FINAL REPORT:
COASTAL MENDOCINO COUNTY CULVERT INVENTORY AND FISH PASSAGE EVALUATION

By

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INTRODUCTION

The inventory and fish passage evaluation of culverts within the coastal Mendocino County road system was conducted between August, 1998 and December, 2000 under contract with the California Department of Fish and Game (CDFG) (contract # **FG 8072 WR**). 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 limited to county-maintained crossings within anadromous stream reaches within coastal watersheds known to historically and/or currently support runs of coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss irideus*). For numerous reasons, the Russian River watershed was excluded from this inventory.

The inventory and assessment process included:

1. locating stream crossings within anadromous stream reaches;
2. visiting each culvert location during both late-summer/early fall low flow and during winter storm events;
3. collecting information regarding culvert specifications;
4. assessing fish passage using culvert specifications and passage criteria for juvenile and adult salmonids (from scientific literature and FishXing computer software);
5. assessing quality and quantity of stream habitat above and below each culvert; and
6. assessing fish passage by direct observation at culvert sites during fall/winter migration period.

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); and
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 judgement was a vital component of the ranking process. Site-specific information that is difficult to assign a discrete numerical value was also considered.

Examples include:

1. Direct observations of attempted migration at known barriers. Treating these sites should result in a high probability of immediate utilization of re-opened habitat.

2. Fish behavior at culverts. Recent studies suggests salmonids experience migration difficulties at road crossings that exhibit hydraulic characteristics within the reported abilities of several salmonid species (Taylor 2000; Love et al. pers. comm.).

3. Physical stress or danger to migrating salmonids. Recent studies have revealed several sites where concentrations of migrating salmonids were subjected to decades of predation by birds and mammals or poaching by humans (Taylor 2000). Inability to enter coolwater tributaries to escape stressful/lethal mainstem water temperatures during summer months has also been observed. These factors should weigh heavily in priority ranking.

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 Culvert Inventory

A hard copy and a diskette of this project-scheduling document were distributed to the following agencies and departments: Mendocino County Department of Transportation; Mendocino County Water Agency; CDFG- Inland Fisheries Division and Region 1 Office (copy for each office); and Five-Counties Salmon Group.

Final report includes:

1. A count and location of all culverted stream crossings. Locations were identified by stream name; road name; watershed name; mile marker or distance to nearest crossroad; Mendocino county road map #; Township, Range and Section coordinates; and lat/long coordinates. 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, rust line height, and ability to pass flow (and debris) during the past two winters of moderately large storm events. Presence or absence and condition of trash racks was also assessed. 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. First, information collected on culvert specifications was used to calculate hydraulic characteristics of each culvert over a range of expected migration flows. These values were compared to values cited in current scientific literature regarding the leaping and swimming abilities of juvenile and adult coho salmon,

steelhead, and chinook salmon. FishXing (a computer software program) modeled culvert hydraulics over the range of migration flows and compared these values with leaping and swimming abilities of the species and lifestage of interest. Secondly, passage was assessed by on-site observations of fish movement during expected periods of migration; primarily during and after rain storms between the months of December and March.

5. Photo documentation of each culvert to provide visual information regarding inlet and outlet configurations. Site photographs were digitized and provided on diskettes for easy insertion into future reports, proposals, or presentations

6. An evaluation of quantity and quality of fish habitat above and below each culvert location. Some information was obtained from habitat typing surveys previously conducted by CDFG, watershed groups, and/or timber companies. Where feasible, a first-hand inspection and evaluation of stream habitat occurred. Length of potential anadromous habitat was also estimated from USGS topographic maps. In situations where formal habitat typing surveys were not conducted and/or access to stream reaches was not permitted, professional judgement of biologists 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. For example, some stream crossings may require a bridge or properly-sized culvert set below stream grade to accommodate fish passage, whereas other locations may just require building up the outlet pool with rip rap to backflood the culvert inlet and/or baffles to reduce velocities within the culvert.

