

**FINAL REPORT:
MORRO BAY WATERSHED STREAM CROSSING INVENTORY AND FISH
PASSAGE EVALUATION**

**Prepared for the
Coastal San Luis Resource Conservation District**

**By
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INTRODUCTION

The inventory and fish passage evaluation of stream crossings within the Morro Bay watershed was conducted between November, 2002 and January, 2003. The primary objective was to assess passage of juvenile and adult steelhead and develop a project-scheduling document to prioritize corrective treatments to provide unimpeded fish passage at eight road/stream intersections, three low-elevation dams, and a natural waterfall. The inventory was focused at sites within reaches of Chorro Creek and several of its tributaries known to historically and/or currently support runs of steelhead (*Oncorhynchus mykiss irideus*) – listed as threatened by the Endangered Species Act by the National Marine Fisheries Service (NMFS). Chorro Creek and Los Osos Creeks are the major sub-waters of Morro Bay with drainage areas of 43 square miles and 23 square miles, respectively (Figure 1).

Please note that for this report the term **stream crossing** is defined as any human-made structure, (used primarily for transportation purposes) that crosses over or through a stream channel, such as a paved road, unpaved road, railroad track, biking or hiking trail, golf-cart path, or low-water ford. Stream crossings include culverts, bridges, and low-water crossings such as paved and unpaved fords. For the purpose of fish passage, the distinction between types of stream crossings is not as important as the effect the structure has on the form and function of the stream. A stream crossing encompasses the structure employed to pass stream flow as well as associated fill material within the crossing prism.

The inventory and assessment process included:

1. Visiting each previously identified site to confirm the type of structure and collect site-specific information to assess fish passage.
2. At crossings with culverts - collecting information regarding culvert specifications and surveying a longitudinal profile.
3. At dams and natural waterfall – surveying a longitudinal profile.
4. At crossings - assessing fish passage using culvert specifications and passage criteria for juvenile and adult salmonids (state and federal criteria) by employing a first-phase evaluation filter and then using a computer software program (FishXing) on a subset of sites defined as partial/temporal barriers.
5. At dams and natural waterfall – assessing fish passage by comparing the drop height and depth of the downstream pool to passage criteria for juvenile and adult salmonids (state and federal criteria) by employing a first-phase evaluation filter and then using a computer software program (FishXing) on a subset of sites defined as partial/temporal barriers.
6. Assessing quality and quantity of stream habitat above and below each culvert.

The prioritization process ranked sites by assigning numerical scores for the following criteria:

1. Presumed species diversity within stream reach of interest (and federal listing status).
2. Extent of barrier for each species and lifestage for range of estimated migration flows.
3. Quality and quantity of potential upstream habitat gains.
4. Sizing of current stream crossing (risk of fill failure).
5. Condition of current crossing (life expectancy).

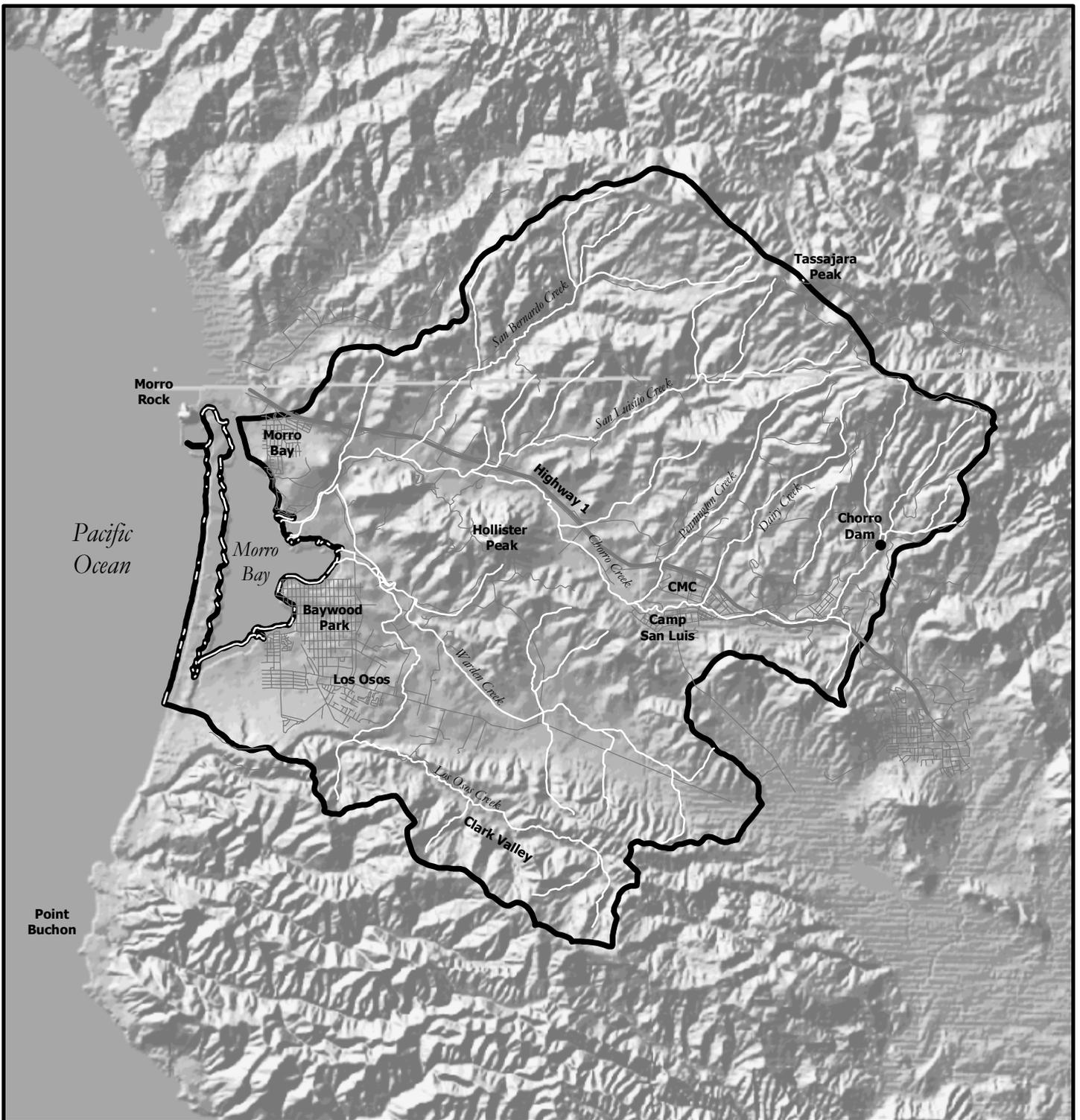
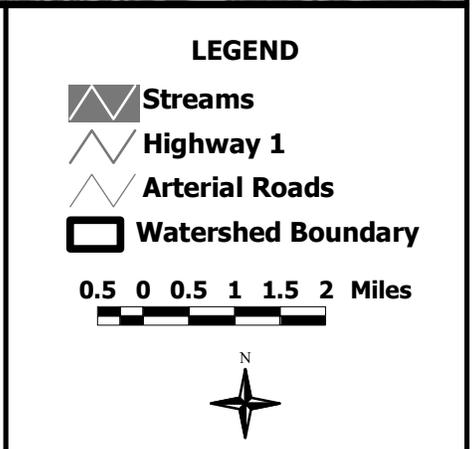


FIGURE 1
Morro Bay Watershed
Steelhead Restoration Plan
Location Map



The initial ranking was not intended to provide an exact order of priority, but rather to produce a first-cut rank in which sites could be grouped as high, medium, or low priority. Professional judgment was a vital component of the ranking process. On a site-specific basis, some or all of the following factors were considered in developing the final ranked list.

1. Streams that currently support runs of steelhead. Treating barriers in these watersheds should result in a high probability of immediate utilization of re-opened habitat.
2. Physical stress or danger to migrating salmonids. Recent studies have revealed numerous sites in California where concentrations of migrating salmonids were annually subjected to predation by birds and mammals or poaching by humans (Taylor 2000 and 2001). Inability to enter cool-water tributaries to escape stressful/lethal mainstem water temperatures during summer months has also been observed. These factors should weigh heavily in the ranking.
3. Amount of road fill. At stream crossings that were undersized and/or in poor condition, we assessed the volume of fill material within the road prism potentially deliverable to the stream channel if the culvert were to fail. Large, sudden contributions of sediment from road failures are often detrimental to spawning and rearing habitat located downstream of the crossing.
4. Presence (and location) of other stream crossings and other types of barriers. In many cases, a single stream was crossed by multiple roads under a variety of management or ownership. In these situations, close communication with other road managers and property owners was important. When multiple stream crossings were identified as migration barriers, a coordinated effort will be required to identify and treat them in a logical manner – generally in an upstream direction starting with the lowermost crossing.
5. Remediation project cost. One should examine the range of treatment options and associated costs when determining the order in which to proceed and what should be implemented at specific sites. In cases where Federally listed fish species are present, costs must also be weighed against the consequences of failing to comply with the Endangered Species Act by not providing unimpeded passage.
6. Scheduling of other road maintenance and repair projects. Road managers should consider upgrading all migration barriers during other activities they may perform to the roadway, such as repaving, chip-sealing, or widening. When undersized or older crossings fail during storms, road managers should be prepared to install properly-sized crossings that provide unimpeded passage for all species and life-stages of fish.
7. Other factors impacting steelhead. In many cases, other limiting factors besides migration barriers exist that impair salmonid productivity. On a watershed or sub-basin level, restoration decisions must be made after carefully reviewing potential limiting factors, the source of the impacts, and the range of restoration options available, and what restoration activities are actually feasible.

Additional physical, operational, social, and/or economic factors exist that may influence the final order of sites; but these are beyond the scope of this project.

Final Product of Fish Passage Inventory

Final report includes:

1. Site location information. Locations were identified by stream name; road or site name; (road number – if applicable); watershed name; mile marker or distance to nearest named crossroad; USGS Quad name; Township, Range and Section coordinates; and lat/long coordinates (NAD27 datum). Each evaluated site was previously provided a unique ID # in the *Steelhead Restoration Planning Project* for GIS purposes (Dvorsky, 2002). All location data were entered into a spreadsheet for potential database uses.
2. For each site with a crossing/culvert, the following specifications were collected, including: length, dimensions (diameter, rise-and-span, or height-and-width), position relative to flow and stream gradient, amount of fill material, depth of jump pool below culvert, height of leap required to enter culvert, overall condition of the pipe and rust line height, previous modifications (if any) to improve fish passage, and evaluate effectiveness of previous modifications. At each crossing, a longitudinal survey and a cross-sectional survey were completed. All site-specific data were entered into a spreadsheet for potential database uses.
3. For each site with a dam or natural waterfall, a longitudinal survey and a cross-sectional survey were completed. All survey data were entered into a spreadsheet for potential database uses.
4. An evaluation of fish passage at each site. Fish passage was evaluated by two methods. Initially, fish passage was assessed by employing a first-phase evaluation filter that was developed for Part 10 of the California Department of Fish and Game's (CDFG) *Salmonid Stream Habitat Restoration Manual* (Taylor and Love, 2002). The filter quickly determined if a site either met fish passage criteria for all species and life stages as defined by CDFG for the range of migration flows (**GREEN**); failed to meet passage criteria for all species and life stages (**RED**); or was a partial/temporal barrier (**GRAY**). Then FishXing (a computer software program) was used to conduct in-depth passage evaluations on the **GRAY** sites by modeling culvert hydraulics over the range of migration flows and comparing these values with leaping and swimming abilities of adult steelhead and several juvenile life-stages.
5. Digital photo documentation of each crossing to provide visual information regarding inlet and outlet configurations; as well as insertion in future reports, proposals, or presentations.
6. An evaluation of the quantity and quality of fish habitat above and below each site location. Most information was obtained from previously conducted habitat typing and fisheries surveys. The San Luis Coastal RCD assimilated most of the habitat and fisheries data that were available from CDFG and previous studies. Where feasible, a first-hand inspection and evaluation of stream habitat was undertaken as part of this study. Length of potential anadromous habitat was also estimated from USGS topographic maps. In situations where formal habitat typing surveys were not conducted and/or access to stream reaches was not permitted, professional judgment of biologists and/or watershed coordinators familiar with watershed conditions was utilized.

7. A ranked list of sites that require treatment to provide unimpeded fish passage to spawning and rearing habitat. On a site-by-site basis, general recommendations for providing unimpeded fish passage were provided.

Project Justification

Migration Barrier Impacts to Salmonids

Fish passage through culverts at stream crossings is an important factor in the recovery of depleted salmonid populations throughout the Pacific Northwest. Although most fish-bearing streams with culverts tend to be relatively small in size with only a couple of miles or less of upstream habitat, thousands of these exist and the cumulative effect of blocked habitat is probably quite significant. Recent research regarding watershed restoration considers the identification, prioritization, and treatment of migration barriers to restore ecological connectivity for salmonids a vital step towards recovering depressed populations (Roni et al. 2002). Culverts often create temporal, partial or complete barriers for anadromous salmonids on their spawning migrations (Table 1) (adapted from Robison et al. 2000).

