MARIN COUNTY STREAM CROSSING INVENTORY AND FISH PASSAGE EVALUATION

FINAL REPORT

Prepared for the County of Marin – Department of Public Works

By

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INTRODUCTION

The inventory and fish passage evaluation of county-maintained stream crossings within the County of Marin was conducted between May, 2002 and June 2003. The primary objective was to assess passage of juvenile and adult salmonids and develop a project-scheduling document to prioritize corrective treatments to provide unimpeded fish passage at road/stream intersections. The inventory was focused primarily on County-maintained crossings within anadromous stream reaches within Marin County watersheds known to historically and/or currently support runs of coho salmon (*Oncorhynchus kisutch*) and/or steelhead (*O. mykiss irideus*). However, a number of city and state-maintained crossings were also evaluated.

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. Locating stream crossings within anadromous stream reaches.
2. Visiting each crossing on an initial site visit to determine the type of crossing and assessment of stream channel as suitable fish habitat.
3. At crossings with culverts - collecting information regarding culvert specifications and surveying a longitudinal profile.
4. 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 by the filter.
5. Assessing quality and quantity of stream habitat above and below each culvert.

The prioritization process ranked culvert 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).

The initial ranking was not intended to provide an exact order of priority, rather 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 these factors were considered in developing the final ranked list.

1. Streams that currently support runs of steelhead and/or coho salmon. Treating migration 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 at crossings where migration attempts were observed. Recent studies have revealed numerous sites in California where concentrations of migrating salmonids were subjected to decades of predation by birds and mammals or poaching by humans (Taylor 2000 and 2001). Observations of adult coho salmon injuring themselves on failed leap attempts have also been made (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 priority 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 salmonid spawning and rearing habitat.

4. Presence or absence 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 watershed coordinators 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 salmonids.

7. Other factors impacting salmon and 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 Stream Crossing Inventory

Final report includes:

1. A count and location of all stream crossings with culverts. Locations were identified by stream name; road name; road number; watershed name; mile marker or distance to nearest named crossroad; Marin County road map #; USGS Quad name; Township, Range and Section coordinates; and lat/long coordinates (NAD27 datum). Each evaluated crossing was provided a unique ID # by the County of Marin for GIS purposes. All location data were entered into a spreadsheet for potential database uses.

2. For each site, culvert specifications were collected, including: length, diameter, type, position relative to flow and stream gradient, amount of fill material, depth of jump pool below culvert, height of leap required to enter culvert, previous modifications (if any) to improve fish passage, and evaluate effectiveness of previous modifications. All site-specific data were entered into a spreadsheet for potential database uses.

3. Information regarding culvert age, wear, and performance was collected, including: overall condition of the pipe and rust line height. All culvert specifications were entered into a spreadsheet for potential database uses.

4. An evaluation of fish passage at each culvert location. 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 culvert 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 the species and life stages of interest.

5. Digital photo documentation of each crossing was taken 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 crossing location. Most information was obtained from habitat typing and fisheries surveys previously conducted by various federal and state agencies, as well as watershed groups and private consultants. Where feasible, a first-hand inspection and evaluation of stream habitat occurred. Lengths of potential anadromous habitat were 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 culverts 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 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
- 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 road 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, coho salmon, coastal rainbow trout (steelhead are anadromous coastal rainbow trout), and coastal cutthroat trout (*Oncorhynchus 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 culverts in northern California confirmed similar upstream movements of three year-classes of juvenile steelhead (young-of-year, 1-year old and 2-year old) (Taylor 2001; Taylor 2000).

The variable life history of resident coastal rainbow trout is exhibited by seasonal movements in and out of one or more tributaries within a watershed. These smaller tributaries are where most culverts are still located since larger channels tend to be spanned by bridges.

County Planning Efforts to Address Migration Barriers

In response to the 1996 and 1997 federal listings of coho salmon as threatened in northern California, six counties (Sonoma, Marin, Napa, San Mateo, Alameda, and Santa Cruz) formed the FishNet 4C Group to examine various land-use activities conducted or permitted under county jurisdiction that may impact coho salmon habitat. Initial meetings identified causative factors of potential impacts, information gaps, and priority tasks required to obtain missing information. A high-priority task included conducting stream crossing inventories on County-maintained roads to evaluate fish passage and prioritize treatments.

Anadromous salmonids will benefit from this planning effort because the final document provides the County of Marin's Public Works Department with a prioritized list of culvert locations to fix that will provide unimpeded passage for all species (and life stages) of salmonids. Report information will assist in proposal development to seek State and Federal money to implement treatments. The inventory will also provide the County with a comprehensive status evaluation of the overall condition and sizing of culverts within fish-bearing stream reaches, providing vital information to assist the County's general planning and road's maintenance needs.

METHODS AND MATERIALS

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

1. Location of stream crossings.
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 fairly consistent with the protocol recently developed for the CDFG *California Salmonid Stream Habitat Restoration Manual* (Taylor and Love, 2003). These methods were developed to be consistent with current state and federal fish passage criteria for anadromous salmonids (CDFG 2002, NMFS 2001).

Two modifications to the original CDFG protocol were made during the County of Marin fish passage assessment project:

- Use of more rigorous criteria (minimum water depths and swimming abilities) for assessing passage of adult salmonids (see page 19).
- A reduction of the weight of culvert sizing and condition in the ranking score (see page 26).

These modifications to the original CDFG protocol were initiated in response to results generated by the original methods in Five-Counties' assessments. All protocol changes were discussed with CDFG and NMFS personnel prior to their use in the Marin County assessment project. In-depth explanations to the rationale of modifying the methodology are provided at the appropriate places within the Methods and Materials section of this final report.

Location of Stream Crossings

Preliminary project scoping for stream crossings to survey included examination of Marin County road system maps and counting road/stream intersections on known (current and historic) anadromous stream reaches. Approximately 150 county-maintained stream crossings were initially identified within anadromous stream reaches; however it was not clearly known how many of these were bridges that currently provided unimpeded access. Because the use of maps was considered a rough, first-cut at locating potential stream crossings, additional sites were also

investigated once the project started. Many of these additional sites included city and state-maintained crossings.

Initial Site Visits

The objective of the initial site visits was to collect physical measurements at stream crossings with culverts to utilize with the first-phase evaluation filter and with the FishXing passage evaluation software. Notes describing the type and condition of each culvert, as well as qualitative comments describing stream habitat immediately above and below each culvert were also included. Photographs of the outlet and inlet were taken at each site.

Stream Crossing Type

Potential sites were visited in the field and all crossings were first identified as either: culverts, bridges, or fords. The field measurements were only collected on culverts, however this included crossings identified on County road maps as bridges because of the length of their span. Typically any structure with a combined span greater than 20 feet was defined by road managers as a bridge – yet from a fish passage perspective if these structures had a smooth concrete floor they were defined as concrete box culverts, surveyed, and evaluated for passage.

Culvert Location

The location of each culvert was described by: County of Marin road system map # ; road name and number; 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 county road culvert crossed single stream, a number was assigned to the stream name with the #1 culvert located farthest downstream (numbering then proceeded in an upstream direction). Lat/long coordinates were determined using Terrain Navigator (Version 3.01 by MapTech), a geo-referenced mapping software program; or in the field with a handheld GPS unit. 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 culvert 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.

Once a site was located in the field by the two-person survey crew, bright orange safety cones with signs marked "Survey Party" were placed to warn oncoming traffic from both directions. Bright orange vests were also worn by the survey crew to increase one's visibility to traffic. If sites were close to private residences, or the property was posted - we attempted to contact the property owners to inform them of our survey of the County-maintained stream crossing.

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 culvert, usually in the riffle crest of the first pool or run habitat unit above the culvert. This pool or run was considered the first available resting habitat for fish negotiating the culvert. The tape was set to follow any major changes in channel direction. The tape was set through the culvert and continued downstream to at least the riffle crest (or control) of the pool immediately downstream of the culvert 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. 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. If possible, a location on the road surface was optimal, allowing a complete survey to be shot from one location. 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 county personnel 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, five required elevations were measured (Figures 1 and 2):

1. culvert inlet,
2. culvert outlet,
3. maximum pool depth within five feet of the outlet,
4. outlet pool 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 2):

- 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.

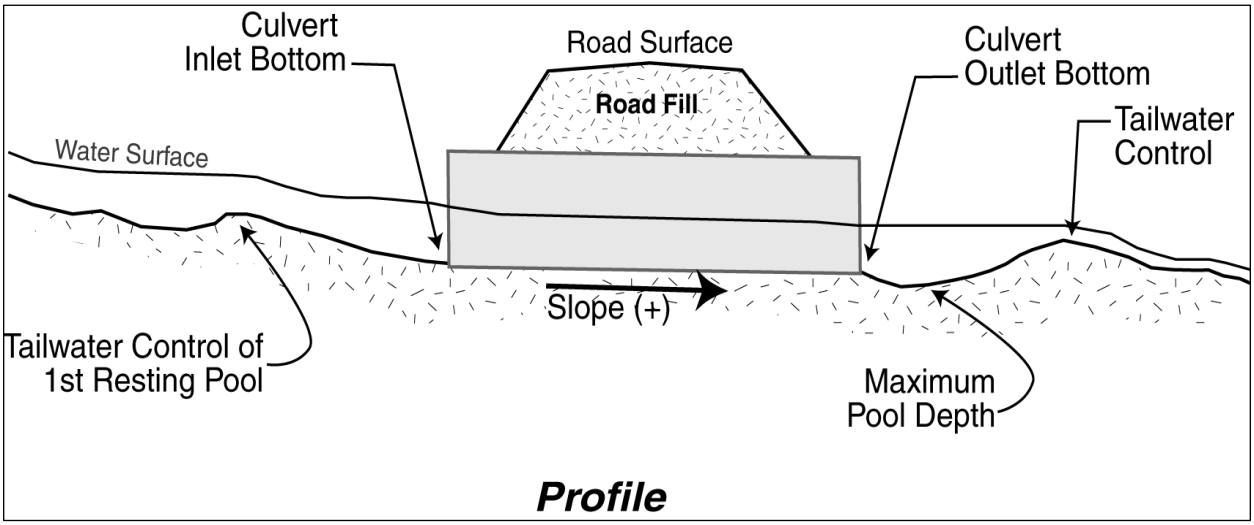

Figure 1. Diagram of required survey points though a culvert at a typical stream crossing.

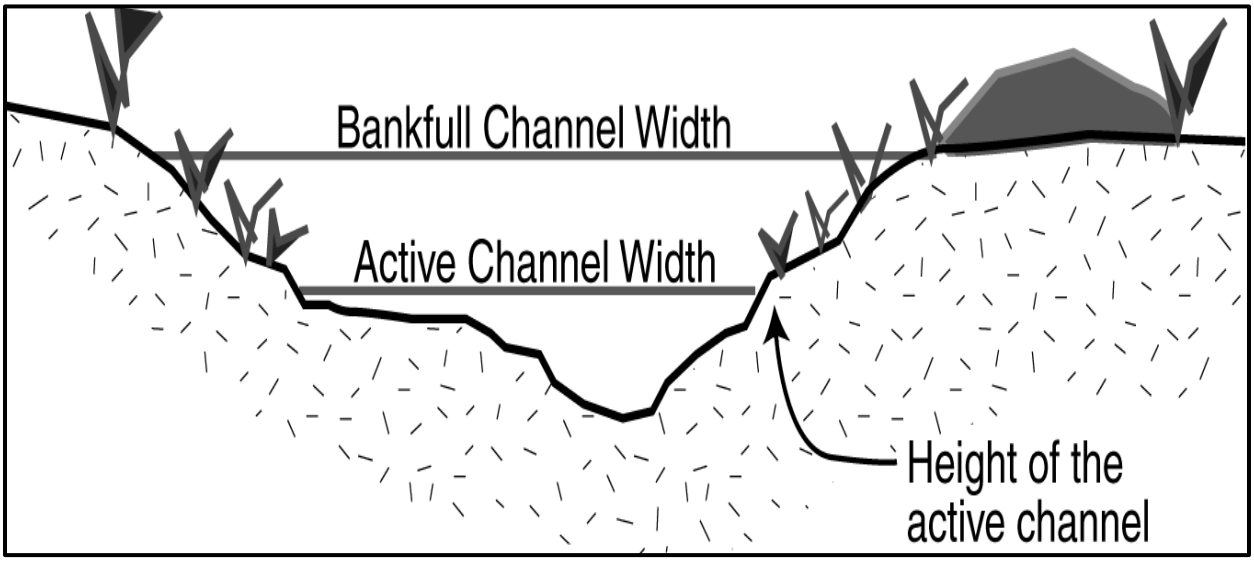

Figure 2. Active channel width versus bankfull channel width.

On a site-specific basis, the following additional survey points provided useful information for evaluating fish passage 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 are measured, the overall slope will predict average velocities less than actual velocities within steeper sections. These breaks-in-slope may act as velocity barriers, which are masked if only the overall slope of the culvert is 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. Measure 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.

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 the culvert (visually beyond any influence the crossing may have on channel width) were taken. Active channel is 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).

Although not required, in many cases a cross-section survey of at least the bankfull channel width at the outlet pool control was measured. Each cross-section was comprised of approximately eight elevations from the left bank-full channel margin to the right bank-full margin. These cross sections allowed for a more accurate modeling of changes in tail-water elevations with the FishXing software.

Fill Estimate:

At each 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 3):

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).

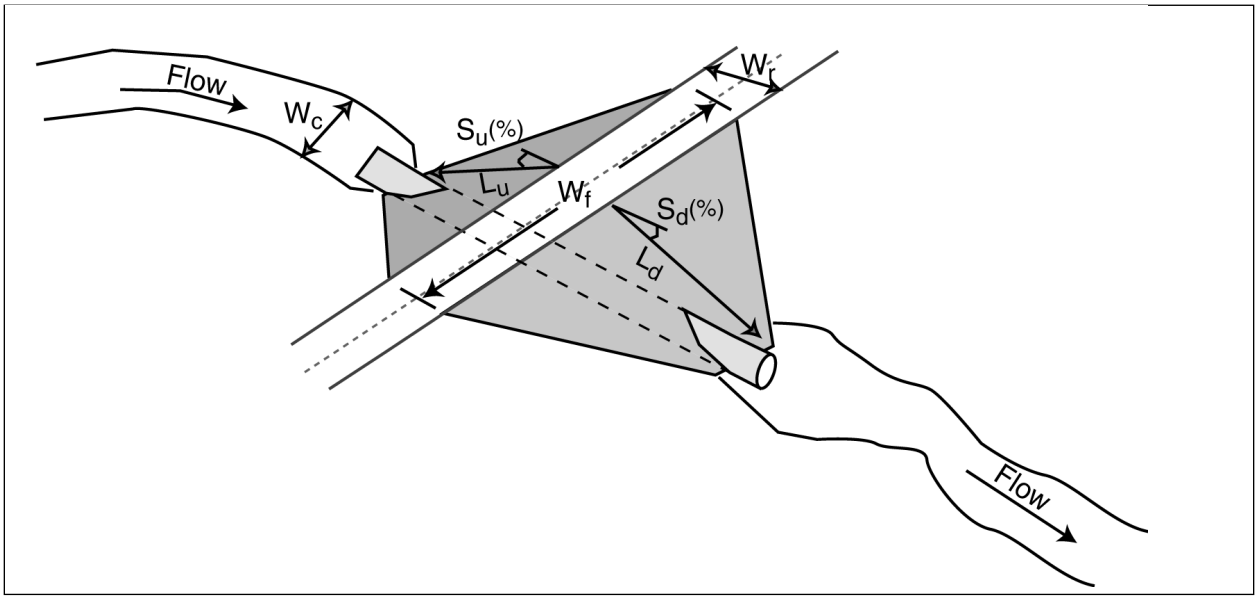

Figure 3. Road fill measurements.

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) Total fill volume, V:

$$V = V_u + V_d + V_r$$

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 site, the following culvert 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 metal 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 relative to flow 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 culvert 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 fish species and lifestages (CDFG 2002; NMFS 2001).

Using the field inventory data, calculate: average active channel width, culvert slope, residual inlet depth and drop at outlet (Figure 4). The first-phase passage evaluation filter was employed to reduce the number of crossings which required an in-depth passage evaluation with FishXing. The filter criteria were designed to quickly classify crossings 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 5). 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.

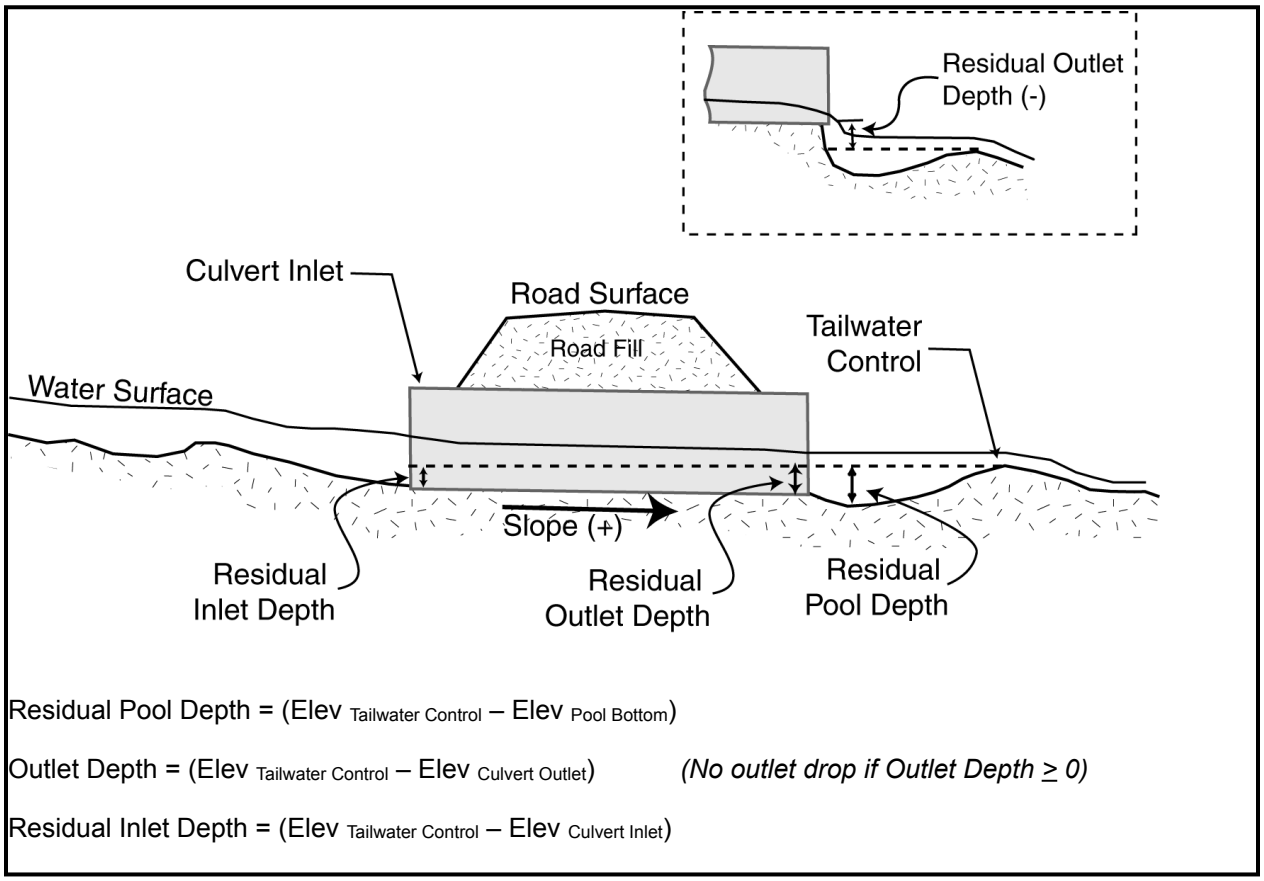

Figure 4. Measurements used in Green-Grey-Red filtering criteria.

