site ranked Low priority for remediation due to small stream-size and mostly high gradient channel upstream. Harper Creek is located entirely within Humboldt Redwoods State Park and has ample summer stream flows and excellent riparian forest canopy, but overall, is expected to provide minimal Pacific lamprey habitat.
715448	Dean Cr.	Hwy 283 / Wildwood Ave.	Total barrier	Perched streambed	0%	15	3.6	0.9	0.0	0.0	15.9	Low	ns	Site ranked Low priority for remediation due to small stream-size. Because Dean Cr. has ample summer flows, cool water temperatures, intact riparian canopy, and a considerable length of moderate gradient (2-4%) channel, this site should be higher priority for remediation than many other sites in the small stream-size category.

PAD ID	Stream	Road name	Passage designation	Barrier type	Percent of flows passable[1]	Extent of barrier score	Contributing drainage area (km^2)	Stream size score	Length of channel upstream with gradient <2% (km)	Low gradient score	Total initial ranking score	Relative priority for remediation	Species detected upstream	Ranking and remediation notes
707086	North Fork Ryan Cr.	Hwy 101	Total barrier	Perched outlet	0%	15	2.1	0.5	0.6	0.3	15.8	Low	ns	Site ranked Low priority for remediation due to small stream-size. NF Ryan Cr. has some low gradient channel and thus potential to support Pacific lamprey, but overall remediation would provide relatively minimal benefit.
715477	Knack Cr.	Alderpoint Rd.	Total barrier	Perched outlet	0%	15	2.6	0.6	0.0	0.0	15.6	Low	ns	Site was ranked Low priority for remediation due to small stream-size and relatively high gradient channel upstream. Knack Cr. has little if any potential to support Pacific lamprey.
713221	Mountain Cr.	Alderpoint Rd.	Partial barrier	Velocity	12%	12	4.0	1.0	0.0	0.0	13.0	Low	None	Site was ranked Low priority for remediation due to small stream-size and relatively high gradient channel upstream. Although Mountain Cr. appears to have good water quality and there is a short reach of moderate gradient habitat just upstream of site, overall it has limited potential to support Pacific lamprey.

[1] Numerical values based on FishXing model results.
[2] Extent of barrier score adjusted based on professional judgment. Refer to ranking and remediation notes for justification.

Appendix I

Sites Requiring Future Assessment

Table I-1. Prioritized list of sites requiring future assessment in the Lower Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
736772	Salt River	Eel River	Riverside Rd. tidegate	Tidegate	104.1	60.2	26.0	30.1	56.1
736773	Salt River	Salt River	Smith Creek tidegate	Tidegate	78.0	41.9	19.5	20.9	40.4
736771	Salt River	Eel River	Riverside Rd. tidegate	Tidegate	77.9	41.5	19.5	20.8	40.2
736770	Centerville Slough	Salt River	Cutoff Slough tidegate	Tidegate	23.9	15.5	6.0	7.8	13.7
736839	Price Cr.	Eel River	Small rock dam	Dam	32.2	5.2	8.1	2.6	10.6
736840	Price Cr.	Eel River	Small rock dam	Dam	31.1	4.0	7.8	2.0	9.8
736841	Price Cr.	Eel River	Small rock dam	Dam	25.4	1.8	6.4	0.9	7.2
715455	Strongs Cr.	Eel River	Rohnerville Road culvert	Road crossing	16.9	3.6	4.2	1.8	6.0
715539	Reas Cr.	Salt Cr.	Tidegate at Port Kenyon Road	Tidegate	9.1	5.1	2.3	2.6	4.8
705820	Reas Cr. #1	Eel River	Port Kenyon Road	Road crossing	9.0	5.1	2.3	2.5	4.8
715451	Shively Cr.	Eel River	Culvert (on county road) & railroad crossing	Road crossing	10.1	3.3	2.5	1.6	4.2
715450	Greenlow Cr.	Eel River	Culvert	Road crossing	8.7	3.0	2.2	1.5	3.7
736838	Russ Cr.	Centerville Slough	Dam u/s of Centerville Rd.	Dam	8.2	3.1	2.0	1.6	3.6
712006	Nanning Cr.	Eel River	Railroad crossing bridge	Road crossing	10.4	0.9	2.6	0.5	3.1