Typical passage problems created by culverts are:

- Excessive drop at outlet (too high of entry leap required).
- Excessive velocities within culvert.
- Lack of depth within culvert.
- Excessive velocity and/or turbulence at culvert inlet and/or outlet.
- Debris accumulation at culvert inlet and/or within culvert.

Table 1. Definitions of barrier types and their potential impacts.

Barrier Category	Definition	Potential Impacts
Temporal	Impassable to all fish some of the time	Delay in movement beyond the barrier for some period of time
Partial	Impassable to some fish at all times	Exclusion of certain species and life stages from portions of a watershed
Total	Impassable to all fish at all times	Exclusion of all species from portions of a watershed

Even if culverts are eventually negotiated, excess energy expended by fish may result in their death prior to spawning or reductions in viability of eggs and offspring. Migrating fish concentrated in pools and stream reaches below crossings are also more vulnerable to predation by a variety of avian and mammalian species, as well as poaching by humans. Culverts which impede adult passage limit the distribution of spawning, often resulting in under-seeded headwaters and superimposition of redds in lower stream reaches.

Current guidelines for new culvert installation aim to provide unimpeded passage for both adult and juvenile salmonids (CDFG 2002, NMFS 2001). However many existing culverts on federal, state, county, and private roads are barriers to anadromous adults, and more so to resident and juvenile salmonids whose smaller sizes significantly limit their leaping and swimming abilities to negotiate culverts. For decades, “legacy” culverts on established roads have effectively disrupted the spawning and rearing behavior of all four species of anadromous salmonids in California: Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), coastal rainbow trout (steelhead are anadromous coastal rainbow trout), and coastal cutthroat trout (*O. clarki clarki*).

In recent years, there has been a growing awareness of the disruption of in-stream migrations of resident and juvenile salmonids caused at road/stream intersections. In-stream movements of juvenile and resident salmonids are highly variable and still poorly understood by biologists. Juvenile coho salmon spend approximately one year in freshwater before migrating to the ocean, and juvenile steelhead may rear in freshwater for up to four years prior to out-migration (one to two years is most common in California). Thus, juveniles of both species are highly dependent on stream habitat.

Many studies indicate that a common strategy for over-wintering juvenile coho is to migrate out of larger river systems into smaller streams during late-fall and early-winter storms to seek refuge from possibly higher flows and potentially higher turbidity levels in mainstem channels (Skeesick 1970; Cederholm and Scarlett 1981; Tripp and McCart 1983; Tschaplinski and Hartman 1983; Scarlett and Cederholm 1984; Sandercock 1991; Nickelson et al. 1992). Recent research conducted in coastal, northern California watersheds suggests that juvenile salmonids migrate into smaller tributaries in the fall and winter to feed on eggs deposited by spawning adults as well as flesh of spawned-out adults (Roelofs, pers. comm). Direct observation at numerous crossings in northern California has confirmed similar upstream movements of three year-classes of juvenile steelhead (young-of-year, 1-year old and 2-year old) (Taylor 2001 and 2000). For example, in 1996-2000 at the Sullivan Gulch/Riverside Drive culvert (Humboldt County) observations of failed leap attempts by juvenile salmonids often exceeded 100 attempts per hour. In 1998 and 1999, 47 juvenile salmonids were netted while attempting leaps for the purpose of species identification. Of the 47 fish sampled, 43 (or 91%) were steelhead that comprised at least two age classes (young-of-year and 1+ year-olds) (Taylor, unpublished field notes).

Morro Bay Watershed Restoration Project

This migration barrier assessment is part of the Morro Bay Watershed Steelhead Restoration Planning project. This planning project was undertaken by the Coastal San Luis RCD to make steelhead recovery efforts in the Morro Bay watershed more effective by developing a prioritized list of restoration actions. This planning effort is funded by the Morro Bay National Estuary Program, the USEPA (through the California State Water Resources Control Board), the California Department of Fish and Game, and Sustainable Conservation. Besides assessing barriers, the project has gathered existing information regarding factors which may affect steelhead, including past and current land uses in the watershed; past conservation activities; erosion and sedimentation; stream-flow rates; geomorphological condition; canopy cover; and water quality parameters such as temperature, dissolved oxygen, and turbidity.

Additional field work included surveys of stream habitat values and fish populations. All these data will be analyzed to determine the critical unmet habitat needs for steelhead in the watershed, and also identify non-physical factors that may limit steelhead production. A prioritized list of actions that will result in recovery of steelhead populations in the watershed will be developed. These actions may include upslope conservation practices, riparian habitat enhancement, in-stream structure construction, stream bank protection, and/or migration barrier treatment activities.

In 2002, the Coastal San Luis RCD contracted with Swanson Hydrology and Geomorphology to develop the *Steelhead Restoration Planning Project* for the Morro Bay watershed (Dvorsky, 2002). The draft report identified a suite of factors affecting the distribution and abundance of steelhead within Chorro Creek and Los Osos Creek. Fifteen sites were identified as potential migration barriers to steelhead. The report recommended that 12 of the Chorro Creek sites be evaluated and prioritized for treatment to open up access to the watershed's tributaries.

Steelhead populations within the Morro Bay watershed will benefit from this planning effort because the final document provides the Coastal San Luis RCD with a prioritized list of migration barriers to fix that will provide unimpeded passage for all life-stages. Report information will assist in proposal development to seek State and Federal money to implement treatments. The inventory also provides the managers/owners of the various crossings with a comprehensive status evaluation of the overall condition and sizing of culverts within fish-bearing stream reaches, providing vital information to assist road manager's general planning and road's maintenance needs.

METHODS AND MATERIALS

Methods for conducting the inventory and fish passage evaluation included eight tasks; accomplished generally in the following order:

1. Location of stream crossings and other sites.
2. Initial site visits and data collection.
3. Estimation of tributary-specific hydrology and design flows for presumed migration period.
4. Data entry and passage analyses. Passage was first evaluated with a first-phase evaluation filter referred to as the “Green-Gray-Red” filter. Sites determined to be “Gray” then required an in-depth evaluation with FishXing – a computer modeling software.
5. Collection and interpretation of existing habitat information.
6. Prioritization of sites for corrective treatment.
7. Site-specific recommendations for unimpeded passage of both juvenile and adult salmonids.

These methods were consistent with the protocol recently developed for the CDFG *California Salmonid Stream Habitat Restoration Manual* (Taylor and Love, 2002). These methods were developed to be consistent with current state and federal fish passage criteria for anadromous salmonids (CDFG 2002, NMFS 2001).

Location of Sites

A pre-project meeting occurred on 11/20/02 between Ross Taylor and Associates personnel, Coastal San Luis RCD, CDFG, Camp SLO, and CCC’s. The primary objective of the meeting was to determine the sites to survey and arrange access to private property, Camp SLO, and the California Men’s Colony. The initial list of stream crossings and potential migration barriers to survey was provided in Table 2.4 of the Morro Bay planning project report (Dvorsky, 2002). The pre-project meeting identified several sites to be surveyed that had not been identified in the planning project report.

Initial Site Visits

The objective of the initial site visits was to collect physical measurements at stream crossings and other migration barriers to utilize with the first-phase evaluation filter and with the FishXing passage evaluation software. Notes describing the type and condition of each crossing or structure, as well as qualitative comments describing stream habitat immediately above and below each site were also included. Photographs, facing both upstream and downstream (outlet and inlet views at culverts), were taken at each site.

Type of Potential Migration Barrier

Potential sites were first identified as either: culverts, bridges, fords, dams, or natural falls/cascades. The field measurements were collected at all features for evaluation purposes. Although the FishXing evaluation software was developed primarily for modeling culvert hydraulics at stream crossings, the software allowed for analyses of leap heights required for fish passage over low-elevation dams and natural waterfalls.

Site Location

The location of each site was described by: road name and number or common site name; stream name; watershed name; name of USGS quad map; Township, Range, and Section; latitude and longitude; and mile marker or distance to nearest named cross-road. If more than one site crossed single stream, a number was assigned to the stream name with the #1 site located farthest downstream (numbering then proceeded in an upstream direction). Lat/long coordinates were first determined in the field with a handheld GPS unit and then confirmed with a geo-referenced mapping software program (Terrain Navigator, Version 3.01 by MapTech). For data entry and analyses purposes, all lat/long coordinates were provided in the North American 1927 datum (NAD27).

Longitudinal Survey

A longitudinal survey was shot at each site to provide accurate elevation data for FishXing passage analyses. We utilized an auto-level (Topcon AT-G7) with an accuracy of ± 2.5 mm, a domed-head surveyor's tripod, and a 25' leveling rod in 1/100' increments. All data and information were written on water-proof data sheets with a pencil. Data sheets were photocopied to provide back-ups in case of loss or destruction of originals.

To start the survey, a 300-foot tape (in 1/10' increments) was placed down the approximate center of the stream channel. The tape was started on the upstream side of the crossing, dam or waterfall usually in the riffle crest of the first pool or run habitat unit above the site. This pool or run was considered the first available resting habitat for fish negotiating either through a culvert or over a dam or waterfall. The tape was set to follow any major changes in channel direction. The tape was set through the culvert or over the dam/waterfall and continued downstream to at least the riffle crest (or tailwater control) of the pool immediately downstream of the site's outlet. If several "stair-stepped" pools led up to the culvert outlet, then the tape was set to the riffle crest of the lower-most pool. Extreme caution was used when wading through culverts at stream crossings. A hardhat and flashlight were standard items used during the surveys.

The tripod and mounted auto-level were set in a location to eliminate or minimize the number of turning points required to complete the survey. At the Highway One sites, a tripod location near the culvert outlet was optimal, allowing complete longitudinal and cross-sectional surveys to be shot from one location, as well as minimizing time spent on the road surface of this busy traffic corridor. The leveling rod was placed at the thalweg (deepest point of channel cross-section at any given point along the center tape) at various stations along the center tape, generally capturing visually noticeable breaks in slope along the stream channel.

At all sites, a temporary benchmark (TBM) was established in order to allow interested parties to easily re-survey the site to either check the accuracy of our surveys or to conduct a survey prior to implementing a treatment. TBM's were typically established by spray-painting an "X" on a relatively permanent feature such as a concrete wing-wall or head-wall. The locations of all TBM's were clearly marked on the site sketches.

At all sites, a cross-section of the channel was surveyed at the outlet pool's tailwater control. Each cross-section was comprised of approximately eight elevations from the left bankfull channel margin to the right bank. These cross-sections allowed for a more accurate modeling of changes in tailwater elevations with the FishXing software.

At all stream crossings with culverts, the minimum five elevations required to run a FishXing evaluation were measured (Figures 2 and 3):

1. culvert inlet,
 2. culvert outlet,
 3. maximum pool depth within five feet of the outlet,
 4. outlet pool's tail-water control, and
 5. active channel margin between the culvert outlet and the outlet pool control. An active channel discharge is less than a bank-full discharge and is often identified by several features, including (Figure 3):
- Edge of frequently scoured substrate.
 - Break in rooted vegetation or moss growth on rocks along stream margins.
 - Natural line impressed on the bank.
 - Shelving.
 - Changes in soil character.

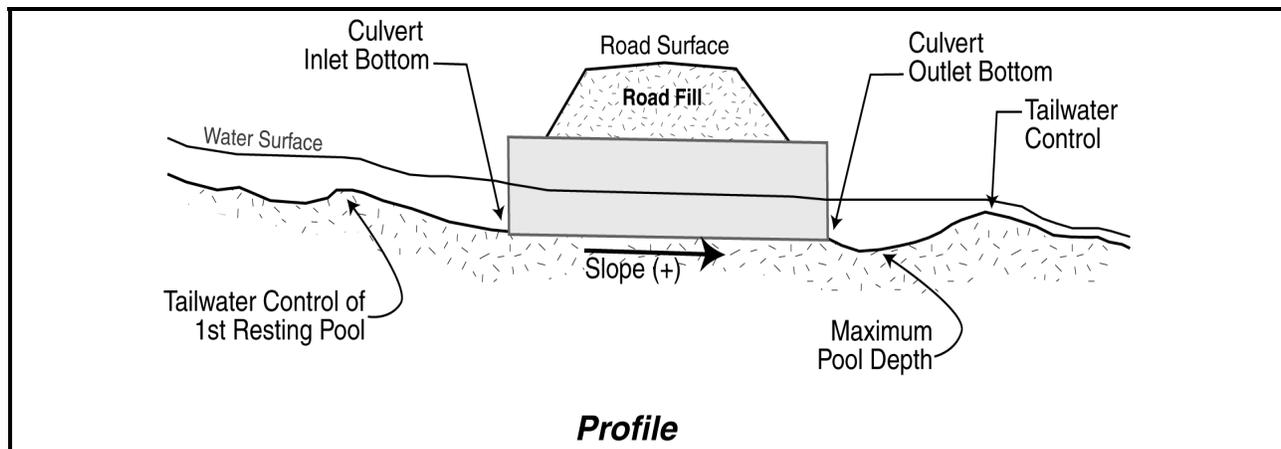


Figure 2. Diagram of required survey points through a culvert at a typical stream crossing.