Many stream crossings have unique characteristics which may hinder fish passage, yet they are not recognized in the filtering process. For culverts 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".

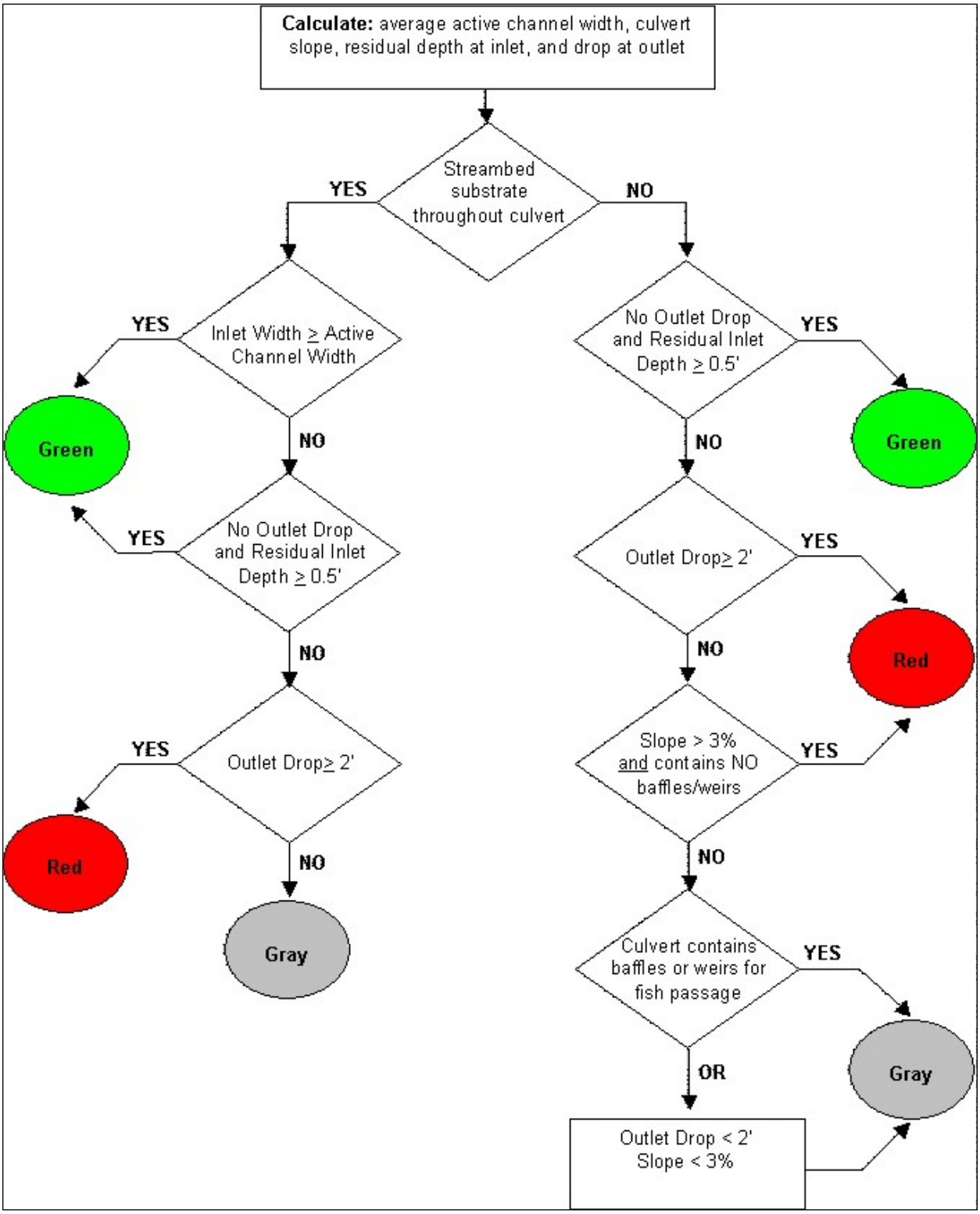

Figure 5. GREEN-GRAY-RED first-phase passage evaluation filter.

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 released in March, 2000. In-depth information regarding FishXing (or a copy of the most-recent version) may be obtained at the Fish Crossing homepage on the internet (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.

Fish Passage Criteria – First Deviation from CDFG Passage Assessment Protocol

FishXing used the survey elevation and culvert specifications to evaluate passage at sites defined as "GRAY" by the first-phase evaluation filter for each species and life-stages of salmonids known to currently or historically reside in the Marin County tributaries of interest. The swimming abilities and passage criteria recommended in the original CDFG fish-passage protocol and the alternate values used in the County of Marin project for each species and life-stage are listed Table 2.

The CDFG fish-passage protocol recommended using conservative values for assessment under the assumption that although many individual fish will have swimming abilities surpassing those listed, swim speeds and minimum water depths were selected to ensure stream crossings accommodated passage of weaker individuals within each age class. This assumption is better suited for the *design* of new crossings where being conservative hopefully allows for the passage of all fish. However, for *assessment* purposes, the use of conservative swimming values and minimum water depths generated many "RED" sites that, in fact, were allowing the passage of adult salmonids. This discrepancy was first noticed during Ross Taylor and Associates' assessment project in Marin County where extensive spawning survey data confirmed adult coho

salmon and steelhead consistently spawning upstream of crossings initially assessed as "RED" (Ketcham and Walder, pers. comm.).

If the objective of the passage assessment is to identify crossings that are truly barriers to adult migration, as well as, accurately estimate the percentage of temporal passage to allow a gradation in the scoring matrix; then using conservative values is not appropriate. The use of more rigorous passage criteria should reduce the number of "RED" sites and generate a wider range of "extent of barrier" scores for the "GRAY" sites.

FishXing used the survey elevation and culvert specifications to evaluate passage at sites defined as "Grey" by the first-phase evaluation filter for each species and lifestages of salmonids known to currently or historically reside in the Marin County streams of interest. The swimming abilities and passage criteria used for each species and lifestage are listed Table 2. Although some 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.

Table 2. Fish species and life stages used in the fish passage along with associated swimming abilities and passage criteria. Values in parentheses are the conservative values 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 and Coho**	**Resident Trout**	**Juvenile Salmonids**
Fish Length	500 mm	200 mm	80 mm
Prolonged Mode			
Swim Speed	(6 ft/sec) **8 ft/sec**	4 ft/s	1.5 ft/s
Time to Exhaustion	30 min	30 min	30 min
Burst Mode			
Swim Speed	(10 ft/sec) **16 ft/sec**	5.0 ft/s	3.0 ft/s
Time to Exhaustion	5 sec	5 s	5 s
Maximum Leaping Speed	(12.0 ft/sec) **16 ft/sec**	6.0ft/s	3.0 ft/s
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	0.3 ft
Minimum Passage Flow *(Use the larger of the two flows)*	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 fish.

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".

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. For most projects, mean annual precipitation (MAP) and potential evapotranspiration (PET) are estimated from regional maps produced by Rantz (1968).

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.

Determination of a crossing's flood capacity 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. Depending on the amount of road-fill, this pulse of sediment may have a minor-to-catastrophic impact on downstream rearing and spawning habitat. Undersized crossings can also adversely affect

sediment transport and downstream channel stability, creating conditions that hinder fish passage, degrade habitat, and may cause damage to other stream crossings 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 (Figure 6). The equations incorporate drainage area, MAP, and mean basin elevation as variables to predict peak flow in Northwestern California streams.

The third step was to compare the stream crossing 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.

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. Identifying the exceedence flows required obtaining average daily stream flow data from gauged streams. Daily average flow data for small streams in Marin County were available from the USGS.

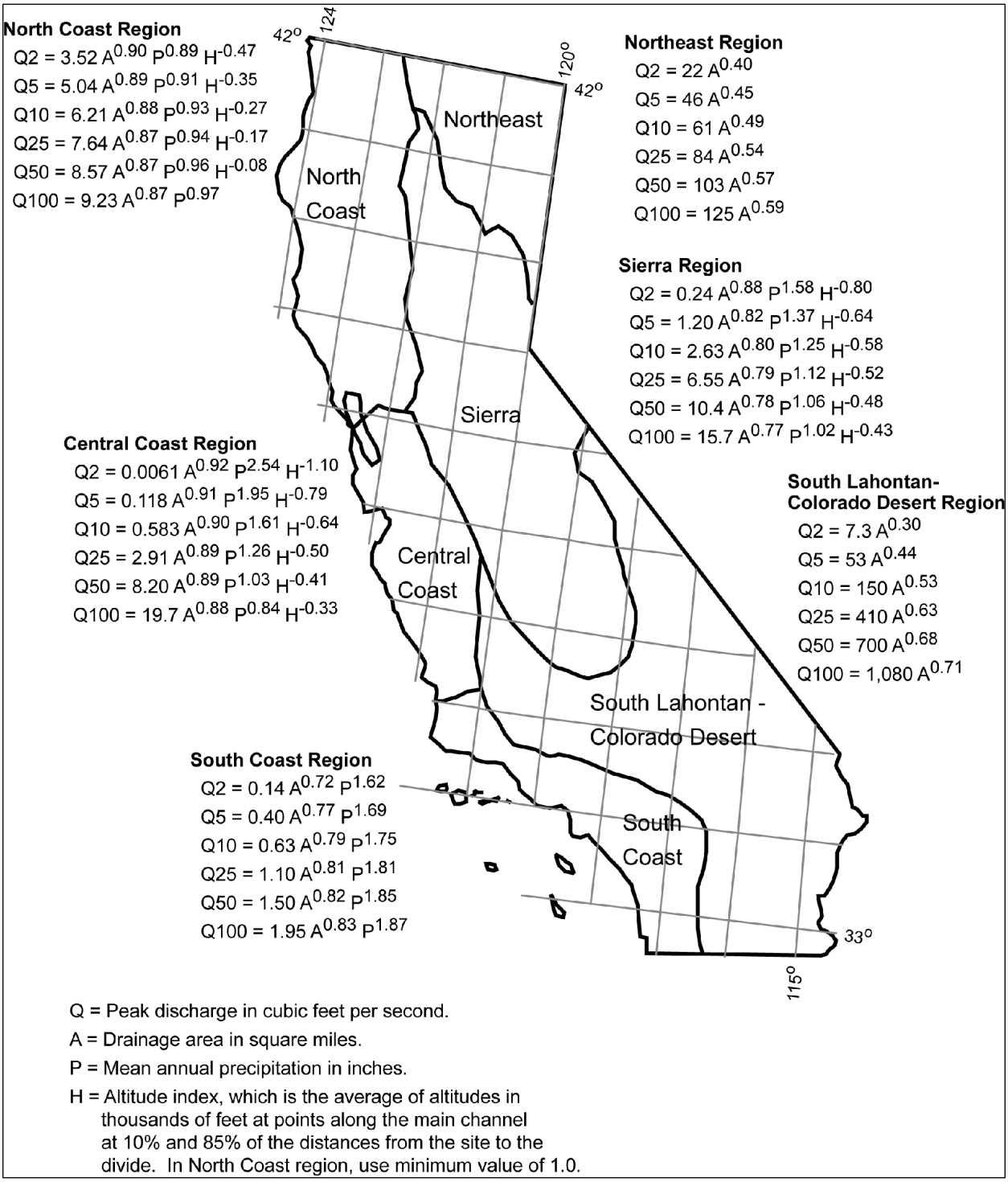

Figure 6. California regional regression equations for estimating peak flows associated with a 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year recurrence interval (Waananen and Crippen, 1977).

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, however in Marin County the abundance of reservoirs made this criteria difficult to adhere to.

2. Divided the flows (Q) for each gauged stream by its drainage area (A), resulting in units of cfs/mi^2.

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 of the 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.

Habitat Information

Because this project addressed fish passage in numerous streams throughout Marin County, the assessment of stream habitat conditions associated with the surveyed stream crossings was based primarily on previously completed surveys and reports, as well as the professional judgment of biologists and restoration groups familiar with the watersheds. Habitat information and fish presence/distribution data were used from reports provided by Marin County Department of Public Works, CDFG, Salmon Protection and Watershed Network (SPAWN), Point Reyes National Seashore, and Friends of the of Corte Madera Watershed. These surveys, reports, and memos also provided information on past, present, and future land uses within watersheds that flow through culverts on the County of Marin's road system.

Professional judgment from on-site inspection of stream crossings and stream habitat also aided habitat assessment and evaluation. In some cases, with landowner permission, longer reaches of

stream were walked to better assess quality of habitat above and below county culverts. These surveys also aided in the examination of stream crossings on private roads.

Habitat Quantity

Lengths of potential anadromous salmonid habitat upstream of each crossing were estimated by two methods:

1. Lengths measured in the field during habitat typing or fisheries surveys. If access was permitted, these surveys were terminated where the field crews thought the limit of anadromy was located. The surveys were often terminated at obvious features such as natural waterfalls, extremely steep-sloped boulder cascades, or at permanent human-made structures such as dams.

2. Measured off of digitized USGS 7.5 Minute Series topographic maps (Terrain Navigator, Version 3.01by MapTech). The upper limit of anadromous habitat was considered when the channel exceeded an eight percent slope for at least a 300-foot channel reach.

The habitat quantity value used in the ranking matrix varied, but usually if a habitat typing survey identified an obvious feature where anadromy was terminated – this was the value used. In other instances, the eight-percent slope was used only if on-the-ground survey information was unavailable.

The presence of additional stream crossings and other types of human-made impediments (such as flash-board dams, etc.), above and below each County-maintained site, was also considered when evaluating potential habitat gains. In many cases, additional stream crossings existed that were maintained by private, city, state, or federal entities. Some city-maintained crossings and a smaller portion of the state (CalTrans) crossings were surveyed, evaluated, and included in the ranking process to provide a more hololistic watershed-level approach to addressing fish passage concerns.

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 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 influenced the exact order of treated sites.

Because the County of Marin intends on treating stream crossings 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

culvert locations 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 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 relatively consistent with those developed for Part IX of CDFG's *Salmonid Stream Habitat Restoration Manual* (Taylor and Love, 2003), except for one aspect. The second deviation from the CDFG protocol entailed reducing the weight of the current crossing's sizing and condition scores on the site's total score. Again, this modification to the CDFG protocol resulted from carefully analyzing data sets from previously completed assessment projects. The ranking matrix developed for the *Restoration Manual* can generate a maximum possible score of 39 points, with a maximum of 10 points (25.6%) associated with crossing condition and sizing. In some instances, crossings with very little upstream habitat (<1,000') and/or met the adult passage criteria on 100% of the range of migration flows were ranking near the top due primarily to poor condition and under-sizing.

Undersized crossings that are in poor condition should be of concern to road managers. However, if the primary purpose of the ranking matrix is to identify sites to treat with fisheries restoration funding, then more weight should be put on the biological-related criteria so that crossings which are serious impediments to migration with significant reaches of potential upstream habitat rank higher than crossings in need of replacement with maintenance funds.

Thus, for the Marin County, Russian River, Santa Cruz County, and the Morro Bay watershed fish passage assessment projects Ross Taylor and Associates has reduced the weight of the sizing and condition criteria by utilizing the average of the two values. This resulted in a maximum possible total score of 34 points, with sizing and condition criteria comprising a weight of 14.7% of the maximum total score.

The method utilized for the Marin County assessment assigned a score or value for the following criteria at each crossing location. The total score was the sum of four criteria: species diversity, extent of barrier, average value of crossing sizing and current condition, and total habitat score.

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 coho salmon = **2** points and steelhead = **2** points. **Maximum score = 4 points.**

2. **Extent of barrier:** for three age classes of salmonids (adults, resident trout/2+, and 1+/ young-of-year), 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 adult species and each year-class of juveniles. **Maximum score = 15 points.**

3. **Sizing (risk of failure):** for each culvert, 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.

4. **Current condition:** for each culvert, 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.

5. **Crossing Score:** for each crossing, combine the sizing and condition values and compute the average value. **Maximum score = 5 points.**

6. **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). **Maximum score = 10 points.**

7. **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 conifers 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.

8. **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 culvert location, 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 slightly 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 serious impediments to migration with significant amounts of upstream habitat for anadromous salmonids. Medium-priority sites were characterized as limited in upstream habitat gains, limited species diversity, and/or were only significant impediments to juvenile migration. Low-priority sites were either limited in upstream habitat, habitat condition was poor, 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.

The County of Marin Public Works should consider ranking medium and low-priority sites a second time focusing mainly on culvert condition, sizing, and amount of fill material within the road prism. A risk assessment may be conducted to determine the consequence of potential sediment delivery to the downstream channel if or when a crossing failed. Most medium and low-priority sites should not be considered candidates for treatment via limited restoration funding sources, unless an imminent site failure would deliver a significant amount of sediment to downstream salmonid habitat.