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
757948	Barber Cr.	Eel River	Vertical concrete falls	Other	4.9	3.0	1.2	1.5	2.7
705817	Reas Cr. #2	Eel River	Centerville Road	Road crossing	4.9	2.7	1.2	1.4	2.6
715540	Russ Cr.	Cutoff Slough	Tidegate at Port Kenyon Road	Tidegate	4.7	2.7	1.2	1.4	2.5
705821	Barber Cr. #2	Eel River	Price Creek School Road	Road crossing	4.2	1.7	1.1	0.9	1.9
715479	Martin Cr.	Larabee Cr.	Bridge (Bridgeville-Blocksburg Road)	Road crossing	7.7	0.0	1.9	0.0	1.9
711998	Shively Cr.	Eel River	Railroad crossing bridge	Road crossing	6.1	0.7	1.5	0.4	1.9
715453	Jameson Cr.	Strongs Cr.	Rohnherville Road culvert	Road crossing	3.9	1.6	1.0	0.8	1.8
707128	Palmer Cr.	Eel River	Culvert Hwy 101	Road crossing	4.3	1.3	1.1	0.7	1.7
722460	Chadd Cr.	Eel River	Culvert Hwy 101	Road crossing	5.1	0.7	1.3	0.3	1.6
722709	Chris Cr.	Larabee Cr.	Culvert 112199	Road crossing	4.7	0.9	1.2	0.4	1.6
736844	Shively Cr.	Eel River	Shively Road culvert	Road crossing	5.4	0.4	1.4	0.2	1.5
715447	Slater Cr.	Eel River	Blue Slide Road culvert	Road crossing	6.0	0.0	1.5	0.0	1.5
711997[1]	Bridge Cr.	Eel River	Lower Eel River	Railroad crossing pipe (Concrete)	5.7	0.0	1.4	0.0	1.4
715473	Bridge Cr.	Eel River	Culvert	Road crossing	5.7	0.0	1.4	0.0	1.4
722722	Chris Cr.	Larabee Cr.	Dam 112212	Dam	4.0	0.7	1.0	0.3	1.3

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
705819	Reas Cr. #3	Eel River	Oeschger Road	Road crossing	3.4	1.0	0.8	0.5	1.3
715475	Burr Cr.	Larabee Cr.	Bridgeville-Blocksburg Road bridge	Road crossing	5.1	0.0	1.3	0.0	1.3
722724	Chris Cr.	Larabee Cr.	Bridge 112214	Road crossing	4.0	0.4	1.0	0.2	1.2
715484	Weber Cr.	Eel River	Culvert at railroad crossing	Road crossing	4.7	0.0	1.2	0.0	1.2
715275	Twin Cr.	Eel River	15ft. log and boulder	Dam	4.3	0.0	1.1	0.0	1.1
757950	Jameson Cr.	Strongs Cr.	Culvert (unknown location)	Road crossing	2.5	0.8	0.6	0.4	1.0
757951	Jameson Cr.	Strongs Cr.	Culvert (unknown location)	Road crossing	2.4	0.5	0.6	0.3	0.9
722287	Bosworth Cr.	Larabee Cr.	Alderpoint Road bridge	Road crossing	2.7	0.0	0.7	0.0	0.7
722447	Unnamed Tributary	Chadd Cr.	Culvert Hwy 101	Road crossing	2.5	0.0	0.6	0.0	0.6
715310	Allen Cr.	Eel River	High gradient and two culverts near the mouth	Road crossing	2.3	0.0	0.6	0.0	0.6
757949	Adams Cr.	Price Cr.	Culvert at stream mile 0.6	Road crossing	2.1	0.0	0.5	0.0	0.5
711999	Darnell Cr.	Eel River	Railroad crossing bridge	Road crossing	2.1	0.0	0.5	0.0	0.5

[1] Site slated to be remediated in summer 2013 (R. Taylor, RTA, pers. comm., 29 March 2013).

Table I-2. Prioritized list of sites requiring future assessment in the Van Duzen River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
715469	Lawrence Cr.	Yager Cr.	Kneeland Road bridge	Road crossing	18.5	3.6	4.6	1.8	6.4
715471	Yager Cr.	Van Duzen River	Crossing at Redwood House Road	Road crossing	8.8	4.1	2.2	2.1	4.3
705823	Wolverton Gulch #1	Eel River	River Bar Road (Bridge)	Road crossing	7.2	4.0	1.8	2.0	3.8
705822	Wolverton Gulch #2	Eel River	River Bar Road	Road crossing	7.2	3.9	1.8	2.0	3.8
722283	Booths Run	Lawrence Cr.	Road Crossing 111772	Road crossing	13.1	0.5	3.3	0.3	3.5
715464	Shaw Cr.	Lawrence Cr.	Railroad car bridge	Road crossing	13.7	0.0	3.4	0.0	3.4
712976	Cummings Cr.	Van Duzen River	Hwy 36 culvert	Road crossing	12.0	0.7	3.0	0.4	3.4
715428	Shaw Cr.	Lawrence Cr.	Unknown passage site	Unknown	13.1	0.0	3.3	0.0	3.3
712969	Wolverton Gulch	Van Duzen River	Hwy 36 culvert	Road crossing	6.9	3.0	1.7	1.5	3.2
715336	Browns Canyon	Van Duzen River	Unknown passage site	Unknown	10.9	0.0	2.7	0.0	2.7
722973	Cooper Mill Cr.	Yager Cr.	P.L. diversion dam	Dam	9.5	0.0	2.4	0.0	2.4
705824	Wolverton Gulch #3	Eel River	Rohnerville Road	Road crossing	5.7	1.3	1.4	0.7	2.1
712972	Wilson Cr.	Yager Cr.	Hwy 36 culvert	Road crossing	4.9	1.7	1.2	0.8	2.1
712971	Fischer Cr.	Barber Cr.	Hwy 36 culvert	Road crossing	3.2	2.2	0.8	1.1	1.9