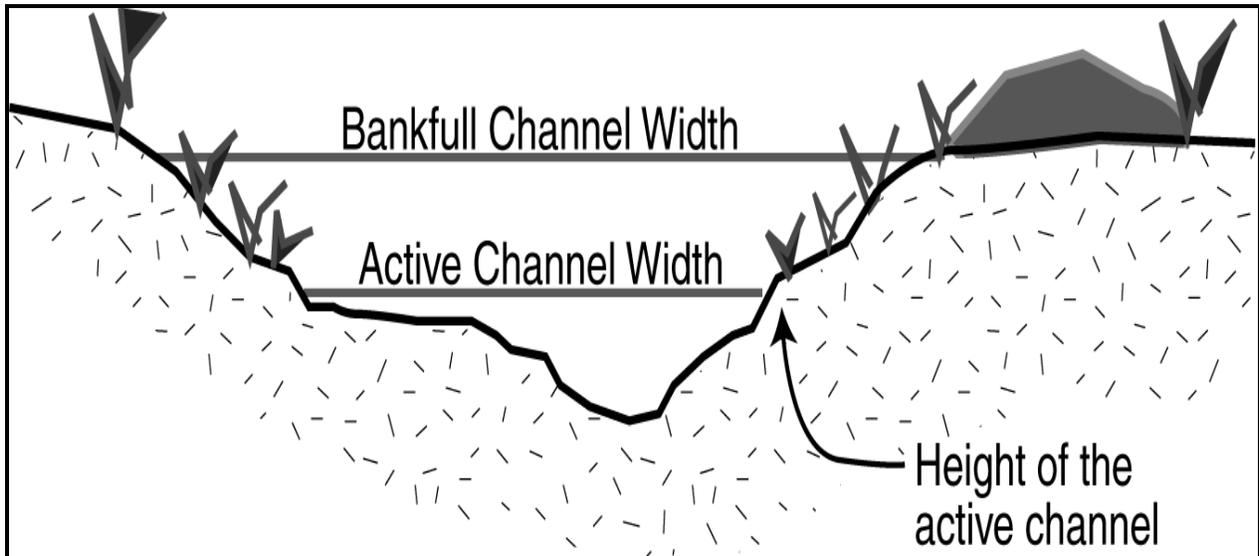


Figure 3. Active channel width versus bankfull channel width.

On a site-specific basis, the following additional survey points provided useful information for evaluating fish passage through culverts with FishXing:

- Apparent breaks-in-slope within the crossing. Older culverts often sag when road fills slump, creating steeper sections within a culvert. If only inlet and outlet elevations were measured, the overall slope would predict average velocities less than actual velocities within steeper sections. These breaks-in-slope may act as velocity barriers, which would be masked if only the overall slope of the culvert was measured. The tripod and auto-level were set within the culvert or channel to measure breaks-in-slope.
- Steep drops in the stream channel profile immediately upstream of the culvert inlet. We measured the elevation at the tail of the first upstream holding water (where the tape was set) to estimate the channel slope leading into the culvert. In some cases, a fish may negotiate the culvert only to fail at passing through a velocity chute upstream of the inlet entrance. Inlet drops often create highly turbulent conditions during elevated flows.
- Concrete aprons located at culvert inlets and outlets. These surfaces extend past the confinement of the culvert and were typically installed to protect the culvert from scour and erosion. However, aprons are often wide, smooth surfaces (often steeply-sloped) that impede passage from a lack-of-depth and excessive water velocities.

At low-elevation diversion dams and natural waterfalls, the following points were surveyed for the longitudinal profile:

1. Channel slope upstream of feature.
2. Lip of drop over dam spillway or waterfall.
3. Maximum pool depth within five feet of drop.
4. Maximum pool depth below feature.
5. Tail-water control elevation.
6. Natural channel slope downstream of feature.

Cross-sections at the tail-water control were completed at one dam site and the natural waterfall. Cross-sections of the dam's wall were completed for the other two dam locations.

All elevations were measured to the nearest 1/100' and entered with a corresponding station location (distance along center tape) to the nearest 1/10'.

Channel Widths

Where feasible, at least five measurements of the active channel width above each site (visually beyond any influence the crossing may have on channel width) were taken. Active channel was defined as the portion of channel commonly wetted during and above winter base flows and is identified by a break in rooted vegetation or moss growth on rocks along stream margins. Some culvert design guidelines utilize active channel widths in determining the appropriate widths of new culvert installations (CDFG 2002; NMFS 2001; Robison et al 2000; Bates et al. 1999).

Fill Estimate:

At each stream crossing with a culvert, the volume of road fill placed above the stream channel was estimated from field measurements. Fill volume estimates are incorporated into the ranking of sites for treatment and can assist in:

1. Calculating culvert flood capacity at HW/Fill =1 (water surface at top of fill prism).
2. Determining potential volume of sediment delivered to downstream habitat if the stream crossing failed.
3. Developing rough cost estimates for barrier removal by estimating equipment time required for fill removal and disposal site space needed.

Road fill volume is estimated using procedures outlined in Flannigan et al. (1998). The following measurements are taken to calculate the fill volume (Figure 4):

1. Upstream and downstream fill slope lengths (L_d and L_u).
2. Slope (%) of upstream and downstream fill slopes (S_d and S_u).
3. Width of road prism (W_r).
4. Top fill width (W_f).
5. Base fill width (W_c).
6. Culvert Dimensions.

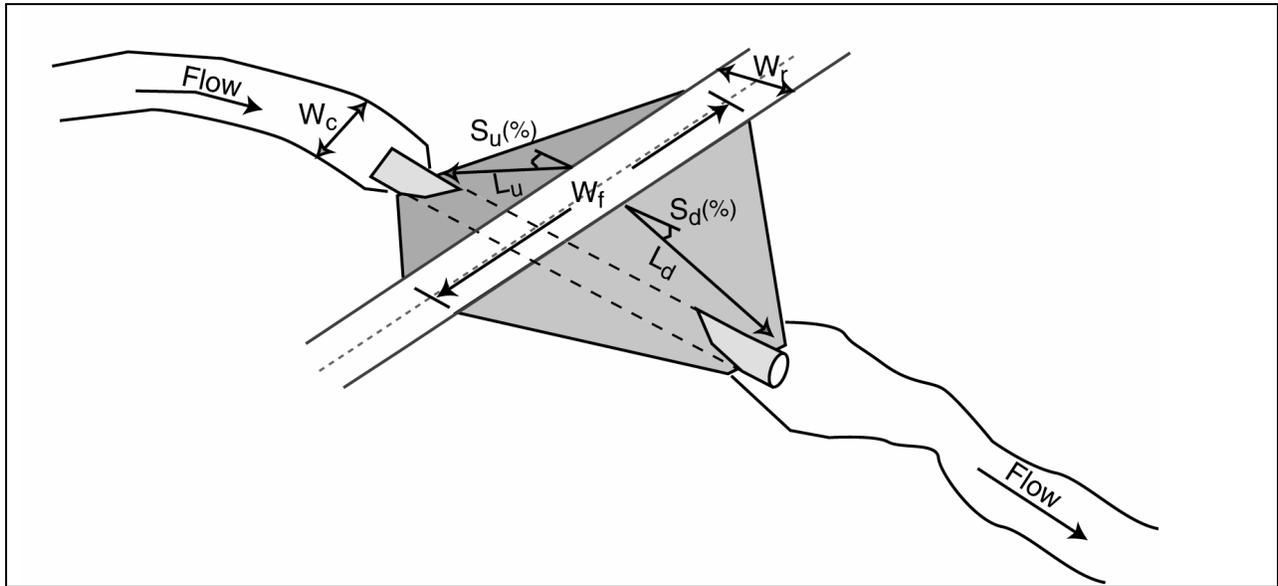


Figure 4. Road fill measurements.

Equations (1) through (4) were used calculate the fill volume.

(1) Upstream prism volume, V_u :

$$V_u = 0.25(W_f + W_c)(L_u \cos S_u)(L_u \sin S_u)$$

(2) Downstream prism volume, V_d :

$$V_d = 0.25(W_f + W_c)(L_d \cos S_d)(L_d \sin S_d)$$

(3) Volume below road surface, V_r :

$$V_r = 0.25(H_u + H_d)(W_f + W_c) W_r$$

where: $H_u = L_u \sin S_u$, and

$$H_d = L_d \sin S_d$$

(4) Culvert Volume, V_c :

Formulas for V_c vary depending on culvert shape/type

Total fill volume, V :

$$V = V_u + V_d + V_r - V_c$$

NOTE: The fill measurements used as part of this inventory protocol were meant to generate rough volumes for comparison between sites while minimizing the amount of time required collecting the information. These volume estimates can contain significant error and should not be used for designing replacement structures.

Other Site-specific Measurements

For each stream crossing with a culvert, the following specifications were collected:

1. Length (to nearest 1/10 of foot);
2. Dimensions: diameter (circular), or height and width (box culverts), or span and rise (pipe arches);
3. Type: corrugated steel pipe (CSP), structural steel plate (SSP), concrete pipe, concrete box, bottomless pipe arch, squashed pipe-arch, or a composite of materials;
4. Overall condition of pipe (good, fair, poor, extremely poor);
5. Height and width of rustline (if present);
6. Position of culvert relative to channel alignment and stream gradient;
7. Depth of jump pool below culvert;
8. Height of jump required to enter culvert;
9. Previous modifications (if any) to improve fish passage; and
10. Condition of previous modifications.

Qualitative notes describing stream habitat immediately upstream and downstream of each culvert were taken. Where feasible, variable lengths of the stream channel above and below crossings were walked to detect presence of salmonids and provide additional information regarding habitat conditions.

Data Entry and Passage Analyses

All survey and site visit data were recorded on waterproof data sheets. Then data for each site were entered into a spreadsheet (Excel 97). A macro was created to calculate thalweg elevations of longitudinal profiles and compute culvert slopes.

First-phase Passage Evaluation Filter: GREEN-GRAY-RED

A filtering process was used to assist in identifying sites which either meet, or fail to meet, state and federal fish passage criteria for all life-stages of steelhead (CDFG 2002; NMFS 2001). Using the field inventory data, at sites with culverts the average active channel width, culvert slope, residual inlet depth and drop at outlet were calculated (Figure 5). The drop height and residual outlet pool depth were calculated for the dams and natural waterfall. The drop height was the difference in elevation between the lip of the drop and the downstream pool's tail-water control. The first-phase passage evaluation filter was employed to reduce the number of sites which required an in-depth passage evaluation with FishXing. The filter criteria were designed to quickly classify sites into one of three categories:

- **GREEN**: Conditions assumed adequate for passage of all salmonids, including the weakest swimming lifestage.
- **GRAY**: Conditions may not be adequate for all salmonid species or lifestages presumed present. Additional analyses required to determine extent of barrier for each species and lifestage.

- **RED:** Conditions do not meet passage criteria at all flows for strongest swimming species presumed present. Assume “no passage” and move to analysis of habitat quantity and quality upstream of the barrier.

Follow the flowchart to determine a stream crossing’s status as Green, Gray, or Red (Figure 6). Depending on geographic location within California, species of interest will vary. Within anadromous-bearing watersheds, CDFG has determined that culverts classified as “Green” must meet upstream passage criteria for both adult and over-wintering juvenile salmonids at all expected migration flows.