However, this information will provide the County of Marin Public Works a list of sites in need of future replacement with county road maintenance funds. When these replacements are implemented, this report should provide guidance on treatments with properly-sized crossings conducive to adequate flow conveyance and unimpeded fish passage.

Additional Considerations for Final Ranking

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

1. Fish observations at crossings. Sites where fish were observed during migration periods were given higher priority in the final ranking. The species of salmonids observed, the number of fish, frequency of attempts, and the number of failed versus successful passage attempts were important variables considered. Sites with fish present are areas where immediate re-colonization of upstream habitat is likely to occur. Several streams in the Five-County region of northern California have experienced immediate re-colonization after migration barriers were treated (Taylor, pers. comm.).

2. Stocks of fish presumed present. Streams currently supporting runs of coho and steelhead were given a higher priority over streams that historically supported anadromous fish populations. This included primarily tributaries to Lagunitas Creek and Olema Creek.

3. Amount of road fill. At stream crossings that were undersized and/or in poor condition, we examined the volume of fill material within the road prism potentially deliverable to the stream channel if the culvert were to fail.

4. Presence, location, and barrier status of other stream crossings. In many cases, an individual stream was crossed by multiple roads under a variety of management or ownership. In these situations, close communication with other road managers was 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. In some cases the lowermost crossing was County of Marin-maintained and these sites were raised slightly in the final ranking. Conversely, the County also maintains crossings above state or federal-maintained crossings that are currently impeding and/or blocking fish migration – these county sites were lowered in the final ranking.

5. Remediation project cost. With the assistance of the County of Marin Public Works Department, the range of treatment options and associated costs were examined when determining the order in which to proceed and the type of treatment to implement at specific sites. In some cases, sites were raised in priority if cost-effective retrofits were feasible treatment options. Conversely, some sites were lowered in priority because the only feasible treatments were full replacements of culverts underneath large amounts of fill and/or buildings.

6. Scheduling of other road maintenance and improvement projects. With the assistance of the County of Marin's Public Works Department, the upgrading of migration barriers during other scheduled maintenance and/or improvement activities was considered. When undersized or older crossings fail during storms, the County should be prepared to install

properly-sized crossings that provide unimpeded passage for all species and life stages of fish.

RESULTS

Initial Site Visits

Initial site visits were conducted at 172 stream crossings and 90 crossings were surveyed and included in the evaluation and ranking process (Appendix A). The reasons for excluding 75 sites from the evaluation varied and are listed in the right-hand column of Appendix A. Of the 90 stream crossings surveyed; 72 crossings were County-maintained, eight crossings were on Highway One, and 16 crossings were within various city limits (Mill Valley = 10 sites, Novato = 3 sites, Fairfax = 2 sites, San Anselmo = 1 site). Towards the end of the field surveys, the County requested that Taylor and Associates evaluate passage at two reaches of concrete flood channel and at several low-elevation dams and weirs as part of the assessment project. Seven of these features were surveyed and assessed for fish passage. The survey data collected at these sites are provided in Appendix D.

The 90 surveyed stream crossings were each given a unique ID number that was determined in an upstream direction starting in western Marin County at the Marin/Sonoma county line and moving in generally a north-to-south direction to Sausalito; then in a south-to-north direction up the east side of Marin County (Table 3). A table of the 90 crossings with culverts that were inventoried and their location information is provided in Appendix A.

The location information, site-specific characteristics, site photographs, maps, and habitat descriptions for the 90 Marin County stream crossings with culverts were assembled in a separate document, titled *Catalog of Marin County Stream Crossings with Culverts Located on Anadromous Stream Reaches*.

The following list is an overview of the culverts inventoried:

1. A wide variety of culvert configurations and materials were discovered.

2. Some crossings were in poor condition (19 sites or 21%) and are due for replacement. Another 29 crossings (or 32% of the sites) were described as in "fair" condition, and starting to show signs of deterioration.

3. Thirty-nine of 90 crossings (or 43.3% of the sites) were property sized when compared to recently released NMFS guidelines that recommend stream crossings pass the 100-year storm flow at less than 100% of inlet height. Another 12 crossings (or 13.3% of the sites) were sized to pass greater than a 25-year storm flow.

4. Twenty-six of the 90 crossings (or 28.8% of the sites) were extremely undersized, overtopping on less than a ten-year storm flow (Table 4). Of these 26 sites, 13 crossings (or 14.4% of the sites) had culverts that overtopped on less than a five-year storm flow – these

sites should be of concern from a road's maintenance and safety point of view (high-lighted with "red" font in Table 4).

Table 3. Site ID numbers for 90 Marin County stream crossings.

SITE ID #	STREAM NAME	ROAD NAME	ROAD ID #
MR-001	Verde Canyon	Marshall-Petaluma Rd	C-112
MR-002	Tomasini Canyon	Mesa Rd	PR-008
MR-003	Second Valley Creek #1	Sir Francis Drake Blvd	A-109
MR-004	Second Valley Creek #2	Cameron Street	IN-006
MR-005	Second Valley Creek #3	Aberdeen Way	IN-001
MR-006	Second Valley Creek #4	Aberdeen Way	IN-001
MR-007	First Valley Creek #1	Sir Francis Drake Blvd	A-109
MR-008	First Valley Creek #2	Inverness Way	IN-013
MR-009	First Valley Creek #3	Laurel Avenue	IN-014
MR-010	Dream Farm Creek	Sir Francis Drake Blvd	A-109
MR-011	Fish Hatchery Creek #1	Sir Francis Drake Blvd	A-109
MR-012	Fish Hatchery Creek #2	Vallejo Avenue	IN-025
MR-013	Haggerty Gulch	Sir Francis Drake Blvd	A-109
MR-014	Old Bear Valley Creek	Sir Francis Drake Blvd	A-109
MR-015	Bear Valley Creek	Sir Francis Drake Blvd	A-109
MR-016	Cemetery Creek	Highway 1	State
MR-017	Boundary Gulch	Highway 1	State
MR-018	Water Tank Gulch	Highway 1	State
MR-019	Horse Camp Creek	Highway 1	State
MR-020	Giacomini Gulch	Highway 1	State
MR-021	John West Fork	Highway 1	State
MR-022	Zanardi Gulch	Platform Bridge Rd.	C-221
MR-023	Tocaloma Creek	Sir Francis Drake Blvd	A-104
MR-024	McIsaac Creek	Sir Francis Drake Blvd	A-104
MR-025	Cheda Creek	Sir Francis Drake Blvd	A 104

MR-026	Devil's Gulch	Sir Francis Drake Blvd	A-104
MR-027	Barnabe Creek	Sir Francis Drake Blvd	A-104
MR-028	Spring Creek #1	Lagunitas Road	SG-013
MR-029	Spring Creek #2	Mountain View Ave	SG-014
MR-030	Arroyo Creek #1	Castro Street	SG-009
MR-031	Arroyo Creek #2	Sir Francis Drake Blvd	A-003
MR-032	El Ceritto Creek #1	Arroyo Road	SG-001
MR-033	El Ceritto Creek #2	Tamal Road	SG-011
MR-034	Arroyo Creek #3	Arroyo Road	SG-001
MR-035	Arroyo Creek #4	Barranca Road	SG-002
MR-036	Arroyo Creek #5	Barranca Road	SG-002
MR-037	Montezuma Creek #1	Guadalupe Ave	SG-005
MR-038	Candelero Creek #1	Montezuma Ave	SG-007
MR-039	Candelero Creek #2	Candelero Road	SG-003
MR-040	Montezuma Creek #2	Montezuma Ave	SG-007

Table 3 (continued). Site ID numbers for 90 Marin County stream crossings.

SITE ID #	STREAM NAME	ROAD NAME	ROAD ID#
MR-041	San Geronimo Creek #1	Montezuma Ave	SG-007
MR-042	Iris Creek	Sir Francis Drake Blvd	A-103
MR-043	Larsen Creek	Sir Francis Drake Blvd	A 103
MR-044	Sylvestris Creek #1	Meadow Way	SG-019
MR-045	Sylvestris Creek #2	Tamarack Road	SG-021
MR-046	Creamery Creek	Meadow Way	SG-019
MR-047	Deer Camp Canyon	San Geronimo Valley Rd	247
MR-048	Bates Canyon	San Geronimo Valley Rd	247
MR-049	Woodacre Creek #1	San Geronimo Valley Rd	247
MR-050	Woodacre Creek #2	Park Street	SG-033
MR-051	Woodacre Creek #3	Carson Road	SG-023
MR-052	West Fork Woodacre Creek #1	Garden Way	SG-029
MR-053	West Fork Woodacre Creek #2	Crescent Drive	SG-040
MR-054	West Fork Woodacre Creek #3	Redwood Drive	SG-035
MR-055	West Fork Woodacre Creek #4	Madrone Avenue	SG-030
MR-056	East Fork Woodacre Creek #1	Oak Grove Avenue	SG-032
MR-057	East Fork Woodacre Creek #2	Garden Way	SG-029
MR-058	East Fork Woodacre Creek #3	Crescent Drive	SG-040
MR-059	East Fork Woodacre Creek #4	Grove Avenue	SG-032
MR-060	San Geronimo Creek #2	Railroad Avenue	SG-034
MR-061	Spirit Rock Creek	Sir Francis Drake Blvd	109
MR-062	Flanders Creek	Sir Francis Drake Blvd	109
MR-063	Schooner Creek	Sir Francis Drake Blvd	109
MR-064	Drakes Creek	Sir Francis Drake Blvd	109
MR-065	McCurdy Creek	Highway 1	State

MR-066	North Fork McCurdy Creek	Highway 1	State
MR-067	Kent Canyon	Muir Woods Road	C-107
MR-068	Arroyo Corte Madera del Presidio #1	Locust Avenue	Mill Valley
MR-069	Arroyo Corte Madera del Presidio #2	None- Under Building	Mill Valley
MR-070	Arroyo Corte Madera del Presidio #3	King Street	Mill Valley
MR-071	Arroyo Corte Madera del Presidio #4	Marguerite Avenue	Mill Valley
MR-072	Arroyo Corte Madera del Presidio #5	W. Blithedale Avenue	Mill Valley
MR-073	Arroyo Corte Madera del Presidio #6	W. Blithedale Avenue	Mill Valley
MR-074	Arroyo Corte Madera del Presidio #7	Blithedale Summit Fire Rd	Mill Valley
MR-075	Old Mill Creek #1	Miller Avenue	Mill Valley
MR-076	Old Mill Creek #2	None- Under Post Office	Mill Valley
MR-077	Old Mill Creek #3	Cascade Drive	Mill Valley
MR-078	San Anselmo Creek #1	Saunders Avenue	San Anselmo
MR-079	San Anselmo Creek #2	Pastori Avenue	Fairfax
MR-080	Fairfax Creek	Bolinas Avenue	Fairfax

Table 3 (continued). Site ID numbers for 90 Marin County stream crossings.

SITE ID #	STREAM NAME	ROAD NAME	ROAD ID#
MR-081	Sleepy Hollow Creek #1	Deer Hollow Road	SF 010
MR-082	Sleepy Hollow Creek #2	Fawn Drive	SF 012
MR-083	Sleepy Hollow Creek #3	Butterfield Road	ASF 002
MR-084	Arroyo San Jose #1 - 4 bays	Bel Marin Keys	BK-001
MR-085	Arroyo San Jose #2	Ignacio Boulevard	Novato
MR-086	Vineyard Creek #1	McClay Avenue	NV 003
MR-087	Vineyard Creek #2	Wilson Road	NV 827
MR-088	Vineyard Creek #3	Trumbull Avenue	Novato

MR-089	Vineyard Creek #4	Mill Road	Novato
MR-090	Leveroni Creek	Novato Boulevard	A-114

Table 4. Hydraulic capacities of 90 Marin County 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 (cfs)	Capacity at HW/F=1 (cfs)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
MR-001	Verde Canyon	Marshall-Petaluma Rd	1,281.0	1,995.0	>250	>250
MR-002	Tomasini Canyon	Mesa Rd	353.3	406.8	**4**	5
MR-003	Second Valley Creek #1	Sir Francis Drake Blvd	200.0	290.0	48	>250
MR-004	Second Valley Creek #2	Cameron Street	77.2	131.5	**3**	14
MR-005	Second Valley Creek #3	Aberdeen Way	170.9	266.6	52	>250
MR-006	Second Valley Creek #4	Aberdeen Way	55.3	98.0	**2**	9
MR-007	First Valley Creek #1	Sir Francis Drake Blvd	200.0	290.0	36	>250
MR-008	First Valley Creek #2	Inverness Way	212.7	313.4	77	>250
MR-009	First Valley Creek #3	Laurel Avenue	212.7	305.8	163	>250
MR-010	Dream Farm Creek	Sir Francis Drake Blvd	180.0	324.0	28	>250
MR-011	Fish Hatchery Creek #1	Sir Francis Drake Blvd	212.7	221.5	18	21
MR-012	Fish Hatchery Creek #2	Vallejo Avenue	212.7	274.8	32	109
MR-013	Haggerty Gulch	Sir Francis Drake Blvd	312.6	468.2	>250	>250
MR-014	Old Bear Valley Creek	Sir Francis Drake Blvd	1.6	320.0	**0**	2
MR-015	Bear Valley Creek	Sir Francis Drake Blvd	354.0	492.0	**2**	4
MR-016	Cemetery Creek	Highway 1	77.2	114.0	7	23
MR-017	Boundary Gulch	Highway 1	378.0	770.0	>250	>250

MR-018	Water Tank Gulch	Highway 1	230.0	560.0	>250	>250
MR-019	Horse Camp Creek	Highway 1	124.0	256.0	6	78
MR-020	Giacomini Gulch	Highway 1	84.0	180.0	**3**	20
MR-021	John West Fork	Highway 1	354.0	534.0	48	>250
MR-022	Zanardi Gulch	Platform Bridge Rd.	212.7	324.3	143	>250

Table 4 (continued). Hydraulic capacities of 90 Marin County 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 (cfs)	Capacity at HW/F=1 (cfs)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
MR-023	Tocaloma Creek	Sir Francis Drake Blvd	77.2	124.8	52	>250
MR-024	McIsaac Creek	Sir Francis Drake Blvd	397.5	825.0	>250	>250
MR-025	Cheda Creek	Sir Francis Drake Blvd	308.5	665.9	38	>250
MR-026	Devil's Gulch	Sir Francis Drake Blvd	3,200.0	4,800.0	>250	>250
MR-027	Barnabe Creek	Sir Francis Drake Blvd	23.8	47.3	**1**	4
MR-028	Spring Creek #1	Lagunitas Road	37.6	69.7	24	>250
MR-029	Spring Creek #2	Mountain View Ave	13.6	23.8	**3**	11
MR-030	Arroyo Creek #1	Castro Street	436.6	587.4	197	>250
MR-031	Arroyo Creek #2	Sir Francis Drake Blvd	536.0	1,000.0	>250	>250
MR-032	El Ceritto Creek #1	Arroyo Road	64.1	109.5	6	38
MR-033	El Ceritto Creek #2	Tamal Road	103.6	186.9	113	>250
MR-034	Arroyo Creek #3	Arroyo Road	374.4	468.0	197	>250
MR-035	Arroyo Creek #4	Barranca Road	64.1	114.8	7	52
MR-036	Arroyo Creek #5	Barranca Road	77.2	145.9	14	>250
MR-037	Montezuma Creek #1	Guadalupe Ave	77.2	114.6	6	21
MR-038	Candelero Creek #1	Montezuma Ave	55.3	110.8	21	>250
MR-039	Candelero Creek #2	Candelero Road	31.2	58.7	**5**	35

MR-040	Montezuma Creek #2	Montezuma Ave	64.1	97.5	77	>250
MR-041	San Geronimo Creek #1	Montezuma Ave	4,470.0	4,500.0	>250	>250
MR-042	Iris Creek	Sir Francis Drake Blvd	195.5	306.0	>250	>250
MR-043	Larsen Creek	Sir Francis Drake Blvd	544.0	656.0	>250	>250
MR-044	Sylvestris Creek #1	Meadow Way	64.1	97.5	12	65

Table 4 (continued). Hydraulic capacities of 90 Marin County 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 (cfs)	Capacity at HW/F=1 (cfs)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
MR-045	Sylvestris Creek #2	Tamarack Road	142.2	404.3	>250	>250
MR-046	Creamery Creek	Meadow Way	77.2	149.2	**5**	41
MR-047	Deer Camp Canyon	San Geronimo Valley Rd	37.6	85.8	6	116
MR-048	Bates Canyon	San Geronimo Valley Rd	120.0	336.0	44	>250
MR-049	Woodacre Creek #1	San Geronimo Valley Rd	1,098.0	1,380.0	>250	>250
MR-050	Woodacre Creek #2	Park Street	340.0	460.0	22	85
MR-051	Woodacre Creek #3	Carson Road	212.1	253.2	8	14
MR-052	West Fork Woodacre #1	Garden Way	92.0	135.0	11	48
MR-053	West Fork Woodacre #2	Crescent Drive	103.6	177.5	18	224
MR-054	West Fork Woodacre #3	Redwood Drive	37.6	79.9	**2**	8
MR-055	West Fork Woodacre #4	Madrone Avenue	77.2	146.7	>250	>250
MR-056	East Fork Woodacre #1	Oak Grove Avenue	92.0	155.0	**3**	11
MR-057	East Fork Woodacre #2	Garden Way	92.0	160.0	**3**	13
MR-058	East Fork Woodacre #3	Crescent Drive	77.2	164.1	**3**	21
MR-059	East Fork Woodacre #4	Grove Avenue	77.2	100.8	**4**	8
MR-060	San Geronimo Creek #2	Railroad Avenue	680.0	1,200.0	>250	>250
MR-061	Spirit Rock Creek	Sir Francis Drake Blvd	103.6	285.8	>250	>250

MR-062	Flanders Creek	Sir Francis Drake Blvd	170.9	370.5	>250	>250
MR-063	Schooner Creek	Sir Francis Drake Blvd	625.2	866.0	16	66
MR-064	Drakes Creek	Sir Francis Drake Blvd	212.7	255.0	**5**	9
MR-065	McCurdy Creek	Highway 1	165.0	345.0	15	>250
MR-066	North Fk McCurdy Ck.	Highway 1	77.2	173.4	6	119