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
715436	Bloody Run Cr.	Van Duzen River	Unknown passage site	Unknown	6.9	0.0	1.7	0.0	1.7
722998	Cooper Mill Cr.	Yager Cr.	Railroad trestle	Road crossing	6.5	0.0	1.6	0.0	1.6
705986	Black Lassic Cr.	Van Duzen River	Van Duzen Road	Road crossing	6.4	0.0	1.6	0.0	1.6
715465	Corner Cr.	Lawrence Cr.	Crossing	Road crossing	5.2	0.5	1.3	0.3	1.5
707876	Black Lassic Cr.	Van Duzen River	Bridge	Road crossing	5.8	0.0	1.5	0.0	1.5
715337	Crooks Cr.	Van Duzen River	Unknown passage site	Unknown	5.5	0.0	1.4	0.0	1.4
705987	Red Lassic Cr.	Van Duzen River-Eel River	Van Duzen Road	Road crossing	4.9	0.0	1.2	0.0	1.2
712970	Barber Cr.	Wolverton Gulch	Hwy 36 culvert	Road crossing	3.7	0.6	0.9	0.3	1.2
715338	Shanty Cr.	Van Duzen River	Unknown passage site	Unknown	4.6	0.0	1.2	0.0	1.2
715466	Fish Cr.	Lawrence Cr.	Bedrock Chute with fishway	Grade control	4.3	0.0	1.1	0.0	1.1
707129	Fox Cr.	Van Duzen River	Culvert Hwy 36	Road crossing	2.9	0.5	0.7	0.3	1.0
715467	Fish Cr.	Lawrence Cr.	Bridge	Road crossing	3.7	0.0	0.9	0.0	0.9
712982	Unknown Trib to Butte Cr.	Butte Cr.	Hwy 36 culvert	Road crossing	3.0	0.2	0.7	0.1	0.9
712975	Fiedler Cr.	Van Duzen River	Hwy 36 culvert	Road crossing	2.9	0.2	0.7	0.1	0.8
712973	Cuddeback Cr.	Van Duzen River	Hwy 36 culvert	Road crossing	2.7	0.1	0.7	0.1	0.7

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
722237	Blue Slide Cr.	Van Duzen River	Culvert 111726	Road crossing	2.3	0.0	0.6	0.0	0.6

Table I-3. Prioritized list of sites requiring future assessment in the South Fork Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
723488	Hollow Tree Cr.	South Fork Eel River	Road 41-HG culvert	Road crossing	45.6	16.3	11.4	8.1	19.5
706986	Rattlesnake Cr.	Eel River, South Fork	Hwy 101 culvert and pool and weir ladder	Road crossing	46.0	7.0	11.5	3.5	15.0
736879	South Fork Salmon Cr.	Salmon Cr.	Salmon Creek Fish Access and Habitat Improvement Project	Other	20.9	6.1	5.2	3.1	8.3
712847	Red Mountain Cr.	South Fork Eel River	Gravel pond summer dam	Dam	29.3	0.7	7.3	0.4	7.7
712848	Red Mountain Cr.	South Fork Eel River	Recreational dam	Dam	27.8	0.7	7.0	0.3	7.3
707103	Rattlesnake Cr.	South Fork Eel River	Hwy 101 culvert	Road crossing	19.7	2.2	4.9	1.1	6.0
715511	Sealy Cr.	Redwood Cr.	Bridge	Road crossing	15.1	3.2	3.8	1.6	5.4
723081	Leggett Cr.	South Fork Eel River	Car bridge	Road crossing	13.0	3.2	3.2	1.6	4.9
723090	Leggett Cr.	South Fork Eel River	Log bridge 112584	Road crossing	12.8	3.0	3.2	1.5	4.7
707098	Streeter Cr.	Tenmile Cr.	Hwy 101 (No road crossing)	Road crossing	12.4	2.6	3.1	1.3	4.4