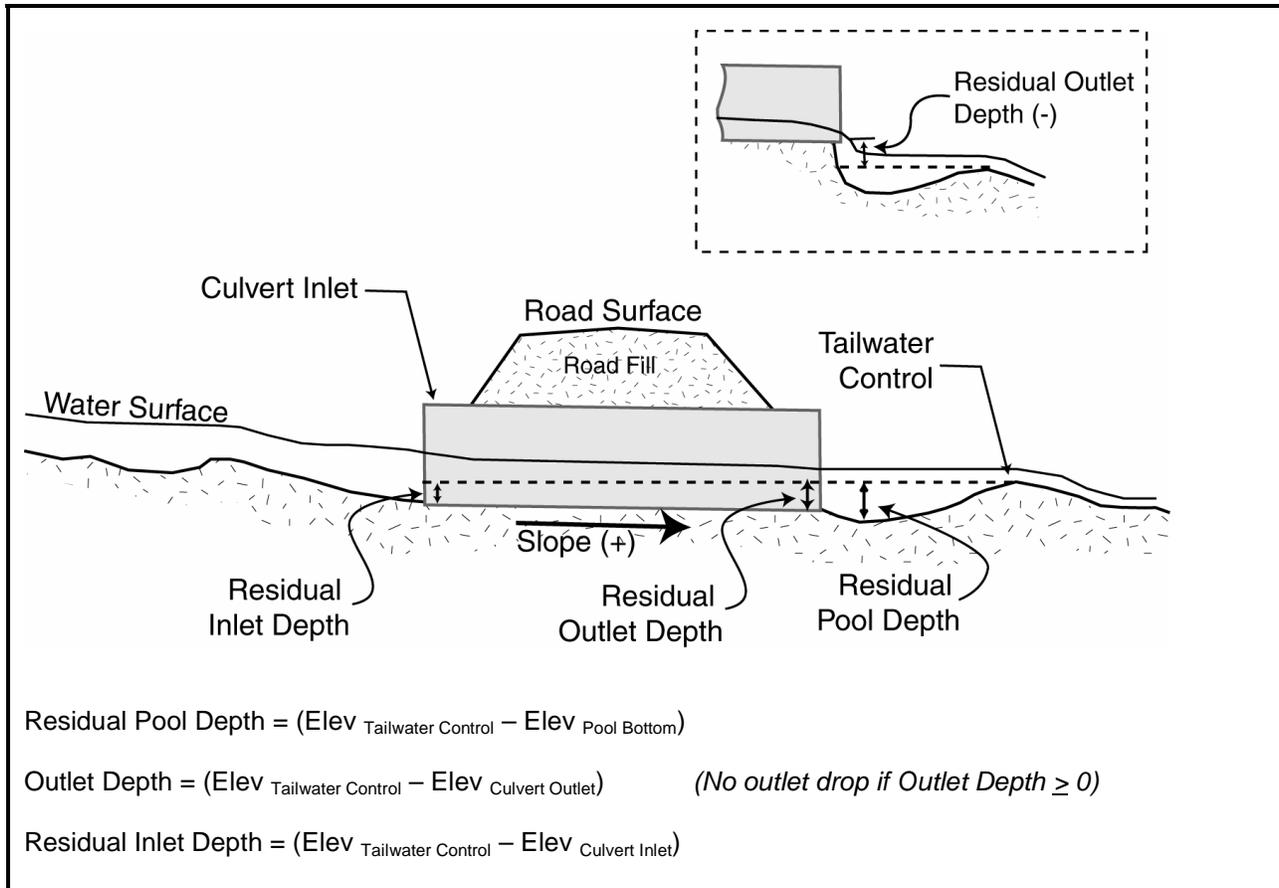


Figure 5. Measurements used in Green-Grey-Red filtering criteria.

Many stream crossings have unique characteristics which may hinder fish passage, yet they are not recognized in the filtering process. For crossings meeting the “Green” criteria, a review of the inventory data and field notes was necessary to ensure no unique passage problems existed before classifying the stream crossings as “100% passable”.

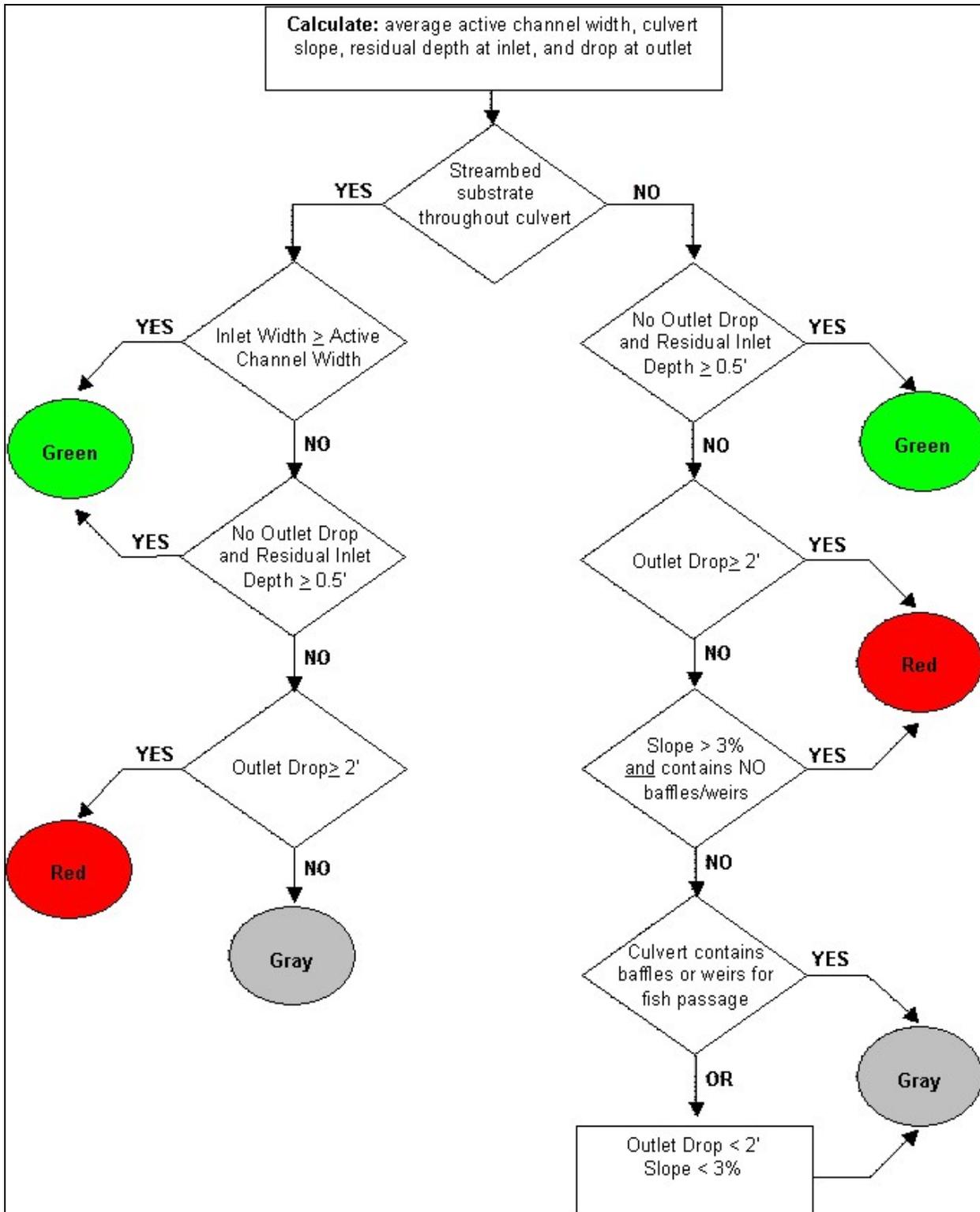


Figure 6. GREEN-GRAY-RED first-phase passage evaluation filter.

NOTE: FishXing Overview, Hydrology and Design Flow, Peak Flow Capacity, and Fish Passage Flows sections were written by Michael Love under a separate contract administered by CDFG (Taylor and Love, 2002).

FishXing Overview

FishXing is a computer software program developed by Six Rivers National Forest's Watershed Interactions Team - a group of scientists with diverse backgrounds in engineering, hydrology, geomorphology, geology and fisheries biology. Mike Furniss, a Forest Service hydrologist for Six Rivers, managed program development. A CD-ROM final version of FishXing was initially released in March of 2000. In-depth information regarding FishXing (and a current version) may be obtained at the Fish Crossing homepage on the Internet at: (www.stream.fs.fed.us/fishxing).

FishXing is an interactive software package that integrates a culvert design and assessment model for fish passage nested within a multimedia educational setting. Culvert hydraulics are well understood and model output closely resembles reality. FishXing successfully models (predicts) hydraulic conditions throughout the culvert over a wide range of flows for numerous culvert shapes and sizes. The model incorporates fisheries inputs including fish species, life stages, body lengths, and leaping and swimming abilities. FishXing uses the swimming abilities to determine whether the culvert installation (current or proposed) will accommodate fish passage at desired range of migration flows, and identify specific locations within the culvert that impede or prevent passage. Software outputs include water surface profiles and hydraulic variables such as water depths and average velocities displayed in both tabular and graphical formats.

FishXing used the survey elevation and culvert specifications to evaluate passage at sites defined as "Gray" by the first-phase evaluation filter for several steelhead life-stages. The swimming abilities and passage criteria used for each steelhead life-stage are listed Table 2. Although many individual fish will have swimming abilities surpassing those listed below, swim speeds were selected to ensure stream crossings accommodate passage of weaker individuals within each age class because of the ESA listing status of steelhead within the Morro Bay watershed.

FishXing and other hydraulic models report the average cross-sectional water velocity, not accounting for spatial variations. Stream crossings with natural substrate or corrugations will have regions of reduced velocities that can be utilized by migrating fish. These areas are often too small for larger fish to use, but can enhance juvenile passage success. The software allows the use of reduction factors that decrease the calculated water velocities proportionally. As shown in Table 2, velocity reduction factors were used in the passage analysis of resident fish and juveniles with specific types of stream crossing structures.

Using the FishXing program, the range of flows that meet the depth, velocity, and leaping criteria for each lifestage were identified. The range of flows meeting the passage requirements were then compared to the lower and upper fish passage flows to determine "percent passable".

Table 2. Fish species and life-stages used in the passage assessment along with associated swimming abilities and passage criteria as recommended in the CDFG protocol. Passage flows are based on current adult salmonid criteria combined with observational data from northern California coastal streams.

Fish Species/Age Class	Adult Steelhead	Resident Trout and 2+ Juvenile Steelhead	Young-of-year and 1+ Juvenile Steelhead
Fish Length	>500mm (≈ 20")	200mm (≈ 8")	80mm (≈ 3")
Prolonged Mode			
Swim Speed	6 ft/sec	4 ft/sec	1.5 ft/sec
Time to Exhaustion	30 min	30 min	30 min
Burst Mode			
Swim Speed	10 ft/sec	5.0 ft/s	3.0 ft/s
Time to Exhaustion	5 sec	5 sec	5 sec
Maximum Leaping Speed	12.0 ft/sec	6 ft/sec	3 ft/sec
Velocity Reduction Factors for Corrugated Metal Culverts **	Inlet = 1.0 Barrel = 1.0 Outlet = 1.0	Inlet = 0.8 Barrel = 0.6 Outlet = 0.8	Inlet = 0.8 Barrel = 0.6 Outlet = 0.8
Minimum Required Water Depth	(1 ft) 0.5 ft	(0.5 ft) 0.4 ft	0.3 ft
Minimum Passage Flow <i>(Use the larger of the two flows)</i>	50% exceedance flow or 3 cfs	90% exceedance flow or 2 cfs	95% exceedance flow or 1 cfs
Maximum Passage Flow	1% exceedance flow	5% exceedance flow	10% exceedance flow

** Velocity reduction factors only apply to culverts with corrugated walls, baffles, or natural substrate. All other culverts had reduction factors of 1.0 for all age classes.

Hydrology and Design Flow

When examining stream crossings that require fish passage, three specific flows are considered: peak flow capacity of the stream crossing, the upper fish passage flow, and the lower fish passage flow. Because flow is not gauged on most small streams, it must be estimated using techniques that required hydrologic information about the stream crossing's contributing watershed, including:

- Drainage area;
- Mean annual precipitation;
- Mean annual potential evapotranspiration; and
- Average basin elevation.

Drainage area and basin elevations were calculated from a 1:24,000 USGS topographic map. Mean annual precipitation (MAP) was estimated by using color shaded average annual precipitation PRISM (parameter-elevation regressions on independent slopes model) climate mapping developed by Oregon State Universities Spatial Climate Analysis Service (SCAS). Potential evapotranspiration (PET) was estimated from regional maps produced by Rantz (1968).

Calculation of Peak Flow Capacity

Peak flows are typically defined in terms of a recurrence interval, but reported as a quantity; often as cubic feet per second (c.f.s.). Current guidelines recommend all stream crossings pass the flow associated with the 100-year flood without damage to the stream crossing (NMFS, 2001). Additionally, infrequently maintained culverted crossings should accommodate the 100-year flood without overtopping the culvert's inlet. Please note that peak flow capacity is only applicable for the sites with culverts.

The primary purpose in determining each crossing's flood capacity was to estimate the risk of failure, which in turn, assisted in ranking sites for remediation. Undersized crossings have a higher risk of catastrophic failure, which often results in the immediate delivery of sediment from the road-fill into the downstream channel. Undersized crossings can also adversely effect sediment transport and downstream channel stability, creating conditions that hinder fish passage, degrade habitat, and may cause damage to other stream crossings, adjacent roadways, and/or private property.

The first step was to estimate hydraulic capacity of each inventoried stream crossing.

Capacity is generally a function of the shape and cross-sectional area of the inlet. Capacity was calculated for two different headwater elevations: water ponded to the top of the culvert inlet ($HW/D = 1$) and water ponded to the top of the road surface ($HW/F=1$). Nomograph equations developed by Piehl et. al (1988) were used to calculate capacity of circular culverts. Federal Highways nomographs presented in Norman et. al (1995) were used for pipe-arches, open bottom arches, oval pipes and box culverts. Capacities of embedded culverts were determined using two hydraulic computer models, FishXing and HydroCulv.

The second step was to estimate peak flows at each crossing. This required estimating the 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year peak flows. Regional flood estimation equations developed by Waananen and Crippen (1977) were used to estimate peak flows for the various recurrence intervals. The equations incorporate drainage area, MAP, and mean basin elevation as variable to predict peak flow in Central Coast California streams.