Table 4 (continued). Hydraulic capacities of 90 Marin County 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 (cfs)	Capacity at HW/F=1 (cfs)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
MR-067	Kent Canyon Creek	Muir Woods Road	134.9	236.7	6	43
MR-068	Arroyo Corte Madera del Presidio #1	Locust Avenue	1,052.8	1,568.0	>250	>250
MR-069	Arroyo Corte Madera del Presidio #2	None- Under Building	312.6	2,000.0	25	>250
MR-070	Arroyo Corte Madera del Presidio #3	King Street	409.5	567.0	>250	>250
MR-071	Arroyo Corte Madera del Presidio #4	Marguerite Avenue	980.0	1,600.0	>250	>250
MR-072	Arroyo Corte Madera del Presidio #5	W. Blithedale Avenue	410.0	600.0	>250	>250
MR-073	Arroyo Corte Madera del Presidio #6	W. Blithedale Avenue	756.0	848.4	>250	>250
MR-074	Arroyo Corte Madera del Presidio #7	Blithedale Summit Fire Rd	648.0	810.0	>250	>250
MR-075	Old Mill Creek #1	Miller Avenue	312.6	482.9	14	92

MR-076	Old Mill Creek #2	None- Under Post Office	312.6	464.2	14	74
MR-077	Old Mill Creek #3	Cascade Drive	1,000.0	1,300.0	>250	>250
MR-078	San Anselmo Creek #1	Saunders Avenue	6,401.0	6,600.0	>250	>250
MR-079	San Anselmo Creek #2	Pastori Avenue	4,551.0	7,030.0	>250	>250
MR-080	Fairfax Creek	Bolinas Avenue	465.3	742.5	6	29
MR-081	Sleepy Hollow Creek #1	Deer Hollow Road	1,560.0	1,690.0	>250	>250
MR-082	Sleepy Hollow Creek #2	Fawn Drive	985.5	1,620.0	>250	>250
MR-083	Sleepy Hollow Creek #3	Butterfield Road	542.8	1,180.0	96	>250
MR-084	Arroyo San Jose #1 - 4 bays	Bel Marin Keys	2,112.0	3,408.0	>250	>250

Table 4 (continued). Hydraulic capacities of 90 Marin County 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 (cfs)	Capacity at HW/F=1 (cfs)	Return Interval to Overtop Culvert (years)	Return Interval to Overtop Road Prism (years)
MR-085	Arroyo San Jose #2	Ignacio Boulevard	1,632.0	1,752.0	>250	>250
MR-086	Vineyard Creek #1	McClay Avenue	1,093.3	1,834.0	>250	>250
MR-087	Vineyard Creek #2	Wilson Road	440.0	630.0	70	>250
MR-088	Vineyard Creek #3	Trumbull Avenue	528.0	708.0	>250	>250
MR-089	Vineyard Creek #4	Mill Road	425.4	714.7	108	>250
MR-090	Leveroni Creek	Novato Boulevard	436.6	1,316.2	244	>250

Passage Analyses

The **GREEN**-**GRAY**-**RED** first-phase evaluation filter reduced the number of sites requiring in-depth analyses with FishXing. The initial use of the first-phase filter was followed by FishXing evaluations utilizing the conservative swimming abilities and minimum depth requirement as recommended in the CDFG assessment protocol. This initial analysis resulted in 62 of 90 surveyed crossings (or 69% of the sites) defined as **RED**, or failing to meet CDFG's fish passage criteria for adult and juvenile salmonids throughout the entire range of migration flows (CDFG 2002). Examination of the site photos and fish observations during winter spawning surveys confirmed adult coho salmon and steelhead were migrating through many of these **RED** crossings (Ketcham and Walder, pers. comm.).

When the more rigorous swimming abilities of 8-16-16 ft/sec and a minimum water depth of 0.5 feet were used in a second round of FishXing analyses, the number of **RED** crossings dropped to 46 sites (or 51% of the sites). The range of migration values for **GRAY** sites also increased and resulted in a wider distribution of the ranking scores.

It is important to note that crossings which failed to meet the more rigorous criteria may still actually provide partial or temporal passage during certain flow conditions, especially if FishXing identified the only violation of the passage criteria as a lack-of-depth. However, all **RED** sites were given a "total barrier" score in the ranking matrix.

Eleven stream crossings (12.2% of the sites) were defined as **GREEN** with the first-phase evaluation filter and were assumed to provide unimpeded passage for all age classes of coho salmon and/or steelhead. These crossings were typically culverts that spanned at least the average active channel width and/or were fully embedded with streambed substrate. Due to natural variations in channel morphology, it is recommended that these sites are still periodically inspected to ensure they remain embedded with substrate.

FishXing proved an extremely useful tool in estimating the extent of passage at the 79 **GRAY** and **RED** 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 and assumptions that must be acknowledged.

Over the past six winters, repeated visits to numerous crossings with culverts in northern California during migration flows revealed some confounding results generated by FishXing:

1. Adult salmonids having great difficulties entering perched culverts which FishXing suggested were easily within the species' leaping and swimming capabilities.

2. Adult salmonids successfully migrating through water depths defined as "too shallow" by current fish passage criteria.

3. The behavior and abilities of fish are too varied and complex to be summed up with an equation or number taken from a published article. Even a single fishes' leaping and swimming abilities at a culvert may change as numerous attempts are made. Extensive winter-time observations at culverts in northern California have documented individual fish become fatigued over repetitive attempts, and conversely documented other fish gaining access to culverts after numerous failed attempts (Taylor 2000 and 2001; Love pers. comm.).

Due to these factors, passage evaluation results generated by FishXing were used conservatively in the ranking matrix by lumping "percent passable" into large (20%) categories. Adult steelhead and coho salmon were lumped as the "adult" run, 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 and coho salmon 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 stream crossing location within the eight sub-watershed categories or areas (Figures 7-14). For each site, by species and lifestage, FishXing evaluation results are provided in Appendix B. The "Comments" column in Appendix B lists assumptions made concerning specific sites while running FishXing. Also provided in Appendix B are the hydrologic information utilized to calculate peak flows and fish passage flows.

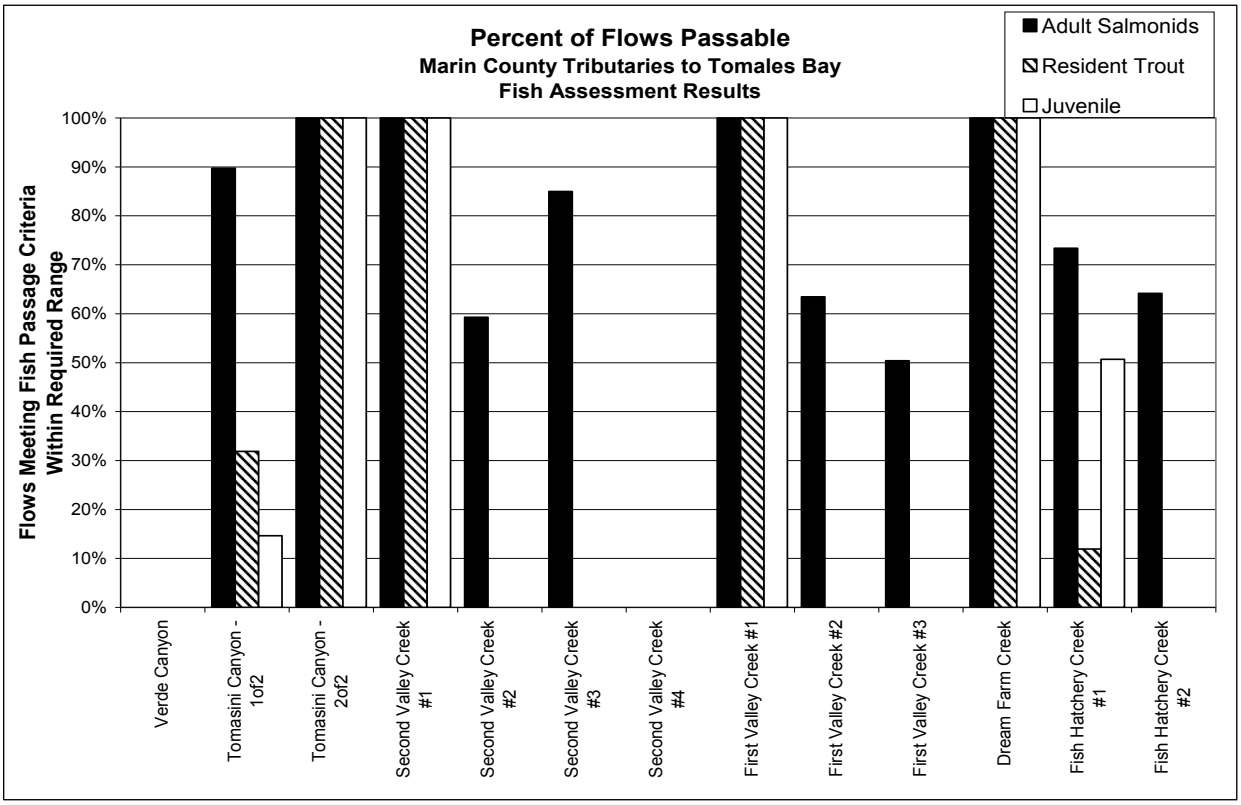

Figure 7. Percent passable as estimated by the Green-Gray-Red evaluation filter and FishXing for 12 Marin County stream crossings within tributaries of the Tomales Bay sub-watershed, by three groups of life stages.

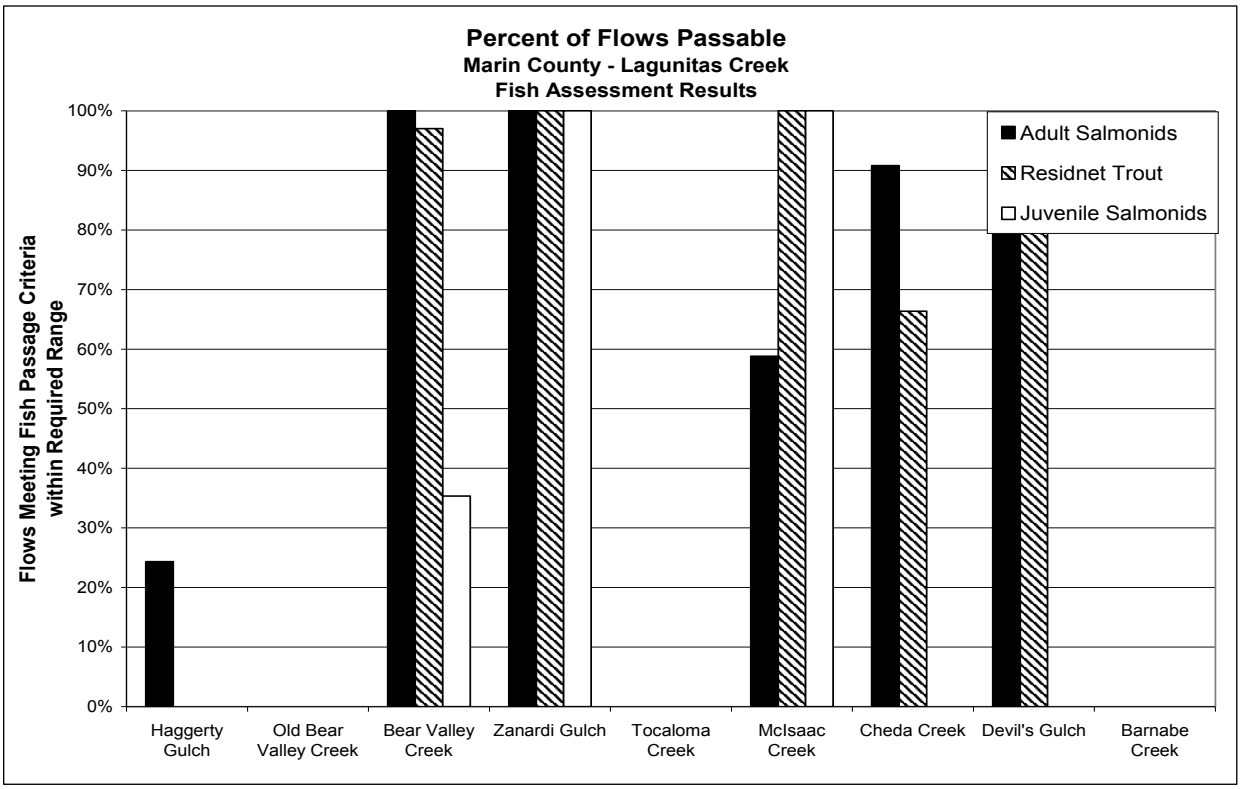

Figure 8. Percent passable as estimated by the Green-Gray-Red evaluation filter and FishXing for nine Marin County stream crossings within tributaries of Lagunitas Creek, by three groups of life stages.

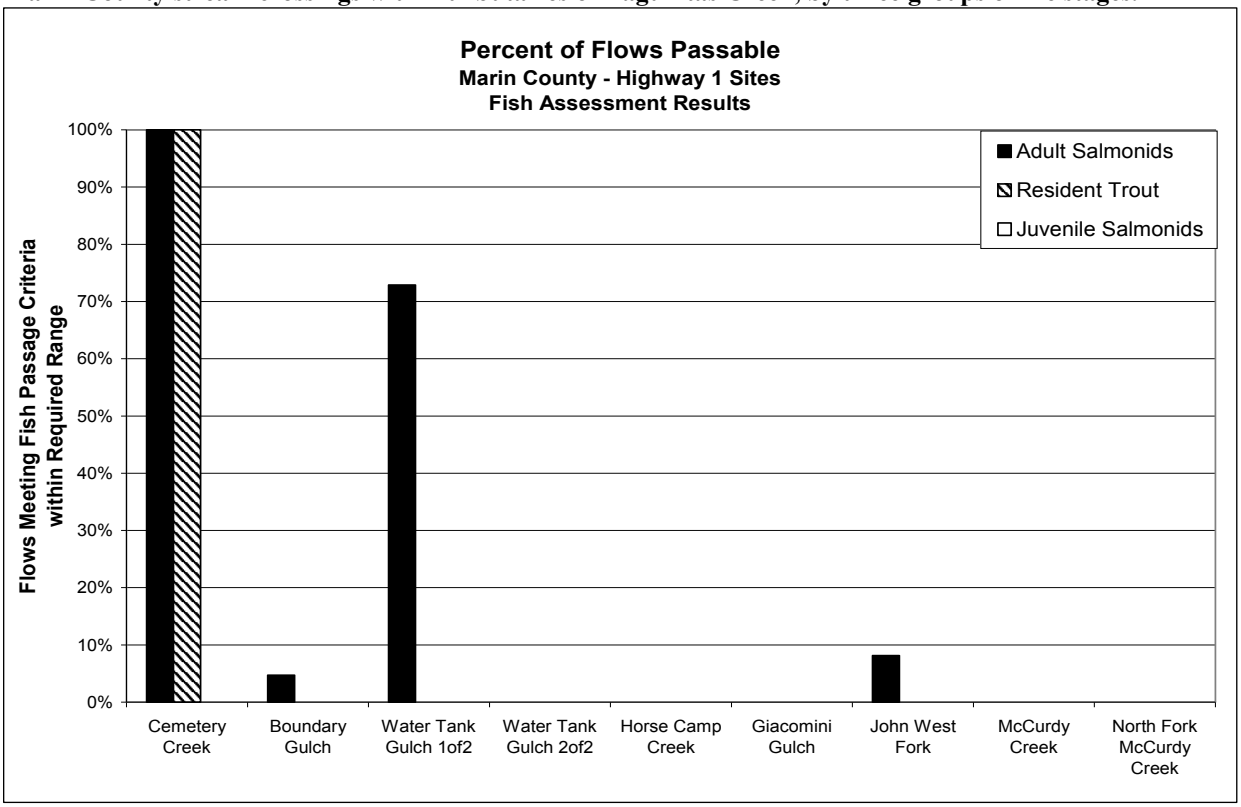

Figure 9. Percent passable as estimated by FishXing for eight Marin County stream crossings located on Highway One on tributaries to Olema Creek and Pine Creek, by three groups of life stages.

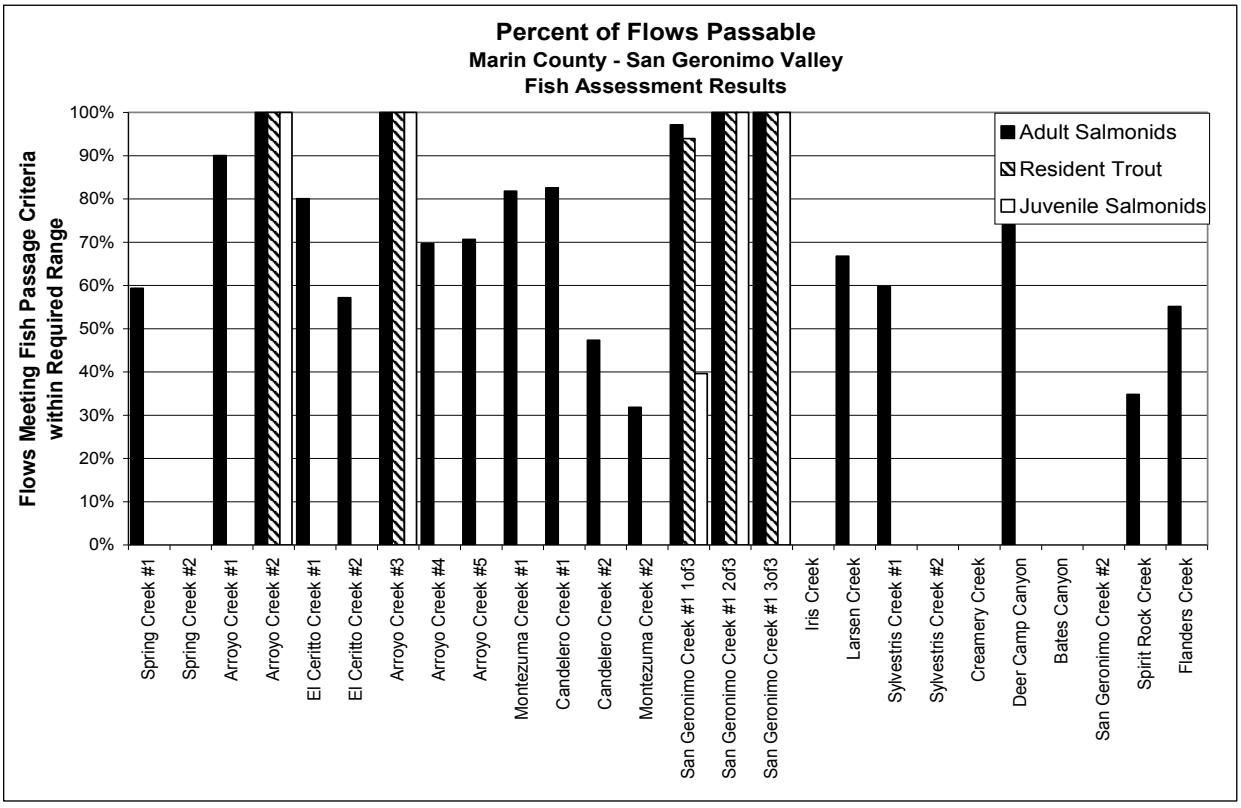

Figure 10. Percent passable as estimated by FishXing for 24 Marin County stream crossings within the San Geronimo sub-basin of the Lagunitas Creek watershed, by three groups of life stages.