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
707102	Rattlesnake Cr.	South Fork Eel River	Hwy 101 culvert	Road crossing	13.0	2.1	3.2	1.0	4.3
707105	Twin Rocks Cr.	Rattlesnake Cr.	Hwy 101 culvert	Road crossing	14.2	1.2	3.6	0.6	4.2
715514	Miller Cr.	Redwood Cr.	Bridge	Road crossing	9.4	3.1	2.4	1.5	3.9
722682	China Cr.	Redwood Cr.	Briceland-Thorne Road bridge	Road crossing	9.8	2.7	2.4	1.4	3.8
715515	Miller Cr.	Redwood Cr.	Bridge	Road crossing	9.1	2.9	2.3	1.4	3.7
722641	China Cr.	Redwood Cr.	Junk 112130	Other	9.2	2.2	2.3	1.1	3.4
707101	Spy Rock Cr. (Rattlesnake Cr.)	South Fork Eel River	Hwy 101 culvert	Road crossing	12.0	0.8	3.0	0.4	3.4
715495	Bull Cr.	South Fork Eel River	Bridge	Road crossing	11.6	1.0	2.9	0.5	3.4
715516	Miller Cr.	Redwood Cr.	Bridge	Road crossing	8.6	2.4	2.2	1.2	3.4
707120	Piercy Cr.	South Fork Eel River	Hwy 101 (no road crossing)	Road crossing	9.4	1.8	2.3	0.9	3.3
712996	Butte Cr. (Coon Cr.)	South Fork Eel River	Hwy 101 culvert	Road crossing	11.7	0.6	2.9	0.3	3.2
722684	China Cr.	Redwood Cr.	Bridge 112173	Road crossing	9.0	1.9	2.2	1.0	3.2
712991	Bear Canyon	South Fork Eel River	Hwy 101 culvert	Road crossing	8.9	1.7	2.2	0.8	3.1
707110	Big Dan Cr.	South Fork Eel River	Hwy 101 culvert	Road crossing	9.7	0.8	2.4	0.4	2.8
705111	Kenny Cr.	South Fork Eel River	Crossing	Road crossing	8.9	0.9	2.2	0.4	2.7

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
715073	Rock Cr.	South Fork Eel River	Branscomb Road culvert	Road crossing	7.9	1.2	2.0	0.6	2.6
706994	Steep Cr. (Steep Gulch)	Tenmile Cr.	Hwy 101 culvert with steepass and baffles	Road crossing	7.5	0.8	1.9	0.4	2.3
715518	Redwood Cr.	South Fork Eel River	Bridge	Road crossing	5.8	1.0	1.5	0.5	2.0
723483	Unnamed Tributary to Mule Cr.	Mule Cr.	Culvert	Road crossing	4.9	1.4	1.2	0.7	1.9
722688	China Cr.	Redwood Cr.	Culvert 112177	Road crossing	5.6	1.0	1.4	0.5	1.9
736755	Mill Cr.	South Fork Eel River	Page and Gates Road bridge	Road crossing	6.2	0.6	1.5	0.3	1.8
715517	Somerville Cr.	Redwood Cr.	Bridge	Road crossing	7.4	0.0	1.8	0.0	1.8
707097	Wilson Cr.	Ten Mile Cr.	Hwy 101 denil and culvert	Road crossing	4.6	1.2	1.2	0.6	1.7
723482	Unnamed Tributary to Mule Cr.	Mule Cr.	Road 41-MU culvert	Road crossing	4.4	1.2	1.1	0.6	1.7
723492	South Fork Redwood Cr.	Redwood Cr.	Road 41-HG-060 culvert	Road crossing	3.6	1.5	0.9	0.8	1.7
715505	Dean Cr.	South Fork Eel River	Bridge, old highway	Road crossing	3.9	1.3	1.0	0.7	1.6
705110[1]	Jack of Hearts Cr.	South Fork Eel River	Earth dam	Dam	3.7	1.1	0.9	0.6	1.5
707159	Durphy Cr.	South Fork Eel River	Culvert Hwy 101	Road crossing	5.9	0.0	1.5	0.0	1.5
722826	Connick Cr.	South Fork Eel River	Bridge 112318	Road crossing	5.7	0.0	1.4	0.0	1.4