The third step was to compare the stream crossing's capacity to peak flow estimates. Risk of failure was assessed by comparing a stream crossing's hydraulic capacity with the estimated peak flow for each recurrence interval. Each crossing was placed into one of six "sizing" categories:

1. equal to or greater than the 100-year flow,
2. between the 50-year and 100-year flows,
3. between the 25-year and 50-year flows,
4. between the 10-year and 25-year flows,
5. between the 10-year and 5-year flows.

6. less than the 5-year storm flow.

These six categories were utilized in the ranking matrix to assign a sizing (or risk of failure) score for each site with a culvert.

Calculation of Fish Passage Flows

It is widely agreed that designing stream crossings to pass fish at all flows is impractical (CDFG 2002; NMFS 2001; Robison et al. 2000; SSHEAR 1998). Although anadromous salmonids typically migrate upstream during higher flows triggered by hydrologic events, it is presumed that migration is naturally delayed during larger flood events. Conversely, during low flow periods on many smaller streams water depths within the channel can become impassable for both adult and juvenile salmonids. To identify the range of flows that stream crossings should accommodate for fish passage, lower and upper flow limits have been defined specifically for streams within California (CDFG 2002; NMFS 2001).

To evaluate the extent to which a crossing is a barrier, passage was assessed between the lower and upper passage flows for each fish species and life-stage of concern. Calculating the exceedence flows required obtaining average daily stream flow data from gauged streams. Daily average flow data for San Luisito Creek, San Bernardo Creek, and Chorro Creek were available from the San Luis Obispo County Public Works.

The following steps were followed to estimate upper and lower passage flows:

1. Obtained flow records from local stream gauges that met the following requirements:
 - At least five years of recorded daily average flows (do not need to be consecutive years);
 - A drainage area less than 100 square miles, and preferably less than 10 square miles; and,
 - Unregulated flows (no upstream impoundments or water diversions) during the migration season is desired.
2. Divided the flows (Q) for each gauged stream by its drainage area (A), resulting in units of cfs/mi².
3. Created regional flow duration curve by taking the median of the exceedence flows (Q/A) of the gauged streams (Appendix C).
4. Determined the upper and lower passage flows for each stream crossing using the regional flow duration curve and the drainage area upstream of a given stream crossing.

When analyzing fish passage with FishXing, these flows were used to determine the extent to which the crossing is a barrier. The stream crossing must meet water velocity and depth criteria between Q_{lp} and Q_{hp} to be considered 100% passable (NMFS 2001). For the ranking matrix, at each stream crossing, the extent of the migration barrier was determined for each salmonid species and life-stage presumed present.

Sacramento Pike Minnow Passage

In-depth passage assessments of Sacramento pike minnow (*Ptychocheilus grandis*) were not conducted for the 12 sites. However, a discussion regarding the swimming and leaping capabilities of pike minnow and the difficulties of feasibly modifying the existing stream crossings to provide adequate passage for steelhead at the 100% exclusion of pike minnow into Chorro Creek's tributaries is included in the Results section.

Habitat Information

Assessment of habitat conditions upstream and downstream of surveyed sites on Pennington Creek, Dairy Creek and Chorro Creek relied on recently conducted habitat typing surveys (Huber 2001 a-c). Key indicators of habitat quality (embeddedness, pool frequency, pool depths, and summer water temperatures) from the surveys were summarized in the *Steelhead Restoration Planning Project* (Dvorsky, 2002). The habitat typing surveys also provided information on past, present, and future land uses. Unfortunately, no information was available to accurately assess the quantity and quality of habitat in San Bernardo and San Luisito Creeks due to lack-of-access permission through several private properties.

Professional judgment from on-site inspection of stream habitat within the vicinity of the surveyed sites also aided assessing habitat quality. In some cases, longer reaches of stream were walked to better assess quality of habitat above and below each surveyed site. However, these short reaches, relative to the large amounts of potential upstream habitat, offered limited insight to the aquatic and riparian habitat potential within San Bernardo and San Luisito Creeks.

Length of potential salmonid habitat upstream of each site was determined from completed survey reports or was estimated off of digitized USGS 7.5 Minute Series topographic maps (Terrain Navigator, Version 3.01 by MapTech). The upper limit of anadromous habitat was considered when the stream channel exceeded an eight degree slope. Lengths of anadromy estimated from topographic maps were utilized in the ranking matrix only for San Bernardo and San Luisito Creeks because of the lack of stream survey data.

The presence and location of additional stream crossings, dams, and other potential impediments, above and below each site was also considered when evaluating potential habitat gains. These sites were either identified from completed habitat typing surveys, topographic maps, or discussions with people familiar with the Chorro Creek watershed (Hardy, Highland, McEwen and Root; pers. comm.). In many cases, additional stream crossings existed that were either private, city, state, or federal. Many of these sites were known bridges that already provide adequate fish passage, thus they were excluded from this inventory.

Initial Ranking of Stream Crossings for Treatment

The ranking objective was to arrange the sites in an order from high to low priority using a suite of site-specific information. However, the “scores” generated were not intended to be absolute in deciding the exact order of scheduling treatments. Once the first-cut ranking (based solely on five scored criteria) was completed, professional judgment played an important part in deciding the order of treatment. As noted by Robison et al. (2000), numerous social and economic factors may often influence the exact order of treating sites.

Because the CSLRCD intends on facilitating the treatment of sites identified as “high-priority” by submitting proposals to various fisheries restoration funding sources, additional opportunities for re-evaluating the biological merit of potential projects will occur through proposal review committees composed of biologists from CDFG and other agencies. The methods for ranking fish passage impediments for treatment is a developing process and will undoubtedly require refinement as additional information is obtained.

This report also acknowledges (but makes no attempt to quantify or prioritize) that other potentially high-priority restoration projects exist in the Morro Bay watershed and throughout California, and these must all be considered when deciding where and how to best spend limited restoration funds. However, recent research regarding watershed restoration considers the identification, prioritization, and treatment of human-made migration barriers to restore ecological connectivity for salmonids a vital (and often initial) step towards recovering depressed populations (Roni et al. 2002).

Ranking Criteria

The criteria and scoring for ranking stream crossings were mostly consistent with those developed for Part 10 of CDFG’s *Salmonid Stream Habitat Restoration Manual* (Taylor and Love, 2002). The CDFG method assigns a score or value for the following criteria at each culvert location and the total score is the sum of five criteria: species diversity, extent of barrier, sizing, current condition, and habitat score.

For the Morro Bay project, we deviated from the CDFG scoring system with the habitat quantity criteria. The CDFG method caps a maximum limit of habitat quantity at 10,000’, or 10 points. The rationale for creating an upper limit was that in previously analyzed data sets with more crossings, having no quantity limit tended to over-weight total scores of sites with large habitat gains, regardless of the quality of the habitat and/or the severity of the barrier. Because there were only 12 sites to rank for the Morro Bay assessment and that 10 of the 12 sites had more than 10,000 feet of potential upstream habitat, the cap was lifted on habitat quantity to better compare sites based on the actual amount of upstream habitat gains possible.

1. **Species diversity:** number of salmonid species known to occur (or historically occurred) within the stream reach at the culvert location. **Score:** Because of ESA listing status as threatened steelhead in the South/Central Coast ESU = **2** points. **Maximum score = 2 points.**

2. **Extent of barrier:** for each of the three groups of steelhead life-stages, over the range of estimated migration flows, assign one of the following values. **Score: 0** = 80-100% passable; **1** = 60-80% passable; **2** = 40-60% passable; **3** = 20-40% passable; **4** = less than 20% passable; **5** = 0% passable (RED by first-phase evaluation filter). For a total score, sum scores given for each life-stage group: adult steelhead, resident trout/2+ juveniles, and young-of-the-year and 1+ juveniles. **Maximum score = 15 points.**

3. **Sizing (risk of failure):** for each crossing, assign one of the following values as related to flow capacity. **Score: 0** = sized to NMFS standards of passing 100-year flow at less than inlet height. **1** = sized for at least a 50-year flow, low risk. **2** = sized for at least a 25-year flow, moderate risk. **3** = sized for less than a 25-year flow, moderate to high risk of failure. **4** = sized for less than a 10-year event, high risk of failure. **5** = sized for less than a five-year event, high risk of failure. **NOTE:** not applicable to the three dams and the natural waterfall, these four sites were scored “0” for sizing.

4. **Current condition:** for each crossing, assign one of the following values. **Score: 0** = good condition. **1** = fair, showing signs of wear. **3** = poor, floor rusting through, crushed by roadbase, etc. **5** = extremely poor, floor rotted-out, severely crushed, damaged inlets, collapsing wingwalls, slumping roadbase, etc. **NOTE:** not applicable to the natural waterfall, this site was scored “0” for sizing.

5. **Habitat quantity:** above each crossing, length in feet to sustained 8% gradient. **Score:** Starting at a 500’ minimum; 0.5 points for each 500’ length class (**example: 0** points for <500’; **1** point for 1,000’; **2** points for 2,000’; **3.5** points for 3,500’; and so on). **No maximum score.**

6. **Habitat quality:** for each stream, assign a “multiplier” of quality (relative to other streams in inventory) after reviewing available habitat information.
 - **Score: 1.0 = Excellent-** Relatively undeveloped, “pristine” watershed conditions. Habitat features include dense riparian zones with mix of mature native species, frequent pools, high-quality spawning areas, cool summer water temperatures, complex in-channel habitat, and/or channel floodplain relatively intact. High likelihood of no future human development. Presence of migration barrier(s) is obviously the watershed’s limiting factor.
 - **0.75 = Good-** Habitat is fairly intact, but human activities have altered the watershed with likelihood of continued activities. Habitat still includes dense riparian zones of native species, frequent pools, spawning gravels, cool summer water temperatures, complex in-channel habitat, and/or channel floodplain relatively intact. Presence of migration barrier(s) is most likely one of the watershed’s primary limiting factor.
 - **0.5 = Fair-** Human activities have altered the watershed with likelihood of continued (or increased) activities, with apparent effects to watershed processes and features. Habitat impacts include riparian zone present but lack of mature native species and/or presence of non-native species, infrequent pools, sedimentation evident in spawning areas (pool tails and riffle crests), summer water temperatures periodically exceed stressful levels for salmonids,

sparse in-channel complex habitat, floodplain intact or slightly modified). Presence of migration barrier(s) may be one of the watershed's limiting factor (out of several factors).

- **0.25 = Poor-** Human activities have drastically altered the watershed with high likelihood of continued (or increased) activities, with apparent effects to watershed processes. Habitat impacts include riparian zones absent or severely degraded, little or no pool formations, excessive sedimentation evident in spawning areas (pool tails and riffle crests), stressful to lethal summer water temperatures common, lack of in-channel habitat, floodplain severely modified with levees, riprap, and/or residential or commercial development. Other limiting factors within watershed are most likely of a higher priority for restoration than remediation of migration barriers.

7. **Total habitat score:** Multiply #5 by #6 for habitat "score". A multiplier assigned for habitat quality, weighs the final score more on quality than sheer quantity of upstream habitat. **Maximum score = 10 points.**

For each site, the five ranking criteria were entered into a spreadsheet and total scores computed. Then the list was sorted by "Total Score" in a descending order to determine an initial ranking. On closer review of the rank, some professional judgment was used to adjust the rank of several sites. The list was then divided subjectively into groups defined as "high", "medium", or "low" priority.

The high-priority sites were generally characterized as complete migration barriers with significant amounts of upstream habitat. Medium-priority sites were characterized as limited in upstream habitat gains, limited species diversity and/or were partial or temporal barriers to salmonid migration. Low-priority sites were limited in upstream habitat, habitat condition was poor, the site was a natural feature, and/or the site allowed passage of adults and most juveniles.

Remediation of culvert sites identified as "high-priority" should be accomplished by submitting proposals to various fisheries restoration funding sources. The information provided in this report should be used to document the logical process employed to identify, evaluate, and rank these migration barriers.

Additional Considerations for Final Ranking

On a site-specific basis, one or both of these factors were considered in rearranging the first-cut ranking to develop a final list for project scheduling:

1. Presence, location, and barrier status of other sites. In many cases, an individual stream was crossed by multiple roads under a variety of management or ownership. In these situations, close communication with various road managers and property owners is important. If multiple crossings are migration barriers a coordinated effort is required to identify and treat them in a logical manner – generally in an upstream direction starting with the lowermost crossing or impediment, regardless of total score.

In other cases, two migration barriers were close together and treatment of just the lower site would open-up only a very short reach of habitat – in these cases, it is often prudent to treat the sites concurrently or in consecutive construction seasons. Adjacent sites, when treated concurrently, may also be planned for construction under a single set of permits which saves time and money, as well as lessens impacts to the stream channel and aquatic biota.

2. Remediation project cost. In some cases, the window of migration can be significantly improved with a minor retrofit or treatment to a site. For example, a low-elevation dam on a small creek that acts as a partial/temporal barrier could be partially removed in several hours with volunteer labor and hand tools. These sites should be identified and treated quickly because of the immediate benefit at a very low cost. These small projects can also be orchestrated to involve the local community and serve further benefit as an educational experience.