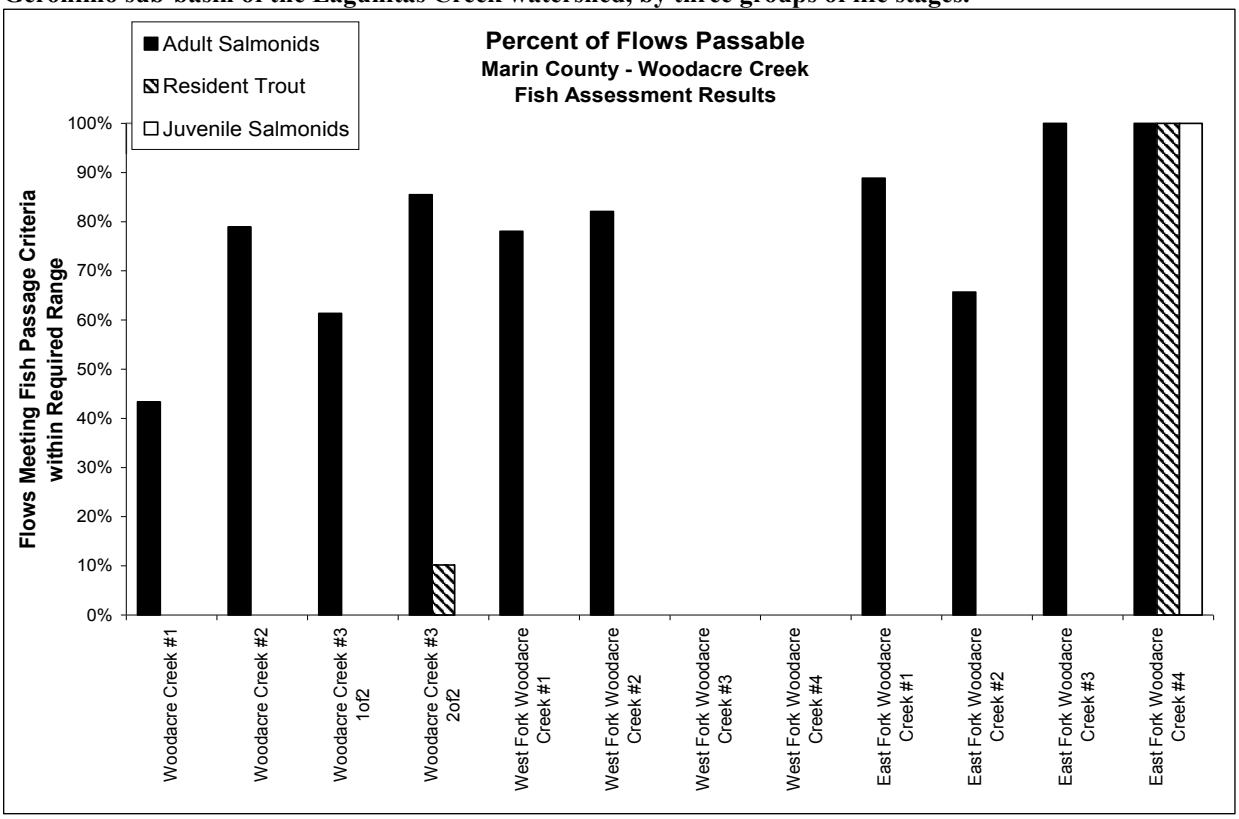

Figure 11. Percent passable as estimated by FishXing for 11 Marin County stream crossings within the Woodacre Creek sub-basin of the Lagunitas Creek watershed, by three groups of life stages.

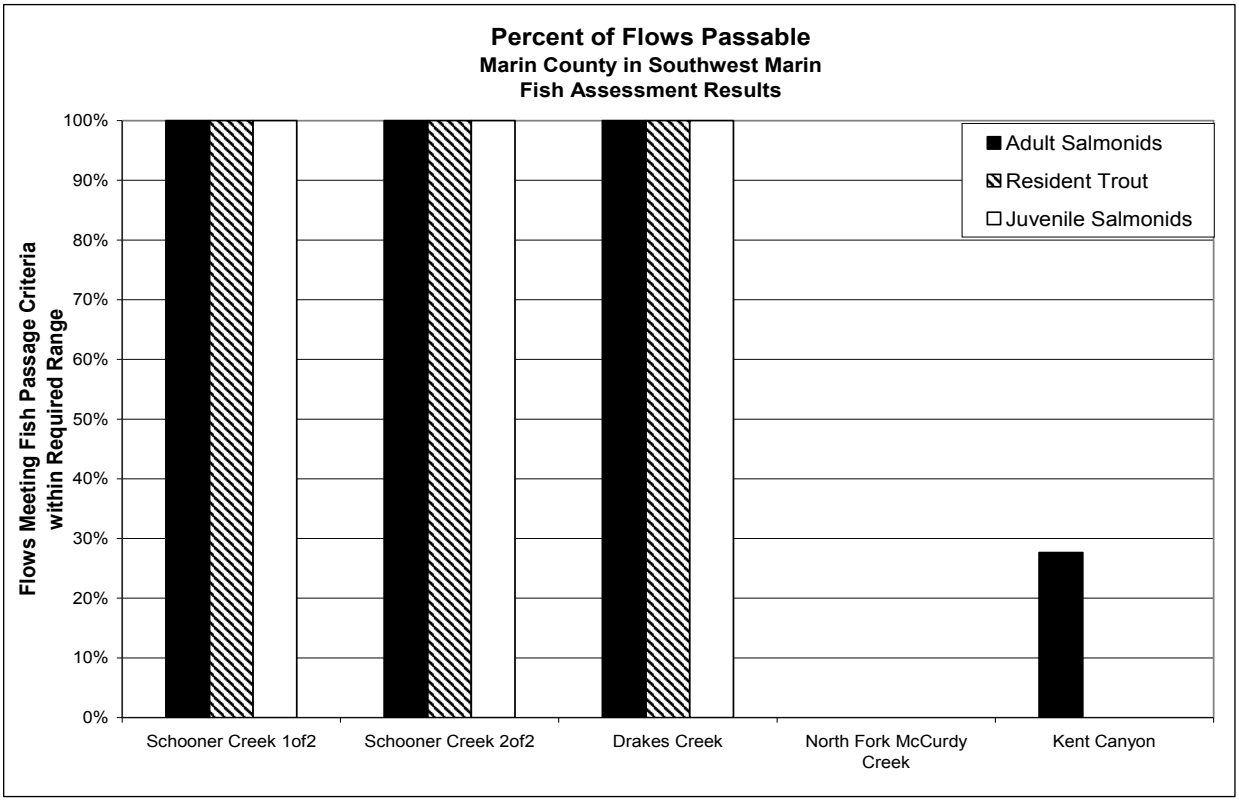

Figure 12. Percent passable as estimated by FishXing for four Marin County stream crossings on tributaries located in southwestern Marin County, by three groups of life stages.

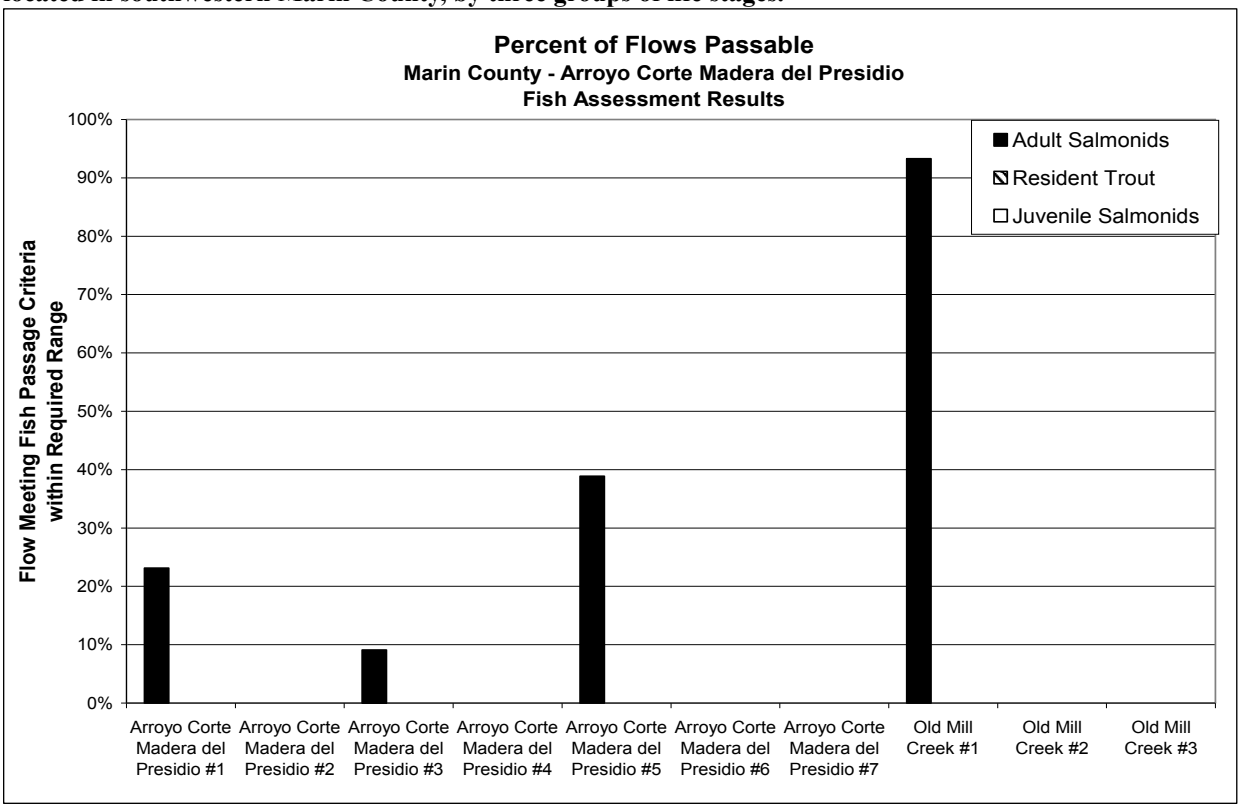

Figure 13. Percent passable as estimated by FishXing for 10 Marin County stream crossings within the Arroyo Corte Madera del Presidio watershed, by three groups of life stages.

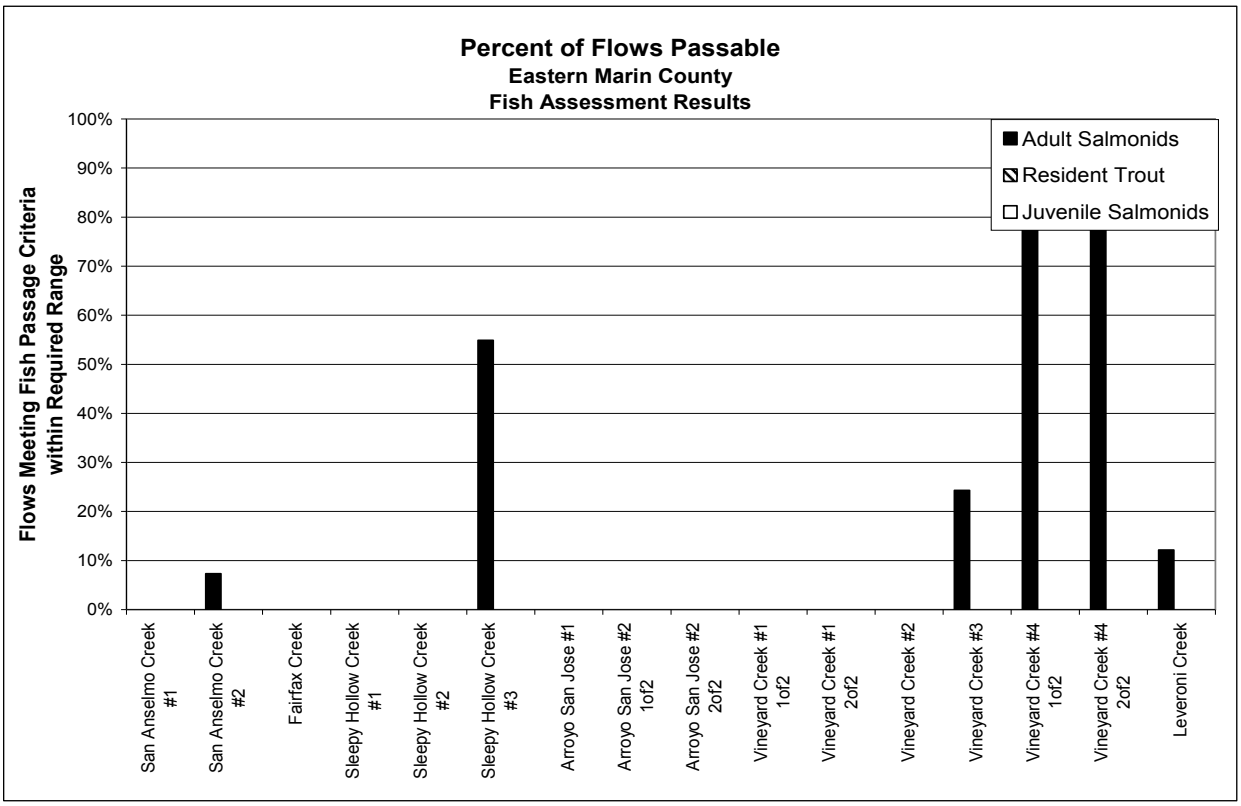

Figure 14. Percent passable as estimated by FishXing for 13 Marin County stream crossings within eastern Marin County watershed, by three groups of life stages.

Ranking Matrix

The 90 Marin County stream crossing locations were sorted by "Total Score", the sum of the four ranking criteria (Appendix C). The right-hand column of the final ranking matrix provides information on the passage analyses, general recommendations for treatment and suggested changes in treatment order due to professional judgment and other factors (Table 5).

As previously mentioned in the Methods section, the primary purpose of the ranking matrix developed for the CDFG protocol was to roughly sort the sites into a descending order of scores where sites could be grouped as high, medium, or low priority. There are many other factors to consider when selecting sites to treat that were not feasible to capture in a discrete scoring matrix. On a site-specific basis, one or more of the following factors were considered when recommending that a site be either raised or lowered in the ranking for project scheduling:

- Additional migration barriers above or below a site – lower in ranking.
- Criteria other than "extent of barrier" accounting for large percentage of final score – lower in ranking.
- Expensive replacement is only feasible treatment option – lower in rank.
- Cost-effective retrofit versus expensive replacement – raise in ranking.
- Site with limited reach of upstream habitat, but of good-quality and currently utilized by coho salmon (or coho known to occur immediately downstream of crossing) – raise in ranking.
- Limited upstream habitat benefit, but high likelihood of crossing failure and potential for significant sediment release to good-quality downstream habitat – raise in ranking.
- Instances where two streams' culverts meet at a common confluence and the two sites could be addressed as a single project – raise in ranking.
- In streams with multiple crossings (such as Arroyo Corte Madre del Presidio or Woodacre Creek) re-arranging sites so that treatment proceeds in an upstream direction – either raise or lower in ranking.

Adjustments to the suggested order of treatment scheduling in this final report were made after three drafts of the ranking matrix and one draft of Table 5 were circulated for review by the County of Marin, CDFG, CalTrans, Point Reyes National Seashore, and several watershed groups. However, as new information becomes available after the completion of this report, the exact order of treatment will probably continue to change. For example, some streams lacked current fisheries or habitat typing information to formulate a quantitative evaluation of potential biological significance of the habitat upstream of some sites. In these cases, recommendations were qualified by the County first obtaining better fisheries and habitat data before committing a site to a treatment schedule.