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
715522	Sawmill Cr.	South Fork Eel River	Railroad car culvert	Road crossing	5.0	0.3	1.2	0.2	1.4
713034	Rocky Glen Cr.	South Fork Eel River	Hwy 254 culvert	Road crossing	5.1	0.0	1.3	0.0	1.3
712855	Grapevine Cr.	Rattlesnake Cr.	Dam	Dam	5.1	0.0	1.3	0.0	1.3
715408	Rock Glen Cr.	South Fork Eel River	Culvert	Road crossing	5.1	0.0	1.3	0.0	1.3
707106	Cummings Cr.	Rattlesnake Cr.	Hwy 101 culvert	Road crossing	4.8	0.0	1.2	0.0	1.2
722896	Coon Cr.	Butte Cr.	Bridge 112388	Road crossing	4.8	0.0	1.2	0.0	1.2
706969	Lewis Cr.	Tenmile Cr.	Culvert and hilti to raise pool level	Road crossing	3.8	0.4	1.0	0.2	1.2
723489	Walters Cr.	Hollow Tree Cr.	Road 41-ES-016-02 culvert	Road crossing	4.6	0.0	1.1	0.0	1.1
713119	Stapp Cr.	Tenmile Cr.	Hwy 101 culvert	Road crossing	2.9	0.6	0.7	0.3	1.0
712992	Unnamed Trib to SF Eel River	South Fork Eel River	Hwy 101 culvert	Road crossing	2.8	0.7	0.7	0.3	1.0
706991	Sheep Camp Cr.	Tenmile Cr.	Rock weirs	Road crossing	2.8	0.6	0.7	0.3	1.0
723276	Dinner Cr.	China Cr.	Briceland Thorne Rd/Shelter Cove Rd.	Road crossing	2.6	0.7	0.7	0.4	1.0
705902	Windem Cr.	South Fork Eel River	Branscomb Road	Road crossing	3.2	0.3	0.8	0.2	1.0
713037	Dry Cr.	South Fork Eel River	Hwy 254 culvert	Road crossing	3.4	0.2	0.9	0.1	1.0
715524	Hartsook Cr.	South Fork Eel River	Fishway	Fish passage facility	2.7	0.5	0.7	0.3	0.9

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
715519	Redwood Cr.	South Fork Eel River	Bridge	Road crossing	3.8	0.0	0.9	0.0	0.9
707158	Anderson Cr.	South Fork Eel River	Culvert Ave. of the Giants	Road crossing	3.6	0.0	0.9	0.0	0.9
715492	Albee Cr.	Bull Cr.	Bridge	Road crossing	3.6	0.0	0.9	0.0	0.9
707160	Hartsook Cr.	South Fork Eel River	Culvert Hwy 101	Road crossing	2.7	0.4	0.7	0.2	0.9
707108	Mad Cr.	Rattlesnake Cr.	Hwy 101 culvert on natural barrier	Road crossing	3.1	0.0	0.8	0.0	0.8
705899	Deer Cr.	South Fork Eel River	Wilderness Lodge Road	Road crossing	3.1	0.0	0.8	0.0	0.8
715409	Tuttle Cr.	South Fork Eel River	Culvert Hwy 101	Road crossing	3.0	0.0	0.7	0.0	0.7
715494	Preacher Gulch	Bull Cr.	Culvert	Road crossing	2.6	0.0	0.7	0.0	0.7
705107	Little Dan Cr.	Big Dann Cr.	Hwy 101 - culvert	Road crossing	2.6	0.0	0.6	0.0	0.6
722698	Unnamed Tributary	China Cr.	Bridge 112187	Road crossing	2.5	0.0	0.6	0.0	0.6
712993	Williams Cr.	South Fork Eel River	Hwy 101 culvert	Road crossing	2.3	0.0	0.6	0.0	0.6
723490	Lost Man Cr.	Hollow Tree Cr.	Road 41-ES-024 culvert	Road crossing	2.2	0.0	0.6	0.0	0.6
705901	Bear Cr.	South Fork Eel River	Branscomb Road	Road crossing	2.2	0.0	0.5	0.0	0.5
707104	Unnamed Tributary to Rattlesnake Cr.	Rattlesnake Cr.	Hwy 101 culvert	Road crossing	2.2	0.0	0.5	0.0	0.5
713040	Mowry Cr.	South Fork Eel River	Hwy 254 culvert	Road crossing	2.1	0.0	0.5	0.0	0.5

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total ranking score
723493	South Fork Redwood Cr.	Redwood Cr.	Road 41-HG-060-05 culvert	Road crossing	2.1	0.0	0.5	0.0	0.5
712998	Mowry Cr.	South Fork Eel River	Hwy 101 culvert	Road crossing	2.1	0.0	0.5	0.0	0.5

[1] Site slated for removal in 2014.