RESULTS

Initial Site Visits

Initial site visits were conducted at 12 locations with potential migration barriers between November 20–25, 2002. These sites included eight stream crossings, three low-elevation dams, and a natural waterfall. A total of 17 longitudinal surveys were completed and included in the evaluation and ranking process because a longitudinal survey was shot for each barrel at sites with multiple pipes and/or bays (Appendix A). One crossing was comprised of three pipe-arch culverts (San Bernardo Creek #1) and two sites were two-bay concrete box culverts (San Luisito Creek #1 and #2).

The 12 surveyed sites were each given a unique ID number that was determined in an upstream direction starting in the lower Chorro Creek watershed (Table 3). Spreadsheets of the 12 sites inventoried with their location, characteristics, and survey data are provided in Appendix A. Site-specific characteristics, site photographs, maps, and habitat descriptions for the 12 sites evaluated are provided in a *Catalog of Stream Crossings and Passage Impediments* (Appendix B).

Table 3. Site ID numbers for 12 Chorro Creek stream crossings and potential migration barriers.

SITE ID #	STREAM NAME	ROAD NAME/SITE LOCATION	SITE DESCRIPTION
#8	San Bernardo Creek #1	Private Drive	Pipe-arch culverts (3 barrels)
#9	San Bernardo Creek #2	Private Drive	Concrete box culvert (single bay)
#18	San Bernardo Creek #3	Private Drive	Circular culvert (single barrel)
#1	San Luisito Creek #1	Highway One	Concrete Box culvert with apron (2 bays)
#2	San Luisito Creek #1	Adobe Road	Concrete Box culvert with apron (2 bays)
#13	Pennington Creek	Highway One	Concrete box culvert with baffles (single bay)
#3	Dairy Creek #1	Highway One	Concrete box culvert (single bay)
#4	Dairy Creek #2	El Chorro Regional Park	Circular culvert (single barrel)
#11	Dairy Creek #3	El Chorro Regional Park	Low-elevation dam – rock and mortar set on bedrock
#14	Chorro Creek #1	Camp SLO near Kern Avenue	Low-elevation dam – rock and mortar set on bedrock
#5	Chorro Creek #2	Camp SLO near Highway One	Natural bedrock waterfall
#7	Chorro Creek #3	California Men’s Colony	Low-elevation dam with low-flow notch – sewer pipe encasement

Hydraulic Capacity

Hydraulic capacity was estimated only for the eight crossings with culverts (Table 4). Two sites (#8 and #4) were extremely undersized and overtopped on less than a 10-year storm flow. San Bernardo Creek #1 was sized for conveying only the four-year storm flow, however the crossing was designed to overtop with a concrete-hardened road prism and a sloped road-approach from both directions. At Dairy Creek #2 in El Chorro Regional Park an obvious debris line and fill-slope scour was observed on the downstream side of the culvert where the creek had recently over-topped the road prism.

Table 4. Hydraulic capacity of eight Morro Bay watershed stream crossings. Capacity is expressed as both a discharge (cfs) and a return-interval (years) for flows overtopping culvert inlet (HW/D=1) and overtopping road prism (HW/F=1).

Site ID #	Stream Name	Road Name	Capacity at HW/D=1 (c.f.s.)	Capacity at HW/F=1 (c.f.s.)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
#8	San Bernardo Creek #1	Private Drive	84	90	4	4
#9	San Bernardo Creek #2	Private Drive	1,876	2,197	>250	>250
#18	San Bernardo Creek #3	Private Drive	633	1,017	18	51
#1	San Luisito Creek #1	Highway One	1,632	3,240	59	>250
#2	San Luisito Creek #2	Adobe Road	1,632	2,184	60	173
#13	Pennington Creek	Highway One	1,137	2,299	>250	>250
#3	Dairy Creek #1	Highway One	1,116	2,256	>250	>250
#4	Dairy Creek #2	El Chorro Regional Park	177	224	8	10

Passage Analyses

The **GREEN-GRAY-RED** first-phase evaluation filter reduced the number of sites requiring in-depth analyses with FishXing. No sites were defined as **GREEN** with the first-phase evaluation filter. Nine of 17 surveyed pipes/bays/dams/natural features (53%) were defined as **RED**, or failing to meet CDFG's fish passage criteria for adult and juvenile steelhead throughout the entire range of migration flows (CDFG 2002). It is important to note that a surveyed location which failed to meet the criteria may still actually provide partial or temporal passage during certain flow conditions because CDFG's criteria were set at conservative values to account for weaker swimming individuals for any given life-stage of steelhead because of the species' federal ESA-listing status. However, for evaluation purposes, all **RED** sites were given a "total barrier" score in the ranking matrix.

FishXing proved an extremely useful tool in estimating the extent of passage at the seven **GRAY** sites and identifying the probable causes of blockages. However, like most models which attempt to predict complex physical and biological processes with mathematics, there were limitations to the software and occasionally assumptions are made regarding site-specific influences on tail-water elevation. The "Comments" column in Appendix C lists assumptions made concerning specific sites while running FishXing

At each site, three FishXing evaluations were completed for several life-stages of steelhead: an "adult" run was conducted for anadromous adults, resident coastal rainbow trout and two-year old (2+) steelhead were grouped as the "resident trout" run, and one-year old (1+) and young-of-the-year (y-o-y) steelhead were grouped as the "juvenile" run.

Passage results generated by FishXing are displayed as "percent passable" for the range of migration flows calculated for each barrel or bay of 12 culverts at eight stream crossing locations (Figures 7). The three dams and the natural waterfall on Chorro Creek were evaluated for passage based primarily on the drop height and pool depth below each structure/feature (Figure 8). For each **GRAY** site, by species and life-stage, FishXing evaluation results are provided in Appendix C.

Passage evaluation results generated by FishXing were used conservatively in the ranking matrix by lumping "percent passable" into large (20%) categories (Appendix D).

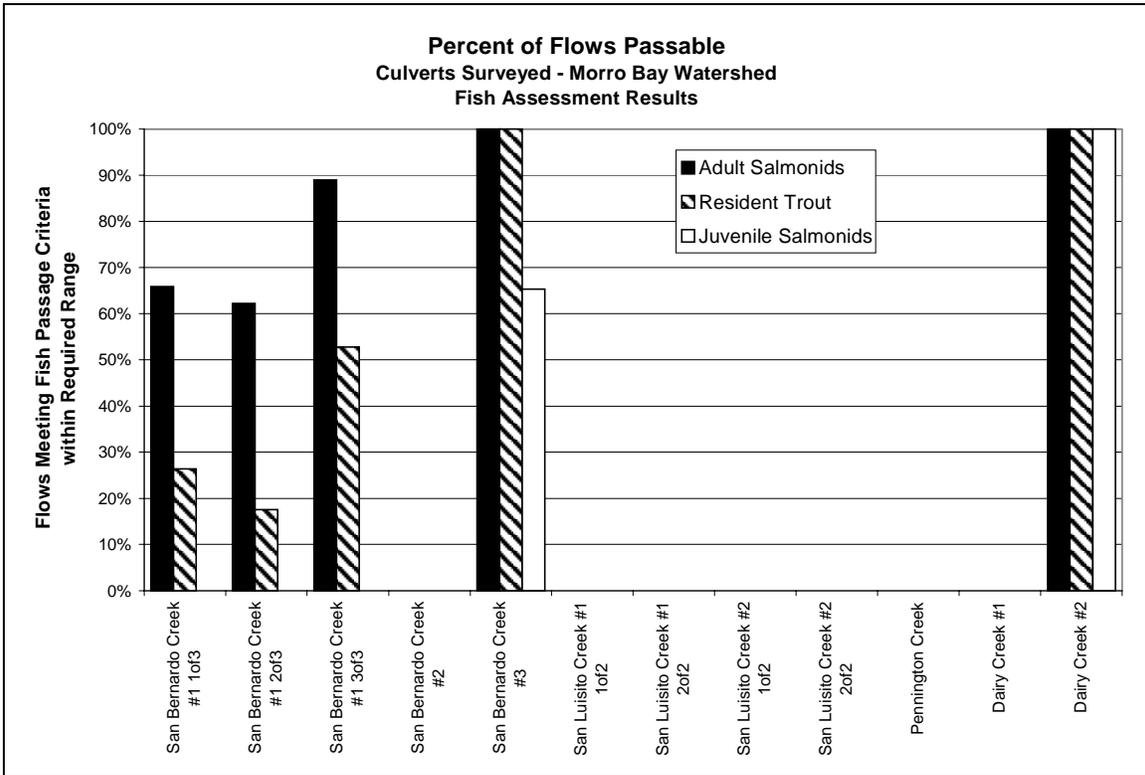


Figure 7. Percent passable estimated by the Green-Gray-Red evaluation filter and FishXing for 12 culvert barrels and bays at eight stream crossings within the Chorro Creek (Morro Bay watershed), by life stages.

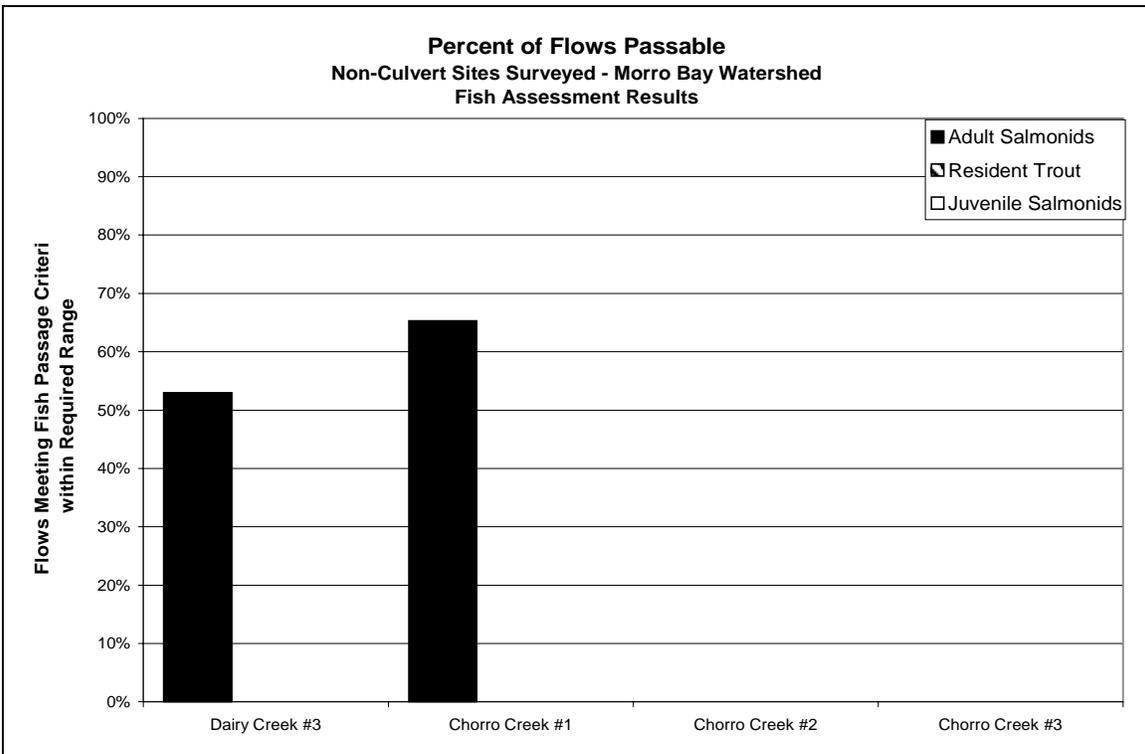


Figure 8. Percent passable as estimated by the Green-Gray-Red evaluation filter and FishXing for three dams and a natural waterfall (Chorro Creek #2) within Chorro Creek (Morro Bay watershed), by life stages.

Ranking Matrix

For the habitat quality modifier value Upper Chorro Creek, Dairy Creek, and Pennington Creek were considered as providing (or having the potential to provide) good-quality spawning and rearing habitat for steelhead and each received a score of **0.75**. San Bernardo Creek was scored a **0.5** and was considered to have fair-quality habitat as judged by driving San Bernardo Creek Road and assessing several hundred feet of channel upstream and downstream of the three sites. San Luisito Creek also was scored a **0.5** and was considered to have fair-quality spawning and rearing habitat, however little is known about San Luisito Creek, and this may be an inaccurate assessment of the habitat quality (Hardy and Highland, pers. comm.). San Luisito Creek currently has the most reliable, continuous summer flows of Chorro Creek’s four main tributaries and may actually deserve a habitat quality score of **0.75**.

The 12 Morro Bay watershed stream crossing locations were initially ranked in a descending by “Total Score”, the sum of the five ranking criteria (Appendix D). The final ranked list of the Morro Bay watershed sites reflects changes made due to professional judgment (Table 5). The 12 ranked sites were subjectively defined as four high-priority sites, two moderate-priority, and six low-priority sites (Figure 9).

Table 5. Ranking for 12 fish passage locations on the Morro Bay watershed.