Table 5. Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Distri	Barrier Score	Length of Upstream	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#1	MR-021	John West Fork	Highway 1	Coho salmon and steelhead	14	7,800	25.4	Although FishXing indicated a lack-of-depth below 24cfs (<0.5', but minor violation) – coho annually spawn above this site since the crossing was modified. However, the crossing is still a serious impediment to migration. High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing unimpeded access to over one mile of spawning and rearing habitat in an Olema Creek tributary that currently supports runs of two ESA-listed species is a high-priority. Full replacement with a bridge or open-bottom arch is recommended. CalTrans should probably treat Highway 1 crossings at Giacomini Gulch and McCurdy Creek prior to
#2	MR-020	Giacomini Gulch	Highway 1	Coho salmon and steelhead	15	6,000	25.0	High-priority due to: severity of the barrier to all life stages of salmonids (outlet perched 3.44 ft.) and significant length of upstream habitat gain. Re-establishing access to over one mile of spawning and rearing habitat in an Olema Creek tributary where both coho and steelhead juveniles have been observed below the crossing is a high-priority. Full replacement with a bridge or open-bottom arch is recommended. CalTrans should probably treat Highway 1 crossings at Giacomini Gulch and McCurdy Creek prior to John West Fork because
#3	MR-066	North Fork McCurdy Creek	Highway 1	Coho salmon and steelhead	15	4,300	23.7	Confluence of North Fork McCurdy and McCurdy Creeks is under a single Highway 1 crossing. High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing access to nearly one mile of spawning and rearing habitat in a Pine Creek tributary that currently supports runs of two ESA-listed species is a high-priority. Full replacement with a bridge or open-bottom arch is recommended. CalTrans should probably treat Highway 1 crossings at Giacomini Gulch and
#4	MR-076	Old Mill Creek #2	None-Under Post Office	Steelhead	15	9,000	23.5	High-priority due to: severity of the barrier to all life stages of steelhead and significant length of upstream habitat gain. Passage through Old Mill Creeks #1 and #2 should be addressed as a single project. Although the crossing is undersized and in poor condition, a full replacement with a bridge or open-bottom arch may not be feasible because the culvert is under a block of buildings. Consider feasibility of jack-and-bore of the current culvert and install a larger culvert with corner baffles. Also consider feasibility of relocating and day-lighting section of channel. Old Mill Creek also has active

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Distri	Barrier Score	Length of Upstream	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank

#5	MR-065	McCurdy Creek	Highway 1	Coho, Steelhead	15	4,300	23.2	Confluence of North Fork McCurdy and McCurdy Creeks is under a single Highway 1 crossing. High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing access to nearly one mile of spawning and rearing habitat in a Pine Creek tributary that currently supports runs of two ESA-listed species is a high-priority. Full replacement with a bridge or open-bottom arch is recommended. CalTrans should probably treat Highway 1 crossings at Giacomini Gulch and McCurdy Creek prior to John West Fork because
#6	MR-069	Arroyo Corte Madera del Presidio #2	None-Under Building	Steelhead	15	11,800	23.0	Outlet pool is the confluence of Old Mill Creek and Arroyo Corte Madera Del Presidio Creek. Because the current culverts are located underneath buildings, a full replacement is probably not a feasible treatment option to improve fish passage. Corner baffles within this culvert and two or three downstream weirs (sloped, concrete with low-flow notches) would cost effectively improve passage. Old Mill Creek #1 is undersized and in poor condition (refer to previous page for suggested treatment. City of Mill Valley Public Works should consult with CDFG and NOAA hydraulic engineers
#7	MR-054	West Fork Woodacre Creek #3	Redwood Drive	Coho, Steelhead	15	1,750	22.9	Site should be dropped in priority until all passage impediments on West Fork Woodacre and mainstem Woodacre Creek downstream of this site are addressed. This site scored fairly high due to its extremely poor sizing and fair condition. Current culvert has a slope = 7.93%. The invert has rusted-through and was reinforced with concrete. A full replacement with a properly sized embedded circular SSP culvert or an open-bottom arch set on concrete footings is the best long-term solution for
#8	MR-049	Woodacre Creek #1	San Geronimo Valley Rd	Coho, Steelhead	12	7,900	22.4	High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing unimpeded access to over one mile of spawning and rearing habitat in a Lagunitas Creek tributary that currently supports runs of two ESA-listed species is a high-priority. When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 43%. This site should be treated before other Woodacre crossings because

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#9	MR-0500	Woodacre Creek #2	Park Street	Coho, Steelhead	11	7,000	22.3	High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing unimpeded access to over one mile of spawning and rearing habitat in a Lagunitas Creek tributary that currently supports runs of two ESA-listed species is a high-priority. When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this site dropped one point in extent-of-barrier score for adults. This site should be treated after Woodacre Creek #1, but before addressing the other nine County-maintained crossings in the Woodacre Creek watershed upstream of this crossing. Full replacement with a bridge or an open-bottom arch is
Tied for #10	MR-0488	Bates Canyon	San Geronimo Valley Rd	Coho, Steelhead	15	900	22.2	High-priority due to: severity of the barrier to all life stages of salmonids, quality of upstream habitat, and poor condition of the current crossing. Although there is only approximately 1,000 feet of spawning and rearing habitat upstream of this crossing, the habitat is of good-quality and the lower section of Bates Canyon is utilized by coho salmon for spawning and rearing. Any tributary that currently supports coho spawning and rearing should be considered an important Lagunitas Creek tributary. The box culvert's outlet is perched 3.1 feet and there is a lack-of-depth in the outlet pool for fish to leap from. Full replacement with a bridge or an open-
Tied for #10	MR-0600	San Geronimo Creek #2	Railroad Avenue	Coho, Steelhead	15	4,200	22.2	High-priority due to: severity of the barrier to all life stages of salmonids and significant length of upstream habitat gain. Re-establishing unimpeded access to nearly one mile of spawning and rearing habitat in a Lagunitas Creek tributary that currently supports runs of two ESA-listed species is a high-priority. The current box culvert's outlet is perched 2.93 feet and there is also a lack-of-depth through the culvert that creates sheet flow with high velocities during migration-level flows. Approximately 800 feet upstream from this County-maintained crossing there is a filled-in dam on private property (Dixon Ranch) that has a six to seven foot drop onto a concrete apron (Walder et al 2002). The County and SPAWN should work with the landowner to treat the dam site (possibly partial removal with grade control weirs to minimize channel head-cutting. Recommended treatment at

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#11	MR-006	Second Valley Creek #4	Aberdeen Way	Steelhead	15	2,200	22.1	**NOTE:** drop in order of County's treatment schedule because the current crossing scored fairly high due to its poor condition and under-sizing. County should focus treatments on streams that currently support runs of coho salmon. There are also partial/temporal passage impediments of Second Valley Creek #2 and #3 that should be treated prior to this crossing. A properly sized, fully embedded SSP culvert or an open-bottom arch
Tied for #12	MR-014	Old Bear Valley Creek	Sir Francis Drake Blvd	Steelhead	15	30,300	22.0	**NOTE:** Drop this crossing completely from the final ranking. This site is the old crossing and the new County crossing (Site ID# MR-015) provides unimpeded passage for all age classes of anadromous salmonids. This culvert is completely filled in with bedload
Tied for #12	MR-078	San Anselmo Creek #1	Saunders Avenue	Steelhead, coho?	15	47,100	22.0	High-priority due to length of potential habitat – more than eight miles. The current fish ladder appears ineffective and should be replaced. A literature review conducted by Taylor and Associates confirmed that the current structure fails to meet Denil fish ladder specifications. The narrow concrete channel downstream of the fish ladder is also an impediment to fish migration. A replacement structure needs to address the downstream concrete channel too. The City of San
#13	MR-001	Verde Canyon	Marshall-Petaluma Rd	Steelhead	15	8,100	21.6	Current crossing's outlet is perched 6.9 feet that spills over riprap. A replacement with a properly sized open-bottom arch set on concrete footings or a bridge is the best long-term solution to provide unimpeded passage. Grade control weirs may be required to minimize potentially extensive head-cutting of the stream channel. Conducting habitat typing and fisheries surveys are recommended to better assess the anadromous fisheries potential of Verde Canyon prior to committing to a treatment
Tied for #14	MR-080	Fairfax Creek	Bolinas Avenue	Steelhead	15	9,600	21.4	**NOTE:** drop in order of treatment scheduling because of high-cost to implement the recommended treatment option (replacement). The current box culvert is 458 feet long and its outlet is perched 4.2 feet. Treatment options at this site are problematic because of several factors. A retrofit is probably not feasible because the box culvert is undersized and the inlet overtops on less than a 10-year storm flow, thus further reduction of capacity by baffles or weirs within the culvert is not recommended. The crossing's outlet is within 25 feet of the confluence of Fairfax Creek and San Anselmo Creek, thus there is insufficient room for a series of downstream boulder weirs to raise tail-water elevation. A full replacement may be cost-prohibitive due to the

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank

Tied for #14	MR-051	Woodacre Creek #3	Carson Road	Coho, Steelhead	11	3,800	21.4	**NOTE:** raise in County's priority so that all Woodacre Creek crossings are treated in a comprehensive program to improve passage in this important coho and steelhead sub-basin of Lagunitas Creek. Current crossing comprised of two culverts is sized to pass less than a 10-year storm flow, is in poor condition, and is due for replacement. Recommended treatment is a properly sized open-bottom arch set on concrete footings or a bridge to provide unimpeded passage and increased storm flow capacity. When the crossing was re-evaluated by FishXing with the more rigorous swimming
Tied for #14	MR-025	Cheda Creek	Sir Francis Drake Blvd	Coho, Steelhead	9	7,800	21.4	**NOTE:** drop in order of County's treatment schedule because the current crossing provides adequate passage. This crossing scored fairly high due to the large amount of high-quality habitat upstream of Sir Francis Drake Blvd. The County should be aware that the current culvert is in poor condition, undersized, and is due for replacement. The best long-term solution is a properly sized bridge or open-bottom arch set on concrete footings to provide unimpeded passage of all age classes of
Tied for #15	MR-027	Barnabe Creek	Sir Francis Drake Blvd	Steelhead?	15	800	21.2	Outlet is perched 6.2 ft. and culvert has 9% slope. Although the upstream channel appears of poor-quality for providing spawning and rearing habitat for salmonids, the crossing is in poor condition, extremely undersized, and is due for replacement. The fill estimate of 250 cubic yards only accounts for the material on the road prism. However, if this crossing were to fail, at least several thousand cubic yards of sediment stored in the channel upstream of Sir Francis Drake Blvd would be mobilized and may have a significant impact on the high-quality habitat in Lagunitas Creek. A full replacement is the best long-term solution to improve fish passage and reduce the likelihood of a catastrophic fill failure. A concrete box culvert with an internal fish ladder may be the only feasible means to facilitate partial/ temporal fish passage due to the steep slope and crossing's close proximity to mainstem Lagunitas
Tied for #15	MR-074	Arroyo Corte Madera del Presidio #7	Blithedale Summit Fire Road	Steelhead	15	5,300	21.2	**NOTE:** drop in order of County's treatment schedule because the current crossing probably provides some passage for adult steelhead. FishXing indicates only lack-of-depth - adult passage probably occurs - drop a bit in final rank. Treatments should first occur at the downstream locations where passage is currently impeded = Arroyo Corte Madera del Presidio #1, #2, #3, #4

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Diversity	Barrier Score	Length of Upstream	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
Tied for #15	MR-077	Old Mill Creek #3	Cascade Drive	Steelhead	15	7,300	21.2	Steep drop at inlet apron/dam impedes fish passage and has created an extremely aggraded upstream channel. Retrofitting the existing crossing to improve fish passage may be feasible by partial removal of the apron/dam at the crossing's inlet. Consider the feasibility of incrementally removing the apron/dam structure over several seasons to gradually release the sediment stored in the aggraded channel reach upstream. However, best long-term solution is a full replacement with a bridge or open-bottom arch set on concrete footings. City of Mill Valley should treat passage

#16	MR-029	Spring Creek #2	Mountain View Ave	Steelhead?	15	200	21.1	**NOTE:** drop in order of County's treatment schedule because Spring Creek may not be suitable for anadromous fish. The culvert has a 8.92% slope and its outlet is perched 5.5 feet. Although there is very little upstream habitat potential, the culvert is in poor condition and is due for replacement. Lack of habitat make this site a poor candidate for treatment with fisheries restoration funding.
Tied for #17	MR-079	San Anselmo Creek #2	Pastor Avenue	Steelhead, coho?	14	43,000	21.0	The current fish ladder appears ineffective and should be replaced. A literature review conducted by Taylor and Associates confirmed that the current structure fails to meet Denil fish ladder specifications. The City of San Anselmo Public Works should consult with CDFG and NOAA hydraulic engineers for design assistance.
Tied for #17	MR-067	Kent Canyon	Muir Woods Road	Steelhead, coho	13	3,900	21.0	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 28%. A full replacement with a properly sized bridge or an open-bottom arch set on concrete footings is recommended as the best long-term solution to provide unimpeded passage and increase storm flow capacity. Conducting habitat typing and fisheries surveys are recommended to better assess the anadromous fisheries potential of Kent Canyon.
#18	MR-046	Creamery Creek	Meadow Way	Steelhead, coho?	15	700	20.9	**NOTE:** drop in order of County's treatment schedule because Creamery Creek has a limited reach of potential upstream habitat. Historical information suggests that this creek once supported anadromous fish, however no observations have been noted in past 10 or more years (Walder et al. 2002). Outlet is perched 8 ft and has steeply-sloped outlet apron. Current culvert is undersized and in poor condition, thus a full replacement is the only feasible treatment option – bridge or an open-bottom arch set on concrete footings. Grade control weirs may be required to minimize head cutting of

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species	Barrier Score	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
Tied for #19	MR-071	Arroyo Corte Madera del Presidio #4	Margueriite Avenue	Steelhead	15	6,600	20.8	Smooth concrete floor with 3.15% slope for 35 feet. For adult salmonids, FishXing indicated strictly lack-of-depth criteria violation. Because the current crossing is properly sized, passage could be cost-effectively improved with a retrofit. Three to four boulder weirs downstream of the outlet would increase tail-water elevation and possibly back-water the culvert. Fully-spanning, sloped concrete weirs within the culvert and an outlet beam with a low-flow notch would increase depths and decrease velocities. **NOTE:** Treatments should first occur at the downstream locations where passage is currently impeded = Arroyo Corte Madera del Presidio #1, #2
Tied for #19	MR-073	Arroyo Corte Madera del Presidio #6	W. Blithedale Avenue	Steelhead	15	5,500	20.8	FishXing indicates lack-of-depth as the only violation of the passage criteria for adult steelhead. From site photos, the crossing appears at least partially passable for adult steelhead. Two to three boulder weirs downstream of the outlet would increase tail-water elevation and possibly back-water the culvert. **NOTE:** Treatments should first occur at the downstream locations where passage is currently impeded = Arroyo Corte Madera del Presidio #1, #2, #3, #4. City of Mill Valley's Public Works Department should consult with CDFG and

#20	MR-042	Iris Creek	Sir Francis Drake Blvd	Coho, Steelhead	15	800	20.7	Outlet is perched approximately five feet and has steeply-sloped outlet apron that is set on natural bedrock outcrop. The current culvert is properly sized for storm flow conveyance, however it is in poor condition - invert is worn down to exposed rebar. Historically, coho salmon have been observed spawning upstream of this perched culvert, but none in the past five winters (Walder et al 2002). A retrofit with a series of four to five downstream weirs to raise tail-water elevation may be feasible
#21	MR-070	Arroyo Corte Madera del Presidio #3	King Street	Steelhead	14	7,700	20.4	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this site dropped one point in extent-of-barrier score for adults. **NOTE:** Treatments should first occur at the downstream locations where passage is currently impeded = Arroyo Corte Madera del Presidio #1 and #2. However, treat prior to upper sites (#4, #6, and #7) that scored slightly higher. Because the current box culvert is properly sized, a retrofit is recommended to improve conditions for fish passage. At least four to five boulder weirs are required to sufficiently raise the tail-water elevation and corner baffles within the culvert will increase depths and decrease

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Diversity	Barrier Score	Length of Upstream Habitat (ft)	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
Tied for #22	MR-068	Arroyo Corte Madera del Presidio #1	Locust Avenue	Steelhead	13	24,800	20.0	**NOTE:** City of Mill Valley should raise this site in project scheduling to treat prior to addressing migration impediments at crossings located upstream that scored higher in the ranking matrix. When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this site dropped two points in extent-of-barrier score for adults. Because the current box culvert is properly sized, a retrofit is recommended to improve conditions for fish passage. A series of sloped, concrete weirs with low-flows notches through the box culvert would increase depths. City of Mill Valley's Public Works
Tied for #22	MR-081	Sleepy Hollow Creek #1	Deer Hollow Road	Steelhead	15	16,800	20.0	Outlet is perched 5.8 ft and spills over bedrock/ concrete drop. Because the current box culvert is properly sized, a retrofit is recommended to improve conditions for fish passage. At least five to six boulder weirs are probably required to sufficiently raise the tail-water elevation and corner baffles within the culvert will increase depths and decrease velocities. Consider feasibility of constructing a concrete fish ladder onto the bedrock outcrop at the culvert outlet – especially if a series of boulder weirs is not feasible due to lack-of-access across private property for construction. A series of sloped, concrete weirs with low-flows notches through the box culvert would increase depths. Recommend consulting with CDFG and NOAA hydraulic engineers for design assistance. **NOTE:** this crossing seriously impedes upstream passage and

Tied for #22	MR-087	Vineyard Creek #2	Wilson Road	Steelhead	15	20,200	20.0	**NOTE:** drop in order of County-wide treatment schedule because there are sites impeding passage in biologically more significant streams in western Marin County. Outlet of current culvert is perched 3.32 ft, and crossing is part of a long concrete flood-channel/ditch. Because the current box culvert is adequately sized, a retrofit is recommended to improve conditions for fish passage. At least two to three concrete weirs (with low-flow notches) are probably required to sufficiently raise the tail-water elevation and corner baffles within the culvert will increase depths and decrease velocities. Sack Crete channel should be partially removed too. Entire

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
Tied for #23	MR-030	Arroyo Creek #1	Castro Street	Coho, Steelhead	10	7,200	19.9	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 100%. However, direct observations during winter migration flows suggests that adult coho salmon have some difficulty negotiating the sheet flow exiting the culvert over the concrete apron and juveniles are unable to migrate upstream (Walder, pers. comm.). Short-term solution to improve passage would be installation of two to three downstream boulder weirs to raise tail-water elevation. The best long-term solution is a replacement with a bridge or open-bottom arch set on concrete footings to restore unimpeded passage for all age classes of salmon and steelhead in this important spawning and rearing tributary to San Geronimo Creek. Grade control structures should
Tied for #23	MR-058	East Fork Woodacre Creek #3	Crescent Drive	Coho, Steelhead	10	1,700	19.9	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 60% to 100%. The current crossing is extremely undersized and in very poor condition, thus a replacement with a properly sized open-bottom arch set on concrete footings is recommended as the best long-term solution to improve fish passage and increase the crossing's hydraulic capacity. **NOTE:** crossing was funded for replacement prior to the start of the Marin County stream crossing inventory – project to be
#24	MR-072	Arroyo Corte Madera del Presidio #5	W. Blithedale Avenue	Steelhead	13	6,500	19.8	FishXing indicated that lack-of-depth was the only violation of the passage criteria – thus actual passage may be higher than predicted. Passage could be cost-effectively improved by installing corner baffles within box culvert. Existing concrete grade control may provide sufficient back-water. **NOTE:** Treatments should first occur at the downstream locations where passage is currently impeded = Arroyo Corte Madera del Presidio #1, #2, #3, #4. City of Mill Valley's Public Works Dept.
#25	MR-019	Horse Camp Creek	Highway 1	Steelhead, coho?	15	1,300	19.7	**NOTE:** drop in order of County-wide treatment schedule because there are sites impeding passage in biologically more significant streams in western Marin County. Outlet is perched 3.3 ft and has a sloped (13%) concrete outlet apron. Current culvert is undersized and overtops on less than a 10-year storm flow. No fisheries or habitat information was available to assess the significance of this Olema Creek tributary. These assessments are