Table I-4. Prioritized list of sites requiring future assessment in the Middle Main Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
705114[1]	Woodman Cr.	Eel River	Fishway at the railroad crossing, with rock falls	Fish passage facility	65.2	6.0	16.3	3.0	19.3
758019	Unnamed Tributary to Woodman Cr.	Woodman Cr.	Woodman Creek Road crossing	Road crossing	20.0	2.7	5.0	1.4	6.3
711970	Brock Cr.	Eel River	Railroad crossing bridge	Road crossing	18.8	0.0	4.7	0.0	4.7
722822	Conley Cr.	Dobbyn Cr.	Alderpoint Road bridge	Road crossing	16.3	0.0	4.1	0.0	4.1
715489	Sonoma Cr.	Eel River	Railroad bridge	Road crossing	12.7	1.5	3.2	0.7	3.9
715488	Sonoma Cr.	Eel River	Culvert at County Road	Road crossing	12.4	1.4	3.1	0.7	3.8
705989	Burgess Cr.	Hembry Cr.	Burgess Ranch Road	Road crossing	6.6	0.2	1.6	0.1	1.7
711956	Soda Cr.	Eel	Railroad crossing culvert (arch, rock)	Road crossing	6.9	0.0	1.7	0.0	1.7

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
711933	Ticknor Cr.	Eel River	Railroad crossing culvert (arch, concrete)	Road crossing	5.7	0.0	1.4	0.0	1.4
711957	Jackass Cr.	Eel	Railroad crossing culvert (arch, rock)	Road crossing	4.8	0.0	1.2	0.0	1.2
711936	Mill Cr.	Eel River	Railroad crossing culvert (arch, concrete)	Road crossing	4.7	0.0	1.2	0.0	1.2
711932	Hamann Cr.	Eel	Railroad crossing culvert (arch, concrete)	Road crossing	4.5	0.0	1.1	0.0	1.1
705825	Jewett Cr.	Eel River	Jewett Road	Road crossing	4.0	0.0	1.0	0.0	1.0
711973	Unnamed 8	Eel	Railroad crossing culvert (arch, concrete)	Road crossing	3.7	0.0	0.9	0.0	0.9
713223	Line Gulch	Dobbyn Cr.	Alderpoint Road	Road crossing	3.7	0.0	0.9	0.0	0.9
711964	Ort Cr.	Eel	Railroad crossing culvert (arch, concrete)	Road crossing	3.6	0.0	0.9	0.0	0.9
711960	Old Car Cr.	Eel River	Railroad crossing culvert (arch, concrete)	Road crossing	3.2	0.0	0.8	0.0	0.8
713230	Sequoia Cr.	Sonoma Cr.	Whitlow Road	Road crossing	3.1	0.0	0.8	0.0	0.8
711978	Unnamed	Eel	Railroad crossing culvert (arch, concrete)	Road crossing	3.0	0.0	0.8	0.0	0.8
711974	Unnamed 7	Eel	Railroad crossing culvert (arch, concrete)	Road crossing	3.0	0.0	0.7	0.0	0.7
711934	Unnamed	Eel River	Railroad crossing culvert (arch, concrete)	Road crossing	2.6	0.0	0.6	0.0	0.6
711983	Unnamed	Eel River	Railroad crossing culvert (CMP)	Road crossing	2.5	0.0	0.6	0.0	0.6
705827	Perrington Cr.	Eel River	Harris Road	Road crossing	2.4	0.0	0.6	0.0	0.6

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km²)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
711988	Devil's Elbow Cr.	Eel River	Railroad crossing culvert (arch, concrete)	Road crossing	2.3	0.0	0.6	0.0	0.6
713228	Devil's Elbow Cr.	Eel River	McCann Road	Road crossing	2.3	0.0	0.6	0.0	0.6

[1] Site slated for removal.

Table I-5. Prioritized list of sites requiring future assessment in the North Fork Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km²)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
715446	Salt Cr.	North Fork Eel River	Unknown passage site	Unknown	54.2	12.6	13.6	6.3	19.9
707894	Bluff Cr.	Kettenpom Cr.	Forest Service Road culvert	Road crossing	19.7	3.3	4.9	1.6	6.6
705990	Wilson Cr.	North Fork Ee River	Zenia Lake Mountain Road	Road crossing	7.5	0.0	1.9	0.0	1.9
705991	Panther Cr.#2	Bar Cr-West Fork Eel-North Fork Eel-Eel River	Ruth Zenia Road	Road crossing	5.0	0.0	1.3	0.0	1.3