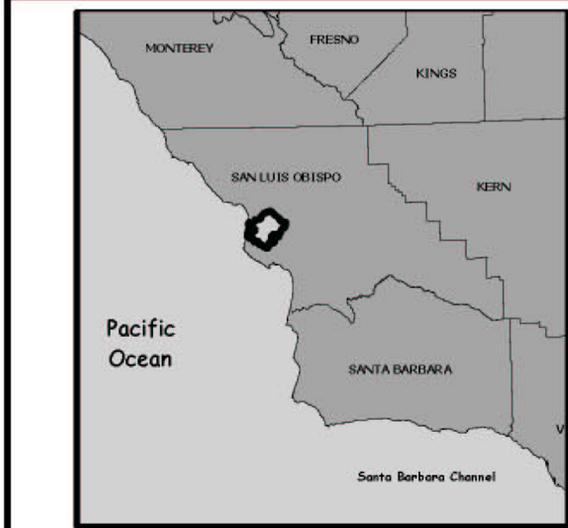
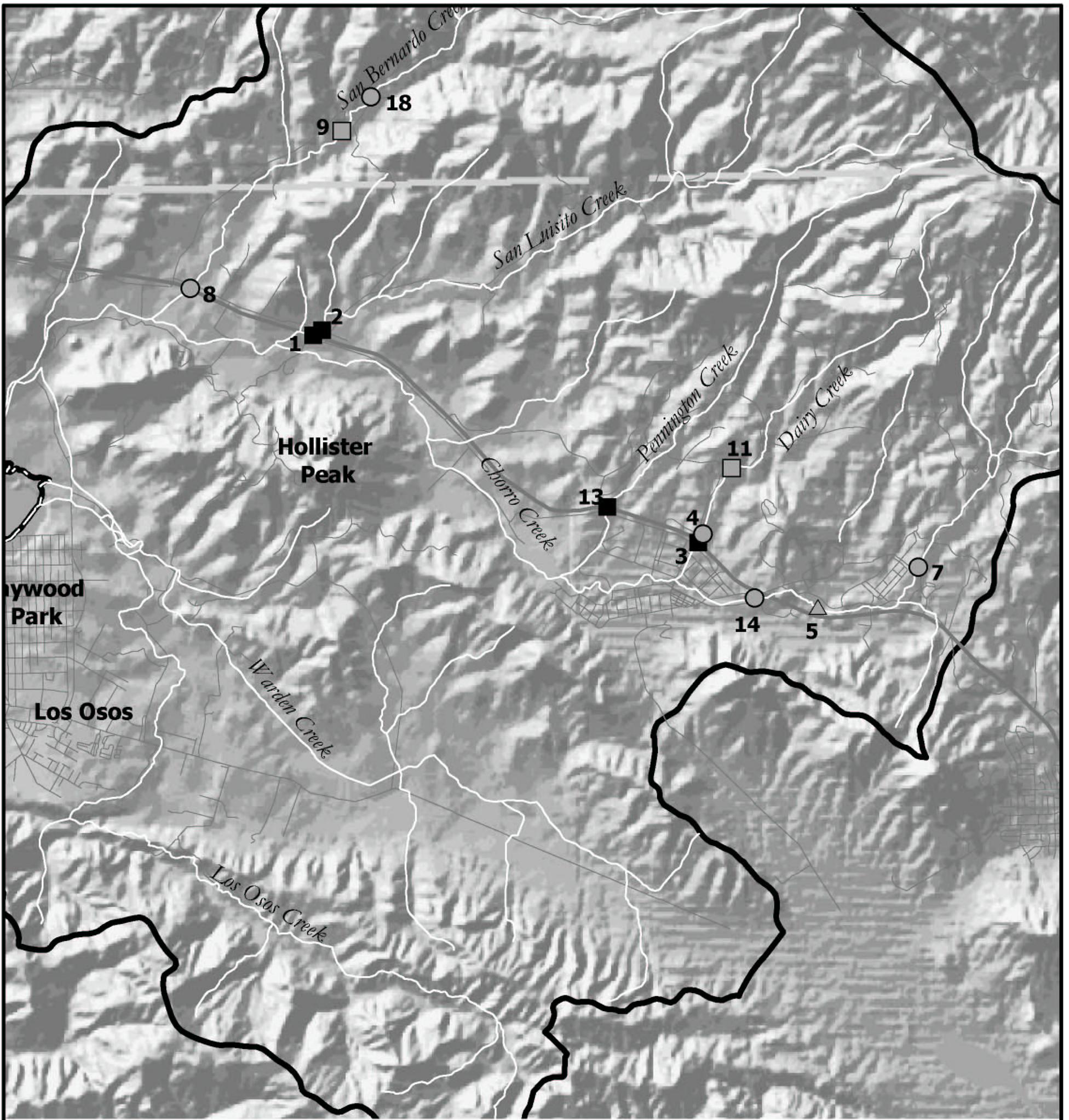
Final Rank	Stream Name and Site ID#	Road or Location Name	Initial Rank	Comments to Final Ranking
#1	Pennington Creek (Site ID#13)	Highway One	1 st	High-priority due to: severity of the barrier = “RED” for all steelhead life-stages and quality and quantity of upstream habitat (nearly four miles). Middle and upper reaches have good-quality, year-round surface flow (Highland, pers. comm.). The upstream habitat is in public ownership and there is a low likelihood of future development and degradation of the aquatic habitat. The current set of 55 off-set baffles appears ineffective due to large amounts of sediment that continually fill the baffles on winter storms. When the baffles fill, the stream flow is then diverted to the un-baffled side of the culvert causing shallow sheet flow and excessive velocities. It is recommended that the off-set baffles are removed and a series of sloped concrete weirs are installed with the expectation of becoming embedded with substrate. CalTrans should consult with CDFG and NMFS hydraulic engineers to develop a soundly-designed retrofit.
#2	San Luisito Creek #1 (Site ID#1)	Highway One	Tied for 3 rd	High-priority due to: severity of the barrier = “RED” for all steelhead life-stages and quality and quantity of upstream habitat (nearly five miles). Migration is severely impeded by the perched and steeply sloped outlet apron and the wide, smooth bays of the box culvert. The upstream habitat is privately owned and little is known about the quality of habitat – however, San Luisito Creek has good year-round flow even in drought years (Highland, pers. comm.). It is recommended that CalTrans consult with CDFG and NMFS hydraulic engineers to develop a soundly-designed retrofit to raise tail-water elevation, increase depths + decrease velocities within the culvert. Treat site concurrently with Site ID #2 because of the proximity of the two crossings.

Table 5. Ranking for 12 fish passage locations on the Morro Bay watershed.

Final Rank	Stream Name and Site ID#	Road or Location Name	Initial Rank	Comments to Final Ranking
#3	San Luisito Creek #2 (Site ID#2)	Adobe Road	Tied for 3 rd	High-priority due to: severity of the barrier = “RED” for all steelhead life-stages and quality and quantity of upstream habitat (nearly five miles). Migration is severely impeded by the perched outlet apron and the wide, smooth bays of the box culvert. The upstream habitat is privately owned and little is known about the quality of habitat – however, San Luisito Creek has good year-round flow even in drought years (Highland, pers. comm.). It is recommended that the SLO County Public Works Department consult with CDFG and NMFS hydraulic engineers to develop a soundly-designed retrofit to raise tail-water elevation, increase depths + decrease velocities within the culvert Treat site concurrently with Site ID #1 because of the proximity of the two crossings.
#4	Dairy Creek #1 (Site ID#3)	Highway One	2 nd	High-priority due to: severity of the barrier = “RED” for all steelhead life-stages and quality and quantity of upstream habitat (nearly four miles). Dropped slightly in final ranking due to tendency of Dairy Creek to go dry in some years. The culvert is sloped at nearly 4% over a 123-foot length causing shallow sheeting at lower flows and excessive velocities at higher migration flows. The upstream habitat is in public ownership and there is a low likelihood of future development and degradation of the aquatic habitat. It is recommended that a series of sloped concrete weirs are installed to create a fish ladder through the culvert. Sediment retention may not occur due to culvert’s >3% slope. Additional weirs are recommended downstream of the outlet to raise the tail-water elevation. CalTrans should consult with CDFG and NMFS engineers to develop a soundly-designed retrofit.
#5	San Bernardo Creek #2 (Site ID#9)	Private Drive	7 th	Moderate-priority (and raised in final rank) due to: severity of the barrier= “RED” for all steelhead life-stages – culvert has a 1.6’ drop over the inlet onto a 4% sloped concrete floor. There is nearly two miles of habitat upstream of the crossing. The upstream habitat is privately owned and little is known about the quality of habitat – however, the upper reaches of San Bernardo Creek have good year-round flow even in drought years (Highland, pers. comm.). A full replacement with a flat-car bridge on new abutments is recommended. Bridge must be wide enough to handle truck traffic to and from the active dairy/ranch located on the private property.
#6	Dairy Creek #3 (Site ID#11)	El Chorro Regional Park	Tied for 4 th	Moderate-priority due to: severity of the barrier = “GRAY” adult steelhead (passable on 53% of migration flows) and “RED” for all juvenile age-classes. There is approximately 3.2 miles of good-quality habitat upstream of this dam. Upstream juvenile passage may be important as lower reaches of Dairy Creek dry-up in low-water years. The dam could be removed over a several year span to allow a gradual metering of the sediment stored on the upstream side. This treatment is inexpensive and could be accomplished with volunteers and hand-tools. A more expensive option would entail removal of dam with heavy equipment and re-grading channel slope, including the removal of sediment stored on the upstream side of the dam.

Table 5. Ranking for 12 fish passage locations on the Morro Bay watershed.

Final Rank	Stream Name and Site ID#	Road or Location Name	Initial Rank	Comments to Final Ranking
#7	Chorro Creek #1 (Site ID#14)	Camp SLO	5 th	Low-priority due to: severity of the barrier = “GRAY” adult steelhead (passable on 65% of migration flows) and “RED” for all juvenile age-classes. There is approximately 3.2 miles of good-quality habitat upstream of this dam. The dam should be removed over a several year span to allow a gradual metering of the sediment stored on the upstream side. Treatment of this site is inexpensive and could be accomplished with volunteers and hand-tools.
#8	San Bernardo Creek #1 (Site ID#8)	Private Drive	6 th	Low-priority due to: although there is approximately 4.2 miles of upstream habitat, the three culverts at this crossing provide good passage for adult and 2+ age-classes of steelhead. The crossing is severely under-sized, but was designed to overtop. If this site fails or is damaged by storm flows, a full replacement with a properly sized open-bottom arch or bridge is recommended.
#9	Chorro Creek #3 (Site ID#7)	California Men’s Colony	8 th	Low-priority due to: although “RED” as determine by the first-phase filter, most adult steelhead can probably pass over this feature – especially if they were athletic enough to negotiate the falls at Site ID #5. Some 2+ juveniles can probably also clear the 2.3’ residual leap height. There is approximately 5,400 feet of good-quality habitat upstream of this dam. Removal of the structure may not be feasible due to water and sewer lines that run under the structure (Highland, pers. comm.). Passage could be improved by widening the structure’s current low-flow notch in a v-sloped manner. Treatment of this site would be inexpensive.
#10	Dairy Creek #2 (Site ID#4)	El Chorro Regional Park	9 th	Low-priority due to: the culvert at this site provides good passage for all age classes of steelhead. However, the stream channel immediately upstream of the culvert inlet is lined with boulders/rip-rap. It is recommended that the boulders at the inlet are reconfigured to reduce the drop and the potential for turbulence at migration-level flows. If this site fails or is damaged by storm flows, a full replacement with a properly sized open-bottom arch or bridge is recommended.
#11	San Bernardo Creek #3 (Site ID#18)	Private Drive	10 th	Low-priority due to: the culvert at this site provides good passage for all age classes of steelhead. It is recommended that this site is periodically inspected for condition and performance. The inlet should be kept clear of storm debris and the outlet should be inspected for scour and potential development of a perched drop.
#12	Chorro Creek #2 (Site ID#5)	Camp SLO	Tied for 4th	Low-priority (and dropped in final rank) due to: this site is most likely a natural feature and is probably passable by some adult steelhead under some flow conditions. There is less than a six-foot difference in elevation between the lip of the falls and the plunge-pool’s tail-water control. Speculation has been made that Chorro Creek was re-aligned to this location when Highway 1 was constructed (Highland, pers. comm.). CalTrans’ records should be searched to confirm or refute the validity of this suggestion. If falls are not natural, then remediation may be warranted to reduce the height of falls.



Regional Location Map

FIGURE 9
Migration Barriers

LEGEND

Passage Priority

- - High
- ◻ - Medium
- ▲ - Low
- - Low to None

▬ Streams

▬ Highway 1

▬ Arterial Roads

▭ Watershed Boundary

N

0.5 0 0.5 1 1.5 2 Miles

Evaluation of Sacramento Pike Minnow Passage as Related to Remediation of Steelhead Barriers

The *Steelhead Restoration Planning Project* final report summarized the unfortunate introduction of Sacramento pike minnow into the Chorro Creek watershed and the subsequent impacts to the already depressed native steelhead population (Dvorksy, 2002). There have been recommendations to assess the feasibility of modifying migration barriers on Chorro Creek tributaries to allow for an acceptable level of adult steelhead passage, at the 100% exclusion of Sacramento pike minnow. This proposal was most likely based on the assumption that there are considerable differences in the physical abilities of steelhead and pike minnow, with pike minnow as the significantly weaker species. To assess the validity of this assumption, a literature search was conducted to glean information regarding the swimming and leaping capabilities of Sacramento pike minnow.