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank

Tied for #26	MR-082	Sleepy Hollow Creek #2	Fawn Drive	Steelhead	15	16,000	19.5	**NOTE:** site should be lowered in project scheduling because site is probably allows some passage and current available habitat is only 4,200 feet (up to Raven Dam). For adult salmonids, FishXing indicated a lack-of-depth violation up to 30cfs, then excess velocities. From site photographs, the crossing appears partially passable for adults. Fish passage could be cost-effectively improved by installing fully-spanning, sloped concrete weirs within the box culvert, a notched outlet beam, and possibly a single downstream
Tied for #26	MR-084	Arroyo San Jose #1 - 4 bays	Bel Marin Keys	Steelhead	15	19,800	19.5	**NOTE:** site should be lowered in project scheduling because of other passage impediments and potentially excessive total cost to restore passage. The outlet of this four-bay box culvert is perched 5.2 feet and drops over riprap. There are numerous passage issues within Arroyo San Jose beyond stream crossings – including sections of concrete flood channel, dams, concrete weirs and riprap. Consider feasibility of partial removal of the invert of one or two bays of the culvert to create an at-grade channel for fish passage. However, the total cost of treating all migration barriers within
Tied for #26	MR-085	Arroyo San Jose #2	Ignacio Boulevard	Steelhead	15	16,800	19.5	**NOTE:** site should be lowered in project scheduling because of other passage impediments and potentially excessive total cost to restore passage. Upstream weir is a barrier – this two-bay box culvert is part of a long section of concrete channel. There are numerous passage issues within Arroyo San Jose beyond stream crossings – including sections of concrete flood channel, dams, concrete weirs and riprap. Installation of corner baffles within the right bank bay will increase water depths and improve passage. However, the total cost of treating all migration barriers within Arroyo
Tied for #26	MR-086	Vineyard Creek #1	McClay Avenue	Steelhead	15	24,000	19.5	Outlet of current two-bay box culvert has five to six foot drop over riprap. Because the current box culvert is properly sized, a retrofit is recommended to improve conditions for fish passage. At least three to four boulder weirs are probably required to sufficiently raise the tail-water elevation and corner baffles within the culvert will increase depths and decrease velocities. Install an inlet beam to direct lower migration flows into a single bay and install corner baffles within both bays. Recommend consulting with CDFG and NOAA hydraulic engineers for design assistance. Note: treat prior to

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#27	MR-043	Larsen Creek	Sir Francis Drake Blvd	Coho, Steelhead	11	5,200	19.1	When the crossing was re-evaluated by FishXing with the more rigorous passage criteria, adult passage changed from 0% to 67%.; however assessment was difficult due to the series of weirs and baffles. Surveys confirm that adult salmonids migrate through this crossing, but weirs leak at lower flows and strand juveniles during out-migration (Walder, pers. comm.). Habitat quantity assumes reach through golf course is restorable, currently there is approximately 1,500 feet of available habitat – up to a perched culvert on a paved golf cart path that is in poor condition with a rusted-through invert (Walder et al. 2002). A replacement with a bridge or open-bottom arch set on concrete footings is the best long-term solution to restore unimpeded passage for all age classes of
Tied for #28	MR-090	Leveroni Creek	Novato Boulevard	Steelhead	14	5,200	18.8	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 11%. Because current culvert is properly sized, a retrofit could improve conditions for fish passage. Several downstream weirs are required to raise tail-water elevation and corner baffles within the culvert are required to increase depths and decrease velocities. However, the poor-quality habitat for spawning and rearing make this a
Tied for #28	MR-039	Candelero Creek #2	Candelero Road	Steelhead	12	1,200	18.8	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 47%. Because the current culvert is in poor condition and extremely undersized, this crossing is due for replacement with a properly sized open-bottom arch set on concrete footings or a fully embedded SSP culvert is recommended. **NOTE:** hardware cloth across the inlet of Candelero Creek
Tied for #28	MR-057	East Fork Woodacre Creek #2	Garden Way	Coho, Steelhead	11	2,500	18.8	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 66%. Adult coho salmon and steelhead have been observed spawning upstream of this crossing (Walder et al. 2002). Because the current culvert is undersized, a full replacement with an open-bottom arch set on concrete footings or a bridge is the only feasible solution to restore unimpeded fish passage and increase storm flow conveyance. The County is replacing East Fork Woodacre #4 in 2004 (funded prior to the County-wide assessment) and should concentrate on treating

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank

#29	MR-004	Second Valley Creek #2	Cameron Street	Steelhead	12	3,400	18.7	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 59%. Because the current culvert is extremely undersized, a full replacement with a properly sized open-bottom arch set on concrete footings or a fully embedded SSP culvert is the only feasible solution to restore unimpeded fish passage and increase storm flow conveyance. **NOTE:** County should lower this crossing in project-
Tied for #30	MR-055	West Fork Woodacre Creek #4	Madrone Avenue	Steelhead	15	<500	18.6	Due to the limited drainage area upstream of the crossing, there was a small range of migration flows (3 to 7 c.f.s.) for assessing adult passage. Lack-of-depth was the only passage criteria violation for adult salmonids, thus some passage may occur. Because the current culvert is in poor condition, a replacement with a properly sized open-bottom arch set on concrete footings or a fully embedded SSP
Tied for #30	MR-023	Tocaloma Creek	Sir Francis Drake Blvd	Steelhead	15	2,500	18.6	Slope of current culvert = 8%. Consider feasibility of replacement with a properly sized fully-embedded SSP culvert or an open-bottom arch set on concrete footings to restore fish passage and improve storm flow conveyance. Natural channel slope may be too steep for an embedded culvert design. Consider feasibility of shortening the total length of the crossing too. A habitat typing survey is recommended to better assess Tocaloma Creek's
Tied for #31	MR-075	Old Mill Creek #1	Miller Avenue	Steelhead	10	9,000	18.5	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 93%. Upstream channel is a concrete ditch with potential lack-of-depth and excessive velocities. Cautiously consider feasibility of installing corner baffles within culvert to increase depths and decrease velocities; however current culvert is sized to convey less than a 25-year storm flow and baffles will reduce capacity and may increase likelihood of flooding and property
Tied for #31	MR-035	Arroyo Creek #4	Barranca Road	Coho, Steelhead	11	1,900	18.5	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 55%. Because the current culvert is extremely undersized, a full replacement with a properly sized open-bottom arch set on concrete footings or a fully embedded SSP culvert is the only

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Distri	Barrier Score	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#32	MR-052	West Fork Woodacre Creek #1	Garden Way	Coho, Steelhead	11	2,450	18.4	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 78%. Adult coho salmon and steelhead have been observed spawning in the 500-foot reach upstream of this crossing (Walder et al. 2002). Because the current culvert is undersized, a full replacement with an open-bottom arch set on concrete footings or a bridge is the only feasible solution to restore unimpeded fish passage and increase storm flow conveyance. **NOTE:** County

#33	MR-037	Montezuma Creek #1	Guadalupe Ave	Steelhead	10	1,800	18.3	The current culvert's perched outlet is the main feature that impedes juvenile fish passage. Because the culvert is sized to over-top on less than a 10-year storm flow, a full replacement is the only feasible option to restore unimpeded fish passage and increase storm flow conveyance. Although scored as "steelhead only" for species diversity, juvenile coho have been observed in the lower reaches of Montezuma Creek (Walder et al. 2002). A properly-sized open-bottom arch set on concrete footings or a fully-embedded SSP culvert are both potential
#34	MR-083	Sleepy Hollow Creek #3	Butterfield Road	Steelhead	13	13,100	18.0	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this site dropped one point in extent-of-barrier score for adults. Fish passage could be cost-effectively improved by installing fully-spanning, slope concrete weirs within the box culvert, a notched outlet beam, and possibly a single downstream boulder weir. Recommend consulting with CDFG and NOAA hydraulic engineers for design assistance. **Note:**
#35	MR-056	East Fork Woodacre Creek #1	Oak Grove Avenue	Coho, Steelhead	10	2,700	17.9	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 89%. Because the current culvert is extremely undersized, a full replacement with an open-bottom arch set on concrete footings is the best option to restore unimpeded passage and increase storm flow conveyance. A construction project may be difficult because the current culvert's outlet is
#36	MR-017	Boundary Gulch	Highway 1	Steelhead, coho?	14	800	17.7	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this crossing dropped one point in extent-of-barrier score for adults. Culvert outlet is perched 2.04 feet. Because the crossing is properly sized a retrofit to improve fish passage is feasible. The limited amount of potential upstream habitat makes this a low priority site for

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#37	MR-053	West Fork Woodacre Creek #2	Crescent Drive	Coho, Steelhead	11	2,100	17.6	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 79%. Adult coho salmon and steelhead have been observed upstream of this crossing (Walder et al. 2002). Because the current culvert is undersized, a full replacement with an open-bottom arch set on concrete footings is the best option to restore unimpeded passage and increase storm flow conveyance. Channel upstream of this crossing is highly aggraded and grade control weirs may be
#38	MR-088	Vineyard Creek #3	Trumbull Avenue	Steelhead	13	17,600	17.5	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, this site dropped one point in extent-of-barrier score for adults. Because the current culvert is properly sized, a retrofit to improve fish passage is a feasible treatment option. Corner baffles within the culvert will increase depths and decrease velocities and a single downstream boulder will raise the tail-water
#39	MR-044	Sylvestris Creek #1	Meadow Way	Steelhead	11	300	17.2	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 60%. Although there is a limited reach of poor-quality habitat upstream of Meadow Way, this crossing is undersized, is in very poor condition, and is due for replacement. Poor candidate for treatment with fisheries restoration funding
#40	MR-045	Sylvestris Creek #2	Tamarack Road	Steelhead?	15	<250	17.1	Culvert outlet is perched = 4.9 feet. **NOTE:** County should drop this site from the ranking of fish passage crossings because this reach of stream is probably not fish-bearing.
#41	MR-047	Deer Camp Canyon	San Geronimo Valley Rd	Coho, Steelhead	10	400	16.7	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 91%. A potential migration barrier caused by a wooden diversion structure is located downstream of this crossing (Walder et a. 2002). Juvenile salmonids have been observed in the outlet pool, but not in the channel upstream of San Geronimo Valley Road (Walder et al. 2002). A long-time landowner has historically noted adult coho salmon and steelhead upstream of the County crossing, but not in recent years (Walder et al. 2002). An on-the-ground assessment of habitat quantity is recommended since the SPAWN migration barrier assessment reported over twice the length of habitat that Taylor and Associates estimated off of the

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#42	MR-0026	Devil's Gulch	Sir Francis Drake Blvd	Coho, Steelhead	5	17,400	16.5	**NOTE:** County should drop this site in the priority ranking because the crossing provides unimpeded passage for adult salmoinds and older age classes of juveniles. The site's total score is based heavily (45%) on the large amount of high-quality upstream habitat, not on the "extent of barrier".
#43	MR-0028	Spring Creek #1	Lagunitas Road	Steelhead	12	500	16.1	**NOTE:** Drop in final ranking because Spring Creek may not be a fish-bearing stream. When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 59%. 4% slope for 40 ft.
#44	MR-0061	Spirit Rock Creek	Sir Francis Drake Blvd	Steelhead	13	1,700	15.9	**NOTE:** Drop in final ranking because of 100% migration barrier immediately upstream of crossing. When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 39%. Perched outlet = 3.79 feet. Taylor and Associates' field crew noted a dam just upstream of this crossing that was approximately 8 feet high. Limited reach of poor-quality habitat makes this site a low priority and a poor candidate for treatment.
#45	MR-0040	Montezuma Creek #2	Montezuma Ave	Steelhead	13	<500	15.6	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 32%. Culvert slope = 4.58% for 33 feet. Two boulder weirs downstream of the crossing would back-water culvert and improve passage conditions by increasing depths and decreasing velocities. However, the limited reach of available habitat upstream of Montezuma Avenue makes this a
Tied for #46	MR-0012	Fish Hatchery Creek #2	Vallejo Avenue	Steelhead	11	1,700	15.4	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 64%. For adult salmonids, lack-of-depth was the only violation of the passage criteria – thus actual passage may be higher than predicted. Passage conditions could be cost-effectively improved by raising the elevation of the existing boulder weir and installing a second a second
Tied for #46	MR-0013	Haggerty Gulch	Sir Francis Drake Blvd	Steelhead	13	800	15.4	For adult salmonids, lack-of-depth was the only violation of the passage criteria – thus actual passage may be higher than predicted. Also, the FishXing evaluation failed to account for any back-watering effect that mainstem Lagunitas Creek would have during elevated flows. No treatment

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#47	MR-008	First Valley Creek #2	Inverness Way	Steelhead	11	3,500	15.3	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 63%. For adult salmonids, lack-of-depth was the only violation of the passage criteria – thus actual passage may be higher than predicted. Juvenile passage may occur too, but the small drainage area upstream of the crossing resulted in the computation of a narrow range of migration flows for FishXing analyses. Downstream concrete
#48	MR-009	First Valley Creek #3	Laurel Avenue	Steelhead	12	1,900	15.0	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 50%. For adult salmonids, lack-of-depth was the only violation of the passage criteria – thus actual passage may be higher than predicted. Juvenile passage may occur too, but the small drainage area upstream of the crossing resulted in the computation of a narrow range of migration flows for FishXing analyses. Downstream concrete
#49	MR-036	Arroyo Creek #5	Barranca Road	Steelhead	11	600	14.8	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 71%. 2.64% slope for 42 feet. No treatment is recommended because some adult passage occurs and there is a limited reach of available upstream habitat.
Tied for #50	MR-032	El Ceritto Creek #1	Arroyo Road	Steelhead, coho?	10	500	14.6	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 80%. Outlet is perched 3.03 feet. Riprap at outlet is problematic and the FishXing analyses is unable to assess the effects the riprap has on creating turbulence and unfavorable hydraulic conditions. The current culvert is undersized and overtops on less than a 10-year storm flow, so a replacement is the only feasible treatment option. SPAWN noted a culvert on a private drive approximately 50-75 feet upstream of this crossing that is undersized, in poor
Tied for #50	MR-062	Flanders Creek	Sir Francis Drake Blvd	Steelhead	12	2,300	14.6	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 55%. Concrete extension at outlet may create confusing attractant flow. Poor quality habitat upstream of Sir Francis Drake Blvd makes this site a low priority for treatment.

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
Tied for #51	MR-089	Vineyard Creek #4	Mill Road	Steelhead	10	16,500	14.5	Dropped one point in extent-of-barrier score for adults - meets criteria on 90% of migration flows. Low-priority because current crossing provides adequate adult passage and upstream habitat is of poor-quality.
Tied for #51	MR-038	Candelero Creek #1	Montezuma Ave	Steelhead	10	1,800	14.5	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 83%. Someone has covered the culvert's outlet with hardware cloth – County should remove this obstruction before it causes the culvert to plug with storm debris and overflow. County should also contact and educate landowner about
#52	MR-018	Water Tank Gulch	Highway 1	Steelhead, coho?	11	1,100	14.1	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 73%. RB bay is fully embedded. Low-priority because current crossing provides adequate adult passage and upstream habitat is of poor-quality.
#53	MR-033	El Ceritto Creek #2	Tamal Road	Steelhead?	12	<500'	14.0	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 0% to 57%. **Note:** This site may be upstream of the limit of anadromy due to the >10% slope estimated off of the USGS topographic map for the reach between El Ceritto Creek #1 and #2.
#54	MR-005	Second Valley Creek #3	Aberdeen Way	Steelhead	10	2,700	13.9	When the crossing was re-evaluated by FishXing with the more rigorous swimming ability criteria and a shallower minimum depth, adult passage changed from 56% to 85%. Fish passage conditions could be cost-effectively improved with two downstream boulder weirs to raise tail-water elevation and corner baffles within the culvert to increase depths and
#55	MR-015	Bear Valley Creek	Sir Francis Drake Blvd	Steelhead	3	30,300	12.5	Current crossing provides adequate passage for adult and juvenile salmonids; however box culvert is extremely undersized (inlet overtops on <10-year storm flow). Periodically inspect for condition and performance. When needed replace with a properly
#56	MR-01	Cemetery Creek	Highway 1	Coho, Steelhead	5	3,100	11.8	Current crossing provides adequate passage for adult and older age classes of juvenile salmonids; however the culvert is extremely undersized, is in poor condition and due for replacement.
#57	MR-04	San Geronimo Creek #1	Montezuma Ave	Coho, Steelhead	0	49,600	11.5	Current crossing provides unimpeded passage for adult and juvenile salmonids and is properly sized – no treatment is recommended.
#58	MR-002	Tomasini Canyon	Mesa Rd	Steelhead	0	17,700	11.0	Current crossing provides adequate passage for adult and juvenile salmonids; however the culvert is extremely undersized, is in poor condition and due for replacement. Best long-term solution is an open-bottom arch or a bridge.

Table 5 (continued). Ranked list of 90 Marin County stream crossings located in anadromous-bearing stream reaches.