Table I-6. Prioritized list of sites requiring future assessment in the Middle Fork Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km²)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
715086	Town Cr.	Middle Fork Eel River	Natural bottom culvert	Road crossing	28.8	7.5	7.2	3.8	11.0
707681	Beaver Cr.	Middle Fork Eel River	Culvert Route M-1	Road crossing	35.8	0.5	8.9	0.3	9.2
707680	Rattlesnake Cr.	Middle Fork Eel River	Culvert Route M-1	Road crossing	28.1	0.0	7.0	0.0	7.0
705119	Town Cr.	Grist Cr.	Town Creek Reservoir	Dam	15.5	2.0	3.9	1.0	4.9
707684	Smokehouse Cr.	Beaver Cr.	Culvert Route M-21	Road crossing	10.1	0.5	2.5	0.2	2.8
706995	Trib to Turner Cr.	Mill Cr.	Hwy 162 pool and weir	Road crossing	6.6	1.8	1.6	0.9	2.5
706984	Poormans Cr.	Eel River, Middle Fork	Hwy 162 culvert with baffles	Road crossing	4.8	2.2	1.2	1.1	2.3
705190	Skidmore Cr.	Black Butte River	Unknown passage site	Unknown	8.8	0.0	2.2	0.0	2.2
707678	Hammerhorn Cr.	Middle Fork Eel River	Culvert Route M-1	Road crossing	8.8	0.0	2.2	0.0	2.2
707677	Bar Cr.	Middle Fork Eel River	Culvert Route M-1	Road crossing	7.9	0.0	2.0	0.0	2.0
719528	Toney Cr.	Eden Cr.	Jayne's Lake	Dam	4.8	1.1	1.2	0.5	1.7
707683	Buck Rock Cr.	Beaver Creek	Culvert Route M-1	Road crossing	5.7	0.0	1.4	0.0	1.4
707689	Fly Cr.	Middle Fork Eel River	Culvert Route M-1	Road crossing	5.6	0.0	1.4	0.0	1.4
705124	Poormans Cr.	Williams Cr.	Poormans Creek culvert	Road crossing	2.8	1.0	0.7	0.5	1.2

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
705118	Turner Cr.	Mill Cr.	Fishway	Fish passage facility	3.4	0.4	0.8	0.2	1.0
718928	Unnamed Tributary	Short Cr.	Williams Valley Dam	Dam	3.9	0.0	1.0	0.0	1.0

Table I-7. Prioritized list of sites requiring future assessment in the Upper Main Eel River sub-basin.

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
706983	Outlet Cr.	Eel River	Denil	Fish passage facility	353.7	171.3	88.4	85.6	174.1
707674	Eel River	Pacific Ocean	Culvert Route M-6	Road crossing	42.7	3.4	10.7	1.7	12.4
706978	Mill Cr.	Outlet Cr.	Pool and weir	Fish passage facility	25.0	11.5	6.3	5.7	12.0
715003	Broaddus Cr.	Outlet Cr.	Denil fishway at Waste Water Treatment Plant	Fish passage facility	20.3	10.2	5.1	5.1	10.2
707687	Panther Cr.	Eel River	Culvert Route 18N35	Road crossing	28.3	1.9	7.1	0.9	8.0
715092	Willits Cr.	Haehl Cr. (Outlet Cr.)	Willits Creek summer dam with denil	Dam	18.2	6.4	4.5	3.2	7.7
712901	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	19.3	5.2	4.8	2.6	7.4
712897	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	19.1	5.0	4.8	2.5	7.3
712902	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	19.0	4.9	4.7	2.5	7.2

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
707682	Welch Cr.	Soda Cr.	Culvert Route 18N43	Road crossing	27.0	0.8	6.8	0.4	7.1
707675	Rattlesnake Cr.	Middle Fork Eel River	Culvert Route M-6	Road crossing	21.8	1.9	5.4	0.9	6.4
707095	Long Valley Bridge	Outlet Cr.	Hwy 101 bridge	Road crossing	12.0	5.8	3.0	2.9	5.9
705137	Willits Cr.	Mill Cr.	Brooktrails summer dam	Dam	14.0	4.7	3.5	2.3	5.8
718926	Davis Cr.	Outlet Cr.	Morris Dam	Dam	13.4	4.0	3.4	2.0	5.4
715169	Mill Cr.	Salmon Cr.	Gabion	Dam	21.2	0.0	5.3	0.0	5.3
712898	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	13.4	3.8	3.4	1.9	5.3
712903	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	13.3	3.6	3.3	1.8	5.2
712899	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	13.2	3.4	3.3	1.7	5.0
712904	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	13.0	3.3	3.2	1.7	4.9
712900	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	12.9	3.2	3.2	1.6	4.8
712905	Cave Cr.	Tomki Cr.	Road crossing	Road crossing	12.7	3.1	3.2	1.5	4.7
718927	Willits Cr.	Mill Cr.	Brookstrails 3 N dam	Dam	12.7	2.5	3.2	1.3	4.4
705736	South Fork Corbin Cr.	Corbin Cr.	South Fork Corbin Creek Road culvert	Road crossing	16.4	0.6	4.1	0.3	4.4
707673	Trout Cr.	Eel River	Culvert Route M-6	Road crossing	11.6	0.0	2.9	0.0	2.9