An exhaustive Internet literature search yielded limited information regarding the leaping and swimming abilities of Sacramento pike minnow or of other sub-species such as the Colorado pike minnow (*Ptychocheilus lucius*) and Northern pike minnow (*P. oregonensis*). Myrick and Cech (2000) investigated the swimming performance of Sacramento pike minnow and three other native non-game fish as related to water temperature. Kolok and Farrell (1994) studied individual variation in swimming and cardiac performance of Northern pike minnow. Both studies determined critical swimming velocities for pike minnow, also defined as maximum prolonged swimming speed. Unfortunately, neither study provided swim-test data on burst speed or exit velocity capabilities. However, the critical swim speeds determined in both studies indicate that pike minnow were excellent swimmers that can swim in a prolonged-mode for extended periods of time. Stronger individuals within a sample of 15 pike minnows with an average length of 30.9 cm ($\approx 12''$) had critical swim speeds of 2.7 feet per second (Kolok and Farrell 1994). These fish were tested by swimming against a flow in a controlled flume where velocities were increased in 0.3 ft/sec increments every 20 minutes until the fish were unable to maintain position in the flume. To reach a critical swimming speed 2.7 feet per second, individual fish swam continuously in a prolonged mode for approximately 120 minutes at 16°C and 100 minutes at 10°C (Kolok and Farrell 1994).

Kolok and Farrell (1994) also indicated that rainbow trout and Northern pike minnow have similar swimming abilities by the following passage in their discussion, "*Species with similar performance capabilities do not necessarily rely on HR (heart-rate) or SV (stroke volume) to the same degree; for example, the rainbow trout relies primarily on SV to increase Q (critical swim speed), while the northern squawfish at 16°C relies almost equally on HR and SV*".

Empirical data of water velocities measured at points through the Redlands Diversion Dam Fish Passageway designed for ESA-listed Colorado pike minnow on the Gunnison River were provided by the Region 6 USFWS Office in Grand Junction, Colorado (Burdick, pers. comm.)(Table 6). The fish passage facility was operational in 1996, was monitored closely with a fish trap at the top of the ladder, and passed 46 Colorado pike minnow in the first four years of operation ranging in lengths of 380 – 760 mm or 15'' – 30'' (Burdick, pers. comm.).

Table 6. Target design velocities and actual measured velocities at the Redlands diversion dam fish passageway located on the Gunnison River.

Location in Baffles	Target Design Velocity (ft/s)	Measured Velocity (ft/s)
Orifice - baffle #3	2.2	2.7 – 3.3
Orifice - baffle #24	2.2	2.3 – 2.7
Orifice - baffle #42	2.2	2.3 – 3.3
Slot – baffle #3	2.7	2.95 – 3.5
Slot – baffle #24	2.7	2.9 – 3.2
Slot – baffle #42	2.7	2.3 – 3.2

No published information was available regarding the leaping ability of Sacramento pike minnow, however the hatchery manager at Van Arsdale Dam on the Eel River has observed numerous pike minnow moving easily up the hatchery ladder designed for adult chinook salmon and steelhead. The hatchery manager considered pike minnow “excellent leapers” (Highland, pers. comm.).

Finally, assumptions of pike minnow as strong swimmers with ample burst speed can be made when one considers the life-history of Sacramento pike minnow and their habitat utilization in their native watersheds as described in Moyle (1976). Although described as rather sedentary and preferring deep pools with slower water velocities, regular upstream migrations are made for spawning and feeding during high water into steeper-sloped tributaries and downstream migrations when flows recede in late-spring and early summer. Larger adult pike minnow are described as ambush predators of other fish species, including salmonids. Ambush predators typically capture prey items with a sudden burst of speed combined with an element of surprise. A fishes’ swimming performance is often a function of body size, with larger individuals having greater capabilities. Sacramento pike minnow are known to exceed 100 cm (39”) in length and in Chorro Creek may have the potential to grow larger than the average Central-coast adult steelhead.

Stream crossings designed to effectively exclude 100% pike minnow from entering Chorro Creek’s tributaries would most likely significantly impede the upstream migration of most adult steelhead and certainly prevent the upstream passage of all age-classes of juveniles. As discussed earlier, seasonal upstream movements of over-wintering juvenile salmonids are recognized as a potentially important life-history strategy. Also, as Chorro Creek’s water temperature rises in the late-spring or early-summer, or as the lower reaches of tributaries dry-up; the upstream movement of juveniles to suitable rearing areas with cool, well-oxygenated surface flow may be a vital survival mechanism.

Scheduling of Site-Specific Treatments

High-Priority Sites

The CSLRCD should initiate discussions with CalTrans to address the retrofits of the Highway 1 crossings at Pennington, Dairy, and San Luisito Creeks. CalTrans should consult with hydraulic engineers at CDFG and NMFS for technical assistance with designs that meet current passage criteria. The County of San Luis Obispo department of Public Works should be contacted in regards to their crossing at San Luisito Creek #2/Adobe Road. Again, this project should be scheduled to coincide with the retrofit of the San Luisito Creek #1/Highway 1.

Moderate-Priority Sites

The CSLRCD should initiate discussions with the private landowner whose property the San Bernardo Creek #2 site (Site ID#9) is located on. If the landowner is willing, the CSLRCD could take the lead on developing a proposal to remove the existing crossing and install a flatcar bridge. The crossing may require a double-wide flatcar bridge to safely accommodate the truck traffic that services the active dairy/ranch facilities located on the private property.

The low-elevation dam at Dairy Creek #3 (Site ID#11) could be modified over several seasons to gradually meter the mobilization of the sediment stored on the upstream side of the structure. Removal could be easily accomplished with volunteer or CCC labor and hand-tools. The CSLRCD or CCC's could take the lead in developing the required permits to conduct the removal. To monitor the effectiveness of the removal and extent of upstream channel head-cutting, several longitudinal profiles should be surveyed before, immediately after, and annually after winter flows. A series of cross-sections should also be considered across the structure. Another option for treatment would be to remove the dam with heavy equipment and re-grade the channel slope, including the physical removal of some of the sediment stored on the upstream side of the dam. This option would be more expensive, but may be more desirable if there were concerns about releasing the stored sediment behind the dam. Prior to selecting an option, the CSLRCD should consider estimating the cubic yards of material currently behind the dam to better assess potential project costs and impacts to the downstream channel.

Low-Priority Sites

The CSLRCD should initiate discussions with the biological staff at Camp SLO to remove the low-elevation dam at Site ID #7 – Chorro Creek #2. The dam should be modified over several seasons to gradually meter the mobilization of the sediment stored on the upstream side of the structure. Removal could be easily accomplished with volunteers or Camp SLO personnel and hand-tools. The Camp SLO's biological staff should take the lead in developing the required permits to conduct the removal. To monitor the effectiveness of the removal and extent of upstream channel head-cutting, several longitudinal profiles should be surveyed before, immediately after, and annually after winter flows. A series of cross-sections across the structure should also be considered.

Site ID#7, the low-elevation concrete dam located on the California Men's Colony, could be modified by widening the current low-flow notch to create a better attractant flow for migrating steelhead at winter migration-level flows. Removal of this site may not be cost-effectively feasible because of water and sewer pipes located underneath the concrete structure (Highland, pers. comm.). The current low-flow notch is rectangular in shape and approximately three feet in width. It is recommended that the notch is tapered in a v-shape to a total width of five to six feet, and that a better-defined low-flow notch is created that concentrates low-flow instead of allowing a wide, shallow sheet flow to form.

Timing of Barrier Remediation Projects

The management approach of trying to maintain crossings that allow partial adult steelhead passage in order to exclude 100% of the pike minnow from Chorro Creek's tributaries is not recommended. First of all it may not be feasible to completely block pike minnow migration and still provide acceptable steelhead passage - if just a few pike minnow enter a creek, a population may take hold. Anecdotal information suggests that several pike minnow were caught and killed by 10-year old boy fishing in the outlet pool below San Luisito Creek #2/Adobe Road (Site ID#2) in the summer of 2002. These fish would have negotiated the Highway 1 culvert downstream of Site ID#2, which is a severe impediment to steelhead migration.

Secondly, to provide for a higher likelihood of steelhead population recovery in the Morro Bay watershed, restoring the ecological connectivity of Chorro Creek's tributaries is vital. Ideally, this means all stream crossings should be designed with open bottoms to simulate streambed conditions that exhibit hydraulic characteristics no different than the creek's natural channel. Under these conditions, adult and juvenile steelhead can more freely access tributary habitat as dictated by seasonal changes in flow and temperature. Maintaining partial barriers to deny pike minnow access would essentially entail leaving the Highway 1 sites at San Luisito, Pennington, and Dairy Creeks in their current state. However, these are all serious impediments to steelhead and need to be fixed.

In order to limit the potential for pike minnow to dominate Chorro Creek's tributary habitat, aggressive measures must be taken to reduce pike minnow numbers in Chorro Creek prior to opening-up tributary access. The *Steelhead Restoration Planning Project* report suggested an advisory panel be formed to scope the feasibility of pike minnow eradication (Dvorsky, 2002). The report also recommended starting the eradication at Chorro Reservoir before attempting population reduction in Chorro Creek.

We recommend that this advisory panel is formed quickly and that the following steps are taken during 2003.

1. Sample tributaries for pike minnow presence. If feasible, sample San Bernardo Creek since there are currently no migration barriers in the lower 2.2 miles and pike minnow should have had free access to this creek since their introduction to Chorro Creek.
2. Conduct observations at Highway 1 culvert outlets from March-June to assess if pike minnow are attempting to migrate upstream for spawning. If a strong upstream movement is observed, consider feasibility of trapping adults on their spawning run as a

means of population reduction. Newly-hatched pike minnow fry also tend to school together along shallow pool margins – explore the feasibility of seining fry.

3. Conduct pilot project of pike minnow removal from Chorro Creek. Because there is most likely a lengthy permit process required to conduct a draw-down of Chorro Reservoir, we recommend that CDFG and the CCC's field-test the feasibility of removing pike minnow with electro-fishing gear. Several teams could block-net pools known to contain large numbers of pike minnow and then conduct repeated electro-fishing passes. Data should be collected on personnel effort, number of pools and length of habitat sampled, and pike minnow removed to assess the cost-benefit. Length, weight, sex, scales/otolith data should be collected on pike minnow to assess population dynamics.
4. Start process of scoping the drawn-down of Chorro Reservoir. Once drained to remove all non-native fish species, if needed, Chorro Reservoir could be dredged to increase storage capacity that would serve to augment summer flow discharges for maintenance of steelhead habitat. Improving flow quantity and quality in Chorro Creek during the summer was a primary recovery objective in the *Steelhead Restoration Planning Project* (Dvorsky, 2002).
5. Education of Chorro Reservoir maintenance staff and personnel. The introduction of pike minnow into the Chorro Creek watershed was a suspected bait-bucket release by fishermen with access to Chorro Reservoir. To reduce the likelihood of future introductions of non-native species, it is imperative to educate all persons with access to the reservoir of the dire consequences their illegal actions have on the watershed's native steelhead population.

State and Federal Assistance with Fish Passage Design

Because the three Highway 1 culverts (Site ID's #1, #13 and #3) and the SLO-county culvert on Adobe Road (Site ID#2) all require extensive retrofits to facilitate the passage of adult and juvenile steelhead, it is recommended that CalTrans and County engineers consult with state and federal hydraulic engineers for assistance in project design options. The agency engineers are knowledgeable in the current design techniques to meet hydraulic conditions set in the state and federal passage criteria guidelines. Agency assistance will increase the likelihood of a functional retrofit, as well as, expedite the often lengthy process of obtaining permits to implement the construction phase of the project.

CDFG: Maintains hydraulic engineers on staff to assist with fish passage issues, permits and designs. To obtain the most recent copy of the CDFG *Culvert Criteria for Fish Passage* (Heise, 2002) visit the department website at: www.dfg.ca.gov or call (916)-445-3399.

NMFS: Also maintains hydraulic engineers on staff to assist with fish passage issues, permits and designs. The agency also developed a list of preferred stream crossing alternatives for new installations and replacements:

1. *No crossing* - relocate or decommission the road.
2. *Bridge* - spanning the stream to allow for long-term dynamic channel stability.
3. *Streambed simulation strategies* – bottomless arch, embedded culvert design, or ford.
4. *Non-embedded culvert* – this often referred to as a hydraulic design, associated with more traditional culvert design approaches limited to low slopes for fish passage.
5. *Baffled culvert, or structure designed with a fish way* – for steeper slopes.

For more information, or to obtain a copy of the NMFS *Guidelines for Salmonid Passage at Stream Crossings* go to the Southwest Region website at: <http://swr.nmfs.noaa.gov> or call (707)-575-6054.

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