Rank	Site ID #	Stream Name	Road Name	Presumed Species Di...	Barrier Scor	Length of Upstrea	TOTAL SCORE	Comments Regarding Site and any Adjustments made to Final Rank
#59	MR-011	Fish Hatchery Creek #1	Sir Francis Drake Blvd	Steelhead	5	3,700	10.9	Current crossing provides adequate passage for adult and juvenile salmonids – no treatment is recommended. Culvert is fully embedded – periodically inspect for condition and performance because passage is possible because of the culvert's
#60	MR-06	Schooner Creek	Sir Francis Drake	Steelhead?	0	15,000	10.0	Current crossing provides adequate passage for adult and juvenile salmonids – no treatment is recommended. When needed, replace with a properly sized open-bottom arch set on concrete
#61	MR-031	Arroyo Creek #2	Sir Francis Drake Blvd	Coho, Steelhead	0	7,100	9.3	Current crossing provides unimpeded passage for adult and juvenile salmonids and is properly sized – no treatment is recommended. Periodically inspect for condition and performance – culvert provides unimpeded passage because it is fully embedded
#62	MR-06	Drakes Creek	Sir Francis Drake	Steelhead?	0	7,400	7.7	Current crossing provides adequate passage for adult and juvenile salmonids, but is undersized and should eventually be replaced with a properly sized open-bottom arch or a bridge
#63	MR-059	East Fork Woodacre Creek #4	Grove Avenue	Coho, Steelhead	0	1,300	7.2	Current crossing provides adequate passage for adult and juvenile salmonids, but is extremely undersized and should eventually be replaced with a properly sized, embedded SSP culvert or an open-bottom arch
#64	MR-00	First Valley Creek #1	Sir Francis Drake	Steelhead	0	4,500	5.8	Current crossing provides unimpeded passage for adults and older juveniles, and adequate passage for 1+ and young-of-year juvenile salmonids – no treatment is recommended
Tied for #65	MR-003	Second Valley Creek #1	Sir Francis Drake Blvd	Steelhead	0	5,000	5.5	Current crossing provides unimpeded passage for adult and juvenile salmonids and is adequately sized – no treatment is recommended.
Tied for #65	MR-024	McIsaac Creek	Sir Francis Drake Blvd	Steelhead, coho?	2	3,000	5.5	Current crossing provides unimpeded passage for adult and juvenile salmonids and is properly sized – no treatment is recommended.
Tied for #65	MR-034	Arroyo Creek #3	Arroyo Road	Coho, Steelhead	0	3,000	5.5	Current crossing provides unimpeded passage for adult and juvenile salmonids and is properly sized – no treatment is recommended.
#66	MR-01	Dream Farm Creek	Sir Francis Drake	Steelhead	0	3,500	4.8	Current crossing provides unimpeded passage for adult and juvenile salmonids and is adequately sized – no treatment is recommended.
#67	MR-02	Zanardi Gulch	Platform Bridge Rd.	Steelhead	0	2,000	3.0	Current crossing provides unimpeded passage for adult and juvenile salmonids and is properly sized – no treatment is recommended.

Scheduling of Site-Specific Treatments

County-Maintained Stream Crossings

During the past few years, several sources of restorations funds have been available for treating high-priority migration barriers – SB271, California Coastal Salmon Recovery Program (CCSRP), Proposition 13 (Clean Water Bond), and funds through the California Coastal Conservancy. Prior to the start of Ross Taylor and Associates' stream crossing inventory, the County of Marin's Public Works Department submitted several proposals to treat migration barriers that appeared to be of high-priority. These sites included

- East Fork Woodacre Creek #3 at Crescent Drive. Funding was obtained in 2002 and the site is scheduled for a replacement during the summer of 2004.

- Bates Canyon Creek at San Geronimo Valley Drive. Funding was obtained in 2003 and the site is scheduled for a replacement during the summer of 2004.

Marin County's Public Works Department is considering the development a multi-year plan for scheduling the funding, permitting, and implementation of the remaining high and moderate priority sites within the Woodacre Creek sub-watershed of San Geronimo Creek and other direct tributaries to San Geronimo Creek. The rationale for focusing the County of Marin's efforts in San Geronimo Creek is that Lagunitas Creek currently support a relatively viable coho salmon population at the southern extent of the species distribution and the watershed is tentatively being considered a "refugia basin" by the State's Coho Recovery Planning Team (formed under the State ESA-listing of coho salmon). Of the 90 crossings evaluated in this assessment, 41 sites are County-maintained sites in Lagunitas Creek, 35 of these crossings are located within the San Geronimo Creek sub-watershed, and 11 crossings are located in the Woodacre Creek sub-watershed.

CalTrans-Maintained Stream Crossings

Four of the Highway One crossings were considered high-priority and should be addressed: Giacomini Gulch, John West Fork, North Fork McCurdy Gulch and McCurdy Gulch. Coho salmon and steelhead have been confirmed in each of these streams downstream of the crossings, and in John West Fork coho salmon are commonly observed upstream of Highway One. The John West Fork crossing was retrofitted in 1999 with two downstream boulder weirs to raise the tail-water elevation and a low-flow channel was created through the culvert with a three-inch high steel rail (Ketcham, 2002). Pre- and post-project monitoring of the distribution and number of coho salmon and steelhead redds, and juvenile out-migrant trapping confirmed that the retrofit improved passage conditions for adult coho and steelhead (Ketcham, 2002). However, FishXing indicates that the modified crossing still has challenging hydraulic conditions over the entire range of estimated migration flows. The current crossing is a complete barrier to all age classes of over-wintering juvenile salmonids that often move into smaller tributaries on a seasonal basis.

The crossing also appears to be disrupting the stream's geomorphic processes, as indicated by the highly-aggraded condition of the channel upstream of Highway One.

CalTrans is currently involved in a state-wide fish passage assessment project of stream crossings and has only collected data at a small percentage of their crossings located within anadromous stream reaches. The development of state-wide or even District-based lists of ranked sites may be years from completion. Regardless of the status of the state-wide assessment, CalTrans should consider treatment of these four sites along Highway One as high-priority given their location in coho-bearing tributaries within the southern range of this ESA-listed species.

City of Mill Valley-Maintained Stream Crossings

Seven crossings in the Arroyo Corde Madre Del Presidio (ACMDP) watershed scored fairly high and should be considered for treatment in the near future: Old Mill Creek #2, ACMDP #2-4, 6-7 and Old Mill Creek #3. Within the entire ACMDP watershed, the upper reaches of ACMDP and Old Mill Creek were identified as having the best remaining spawning and rearing habitat for steelhead (Rich, 1995). In addition, the Old Mill Creek #1 crossing shares a common outlet pool with ACMDP #1 and both sites may be addressed along with Old Mill Creek #2 as a single restoration project.

However, it is recommended that a more thorough assessment of potential migration barriers within Old Mill Creek and ACMDP is completed prior to the City of Mill Valley's Public Works Department committing to an exact treatment schedule. The sites assessed by Ross Taylor and Associates were known or suspected migration barriers, that is, a subset of all the stream crossings. Information obtained from Mill Valley Public Works indicates there are an additional seven crossings with culverts on ACMDP and eight crossings with culverts on Old Mill Creek. In addition, there are an unknown number of private driveway crossings along both stream reaches.

The City of Mill Valley should consider the utility of a restoration strategy that focuses on completely restoring passage to the upper reach of one the stream channels, as opposed to attempting to fix several barriers lower in each system (for the same allocation of funds). Because of the urban nature of the ACMDP watershed, the City of Mill Valley should explore funding sources available specifically for urban stream restoration.

Moderate-Priority Sites

The exact scheduling for treating of the remaining "moderate-priority" sites is unknown at the time because:

1. Marin County has a large task of completing the scheduling, contracting, permitting, and implementation required to treat locations proposed in the tentative long-term scheduling for county-maintained crossings within the San Geronimo Creek watershed. The County should focus on completing these higher priority projects with properly designed and constructed treatments before addressing the next tier of sites.

2. Marin County is a participant in the FishNet 4C Salmon Group, which plans to acquire treatment funds for passage problems in all six counties (Sonoma, Marin, Napa, San Mateo, Alameda, and Santa Cruz). Thus, the remaining "moderate-priority" tier of Marin County culverts should be ranked and evaluated with respect to priority culverts located in the other five counties.

3. When addressing the "moderate-priority" tier of culverts, the current biological condition and/or importance (such as quantity) of the streams start to diminish. Thus, these sites may not rank well compared to other types of projects proposed to state and federal funding sources. However, other sources of funding, such as urban stream programs should be considered. Sites in poor condition and/or undersized should be eventually treated with county maintenance and repair funds.

Low-Priority Sites

Generally low-priority sites either allowed fish passage, or have minimal biological benefit if treated. However, these sites should be examined for "consequence-of-risk" as to current condition, sizing, and quantity of fill within the road prism. All future replacements with county maintenance funds should include properly sized crossings that permit unimpeded passage of adult and juvenile salmonids.

The three most common activities impacting these Marin County streams are agriculture, unfenced grazing, and residential/urban development. Most of these low-priority creeks generally exhibited some or all of the following characteristics:

1. Lack of pools and habitat complexity;
2. Denuded or non-existent riparian zones;
3. Extensive straightening, berming, and diking of channel;
4. High volumes of fine sediment; and
5. Warm summer water temperatures.

Limited fisheries restoration dollars should probably not be spent on improving fish passage in these streams, unless significant improvements occur to impacts of other land management activities. However, Marin County should carefully examine this list and determine which locations may be treated with existing maintenance funds.

For example, Marin County Public Works Department may have a general plan for improvements to specific traffic corridors or routes. Also, when low-priority culverts fail during winter storms, planners should examine the sizing of the failed structure and budget for properly-sized replacements. When applying for FEMA funds, Marin County Public Works should utilize

this report to explain why the replacement should be a larger and higher-quality crossing (for both fisheries and future-flood benefits).

Design Options for Improving Fish Passage

All stream crossing replacement projects should follow recently developed state criteria and federal guidelines for facilitating adult and juvenile fish passage (CDFG 2002; NMFS 2001). However, site-specific characteristics of the crossing's location should always be carefully reviewed prior to selecting the type of crossing to install. These characteristics include local geology, slope of natural channel, channel confinement, and extent of channel incision likely from removal of a perched culvert. For additional information, Bates et al. (1999) is recommended as an excellent reference to use when considering fish-friendly culvert installation options and Robinson et al. (2000) provides a comprehensive review of the advantages and disadvantages of the various treatment alternatives as related to site-specific conditions.CDFG Allowable Design Options

Active Channel Design Option is a simplified design method that is intended to size a crossing sufficiently large and embedded deep enough into the channel to allow the natural movement of bed load and formation of a stable bed inside the culvert. Determination of the high and low fish passage design flows, water velocity, and water depth is not required for this option since the stream hydraulic characteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing.

The Active Channel Design Option is suitable for the following conditions:

- New and replacement culvert installations
- Simple installations with channel slopes of less than 3%.
- Short culvert lengths (less than 100 feet).
- Passage is required for all fish species and lifestages.

Culvert Setting and Dimensions

Culvert Width – the minimum culvert width shall be equal to, or greater than, 1.5 times the active channel width.

Culvert Slope – the culvert shall be placed level (0% slope).

Embedment – the bottom of the culvert shall be buried into the streambed not less than 20% of the culvert height at the outlet and not more than 40% of the culvert height at the inlet. Embedment does not apply to bottomless culverts.

Stream Simulation Design Option

The Stream Simulation Design Option is a design process that is intended to mimic the natural stream processes within a culvert. Fish passage, sediment transport, flood and debris conveyance within the crossing are intended to function as they would in a natural channel. Determination of the high and low fish passage flows, water velocity, and water depth is not required for this option since the stream hydraulic characteristics within the culvert are designed to mimic the stream conditions upstream and downstream of the culvert.

Stream simulation crossings are sized as wide, or wider than, the bankfull channel and the bed inside the culvert is sloped at a gradient similar to that of the adjacent stream reach. These crossings are filled with a streambed mixture that is resistant to erosion and is unlikely to change grade, unless specifically designed to do so. Stream simulation crossings require a greater level of information on hydrology and topography and a higher level of engineering expertise than the Active Channel Design Option.

The Stream Simulation Design Option is suitable for the following conditions:

- New and replacement culvert installations.
- Complex installations with channel slopes less than 6%.
- Moderate to long culvert length (greater than 100 feet).
- Passage required for all fish species and lifestages.
- Ecological connectivity is required.

Culvert Setting and Dimensions

Culvert Width – the minimum culvert width shall be equal to, or greater than, the bankfull channel width. The minimum culvert width shall not be less than six feet.

Culvert Slope - the culvert slope shall approximate the slope of the stream through the reach in which it is being placed. The maximum slope shall not exceed 6%.

Embedment – the bottom of the culvert shall be buried into the streambed, not less than 30% and not more than 50% of the culvert height. Embedment does not apply to bottomless culverts.

Substrate Configuration and Stability

- Culverts with slopes greater than 3% shall have the bed inside the culvert arranged into a series of step-pools with the drop at each step not exceeding 0.5 feet for juvenile salmonids.

- Smooth walled culverts with slopes greater than 3% may require bed retention sills within the culvert to maintain the bed stability under elevated flows.

- The gradation of the native streambed material or engineered fill within the culvert shall address stability at high flows and shall be well graded to minimize interstitial flow through it.

Hydraulic Design Option

The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish. The method targets specific species of fish and therefore does not account for ecosystem requirements of non-target species. There can be significant errors associated with estimation of hydrology and fish swimming speeds that are mitigated by making conservative assumptions in the design process. Determination of the high and low fish passage design flows, water velocity, and water depth are required for this option.

The Hydraulic Design Option requires hydrologic data analysis, open channel flow hydraulic calculations and information on the swimming ability and behavior of the target group of fish. This design option can be applied to the design of new and replacement culverts, and can be used to evaluate the effectiveness of retrofits for existing culverts.

The Hydraulic Design option is suitable for the following conditions:

- New, replacement, and retrofit culvert installations.
- Low to moderate channel slopes (less than 3%).
- Situation where either Active Channel Design or Stream Simulation Options are not physically feasible.
- Swimming ability and behavior of target fish species is known.
- Ecological connectivity is not required.
- Evaluation of proposed improvements to existing culverts.

For more information regarding the Hydraulic Design option, or to obtain the most recent copy of the CDFG *Culvert Criteria for Fish Passage*, contact George Heise, CDFG's hydraulic engineer, at GHEISE@dfg.ca.gov .

NMFS Order of Preferred Alternatives

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

Assessment of Migration Impediments at other Human-made Features

During the field survey phase of the fish passage assessment project, Ross Taylor and Associates' field crew also examined seven sites that were human-made impediments to migration that were not stream crossings. At each location, both longitudinal profiles of the channel and cross-sections were surveyed in ordered to assess passage based on channel slopes, estimated depths during passage flows, leaps required to negotiate weirs, and depths below weirs for executing leap attempts. The survey data for these sites are located in Appendix D.

These sites were not incorporated into the ranked list of sites because of the limitations of using FishXing to provide comprehensive passage assessment scores and the inability to generate peak-flow sizing scores for the ranking matrix. However, the following conclusions and recommendations were generated after examination of the survey data and site photos.

Corte Madera Creek – Concrete flood channel located in lower channel reach.

US Army Corps of Engineers has surveyed this concrete channel in the past therefore Taylor and Associates did not survey. This site is an approximately one-mile long concrete channel with ineffective slots along the invert that were intended to provide resting pools for fish. The current concrete channel was completed in 1972. Slope estimates from US-ACOE general re-evaluation draft report, January 13, 2000 were used to evaluate passage. Lower 1000 feet of channel is not problematic for fish passage due to tidal influence and shallow slope. The upper 4,200 feet of channel is most likely a barrier to adults due to excessive velocities during all migration flows from slope, length and material. This reach of concrete channel blocks migration to all spawning areas in Corte Madera Creek Watershed except for approximately 2.5 miles in Larkspur Creek. Possible recommendations include (1) Removing or roughening the invert along the upper 4,200 feet of channel, (2) Installing a step-pool fish ladder consisting of weirs with pools along the

upper 4,200 feet, or (3) Installing baffles. It is recommended that this reach of channel is improved for fish passage prior to treating sites located upstream.

Ross Creek – Two weirs with concrete aprons near Branson School.

The weirs do not appear to be significant barriers to adult steelhead migration. The weir with the greater drop appears to have sufficient depth in the pool immediately downstream for adult salmonids to execute leap attempts. However, the Taylor and Associates' survey crew noted a potential migration at a culvert upstream on the Branson School property that was not surveyed.

Arroyo San Jose – Concrete flood channel with steeply-sloped banks and weir near Ignacio Blvd.

Concrete channel/apron at inlet is extensive and creates a migration barrier. Flow is cut off by weir at the upstream end of apron. This weir is also a migration barrier because of its height (five-feet) and a lack-of-depth downstream for leap attempts. Combination of box culvert downstream of the concrete channel and the five-foot high weir at the upper end of the concrete creates impassable condition for all species and life stages. For migrating adults in the concrete channel, lack-of-depth is an issue over entire range of migration flows, however excessive velocities do not occur until flows are greater than 70 c.f.s. Recommend first removal of the weir. Once the weir is removed there are several options for the remaining concrete channel, including (1) Removing or roughening the invert of the concrete channel, (2) Installing series weirs with low-flow notches, or (3) Installing baffles.

Arroyo San Jose –Tiered concrete weirs with an apron of concrete and riprap near Ignacio Blvd.

The weirs are a barrier to all age classes of salmonids. There is an excessive jump height of 8.4 feet. Excessive velocities also occur due to length and slope. Adult salmonids have lack of depth problems over entire range of estimated migration flows and velocities exceed swim speeds above 35 c.f.s. Recommend complete removal of weir. If weir is unable to be removed another possibility may be raising tail-water elevation 8 feet with nine to 10 boulder weirs.

Vineyard Creek – Filled-in concrete dam located behind Zioli Court.

A complete barrier to all age classes of anadromous salmonids due to an excessive drop of nearly nine feet, as well as excessive velocities created by the steep slope (if an adult steelhead were to attempt to swim up flow sheeting over the dam). Best long-term option is removal of dam, however this will cause extensive head-cutting of the stream channel. Another option would be to raise tail-water elevation with a series of 10 to 12 boulder weirs. Dam is located upstream of four assessed stream crossings – Vineyard Creek #1 at McClay Avenue is a complete barrier that should be treated prior to removal or modification of this dam. There is approximately 12,000 feet of potential habitat upstream of this dam.

Novato Creek –Two concrete weirs underneath bridge at Delong Avenue.

Structure does not appear to be a significant impediment to fish migration because one weir is scoured below it allowing low flow to pass below it and the other weir has only a 1.5 foot drop. However, the purpose of the weirs is not apparent and their removal would be relatively inexpensive. Further investigation by a qualified engineer is recommended to confirm that the weirs do not provide structural support of the Delong Avenue bridge.

San Anselmo Creek – Dam near Pacheco Avenue with three culvert openings.

Site was not surveyed, but was inspected and photos were taken. Structure does not appear to be a significant impediment to fish migration at low to moderate migration flows due to the removal of the center culvert. However, the structure severely constricts channel width and turbulent hydraulic conditions probably impede passage at higher flows. The dam appears to not serve a functional purpose and its removal would be relatively inexpensive.

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