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
712822	Haehl Cr.	Baechtel Cr.	Road crossing	Road crossing	5.1	2.9	1.3	1.5	2.7
707089	Strong Mountain Cr.	Long Valley Cr.	Hwy 101 and barrier rock falls	Road crossing	8.4	1.0	2.1	0.5	2.6
706990	Sam Watt Cr.	Long Valley Cr.	CMP culvert with baffles	Road crossing	8.4	1.0	2.1	0.5	2.6
712906	Rock Tree Cr.	String Cr.	Grade stabilization	Grade control	5.4	2.3	1.4	1.2	2.5
719282	Davis Cr.	Outlet Cr.	Centennial dam	Dam	6.7	1.6	1.7	0.8	2.5
712894	Unnamed Tributary to Haehl Cr.	Haehl Cr.	Hwy 101 culvert	Road crossing	5.8	2.0	1.5	1.0	2.5
705136	Upp Cr.	Outlet Cr.	Hwy 101 crossing	Road crossing	4.7	2.2	1.2	1.1	2.3
705730	Dutch Oven Cr.	Corbin Cr.	Dutch Oven Creek culvert	Road crossing	8.4	0.0	2.1	0.0	2.1
707686	Horse Cr.	Eel River	Culvert Route M-6	Road crossing	7.5	0.1	1.9	0.0	1.9
705733	Thistle Glade Cr.	Eel River	US Forest Service road culvert	Road crossing	6.4	0.0	1.6	0.0	1.6
713199	Sage Horn Cr.	Salt Cr.	Hearst-Willits Road	Road crossing	2.9	1.4	0.7	0.7	1.4
713200	Sage Horn Cr.	Salt Cr.	Private road	Road crossing	2.9	1.3	0.7	0.7	1.4
712814	Big Canyon	Tomki Cr.	Road crossing (pool and weir)	Road crossing	3.8	0.7	0.9	0.3	1.3
713107	Unnamed Trib to Haehl Cr.	Haehl Cr.	Hwy 101 culvert	Road crossing	2.7	1.0	0.7	0.5	1.2
735069	Moore Cr.	Davis Cr.	Eastside Road	Road crossing	3.9	0.4	1.0	0.2	1.2

PAD ID	Stream name	Tributary to	Site name	Site type	Contributing drainage area (km^2)	Length of channel upstream with gradient <2% (km)	Stream size score	Low gradient score	Total score
705897	Davis Cr. Tributary	Outlet Cr. - Eel River	Eastside Road	Road crossing	3.2	0.7	0.8	0.4	1.2
707078	Unnamed Trib to Broaddus Cr.	Broaddus Cr.	Hwy 20 West road culvert	Road crossing	4.2	0.2	1.1	0.1	1.1
713093	Unnamed Trib to Broaddus Cr.	Broaddus Cr.	Hwy 20 culvert	Road crossing	3.0	0.4	0.7	0.2	1.0
707093	Wilson Gulch Cr.	Long Valley Cr.	Hwy 101 culvert	Road crossing	3.8	0.0	1.0	0.0	1.0
707088	Moss Cove Cr.	Outlet Cr.	Hwy 101 culverts and rock barriers	Road crossing	3.3	0.0	0.8	0.0	0.8
713201	Sage Horn Cr.	Salt Cr.	Private road	Road crossing	2.2	0.5	0.6	0.2	0.8
713209	Salt Cr.	Eel River	Hearst-Willits Road	Road crossing	3.1	0.0	0.8	0.0	0.8
713207	Unnamed Tributary to Salt Cr.	Salt Cr.	Hearst-Willits Road	Road crossing	2.8	0.0	0.7	0.0	0.7
706989	Rocktree Cr.	Tomki Cr.	Pool and weirs	Fish passage facility	2.1	0.3	0.5	0.2	0.7
713208	Unnamed Tributary to Salt Cr.	Salt Cr.	Private road	Road crossing	2.3	0.0	0.6	0.0	0.6
713210	Unnamed Trib to Eel River	Eel River	Hearst Post Office Road	Road crossing	2.3	0.0	0.6	0.0	0.6
705138	Dutch Henry Cr.	Willits Cr.	Dam and reservoir	Dam	2.2	0.0	0.5	0.0	0.5