Project Justification

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. 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 lifestages 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 underseeded 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 (NMFS 2000). However many existing culverts on federal, state, county, and private roads are barriers to anadromous adults, and more so to resident and juvenile salmonids whose smaller sizes significantly limit their leaping and swimming abilities to negotiate culverts. For decades, "legacy" culverts on established roads have effectively disrupted the spawning and rearing behavior of all four species of anadromous salmonids in California: Chinook salmon, (*Oncorhynchus tschawytschaw*), coho salmon, coastal rainbow trout (steelhead are anadromous coastal rainbow trout), and coastal cutthroat trout (*O. clarki clarki*).

In recent years, there has been a growing awareness of the disruption of instream migrations of resident and juvenile salmonids caused at road/stream intersections. Instream 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 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.

In response to the 1994 federal listing of coho salmon as threatened in northern California, five counties (Humboldt, Del Norte, Trinity, Mendocino, and Siskiyou) formed the Five-Counties Salmon 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 culvert inventories on county roads to evaluate fish passage and prioritize treatments.

Anadromous salmonids will benefit from this planning effort because the final document provides Mendocino County's Department of Transportation (DOT) 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 DOT 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 eight tasks; accomplished generally in the following order:

1. Location of culverts.
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.
5. Site visits for migration observations during fall/winter migration flows.
6. Collection and interpretation of existing habitat information.
7. Prioritization of sites for corrective treatment.
8. Site-specific recommendations for unimpeded passage of both juvenile and adults salmonids.

Location of Culverts

Preliminary project scoping included examination of Mendocino County road system maps and counting road/stream intersections on known (current and historic) anadromous stream reaches. The National Marine Fisheries Service (NMFS) coho salmon stock questionnaire list was used to identify and locate coho and steelhead streams on the Mendocino County road maps. NMFS's list of current and historic coho streams was based heavily on a compilation of field and survey reports produced by Brown and Moyle (1989).

Thirty-two county culverts were initially identified on coho and/or steelhead-bearing reaches of streams, primarily within five major watersheds: Eel River, Garcia River, Navarro River, Big River, and Albion River. The remaining culverts were located on smaller coastal streams that drain directly into the Pacific ocean.

Because the use of maps was considered a rough, first-cut at locating potential culverted road crossings, additional sites were also investigated once the project started. Most of these sites were identified by fisheries biologists, restoration/watershed groups, or county personnel with field-level knowledge regarding Mendocino county streams (Bell; Downie; Flosi; Harris; Slota pers. comm.) .

Initial Site Visits

The objective of the initial site visits was to collect physical measurements at each crossing to utilize with the fish passage evaluation computer software (FishXing). 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.

Culvert Location

The location of each culvert was described by: Mendocino County road system map # ; road name; stream name; watershed name; 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 purposes, all lat/long coordinates were provided in the North American 1927 datum.

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 into a bound, water-proof, fieldbook or on water-proof data sheets with a pencil. Fieldbook notes and 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. Vests increased one's visibility to traffic, and decreased suspicions of nearby property owners to our unannounced presence in the roadside stream channel. If sites were close to private residences, we attempted to contact the property owners to inform them of our survey of the county-maintained road 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 inlet, 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, five required elevations were measured:

- culvert inlet,
- culvert outlet,
- maximum pool depth within five feet of the outlet,
- outlet pool control, and
- ordinary high water (OHW) mark at the outlet pool control. The OHW mark should correspond to the height of flow during an active channel discharge event (slightly less than a bankfull channel flow).

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 can bend 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'.

<u>Channel widths</u>

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 (Robison et al 2000; NMFS 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 to increase the accuracy of passage analyses. For more detail, refer to the extensive "Help files" provided with FishXing (Love 2000).

Fill Estimate

At each culvert, the amount of road fill was estimated by calculating the volume of fill prism between the road surface and the culvert (Figure 1) (from Flannigan et al 1999).

Fill volume was estimated to:

1. assist in development of cost estimates for barrier removal by estimating equipment time required for fill removal and disposal site space needed;
2. calculating culvert capacity at HW/D = fill height; and
3. evaluating the consequences of fill failure by: Sediment volume + risk of failure = consequence to stream habitat.

The fill prism was calculated from the following measurements:

1. Upstream and downstream fill slope measurements (L_d and L_u).
2. Slope (%) of upstream and downstream fill slopes.
3. Width of road prism (W_r).
4. Length of road prism (W_u).
5. Channel width (flood prone width) (W_c).

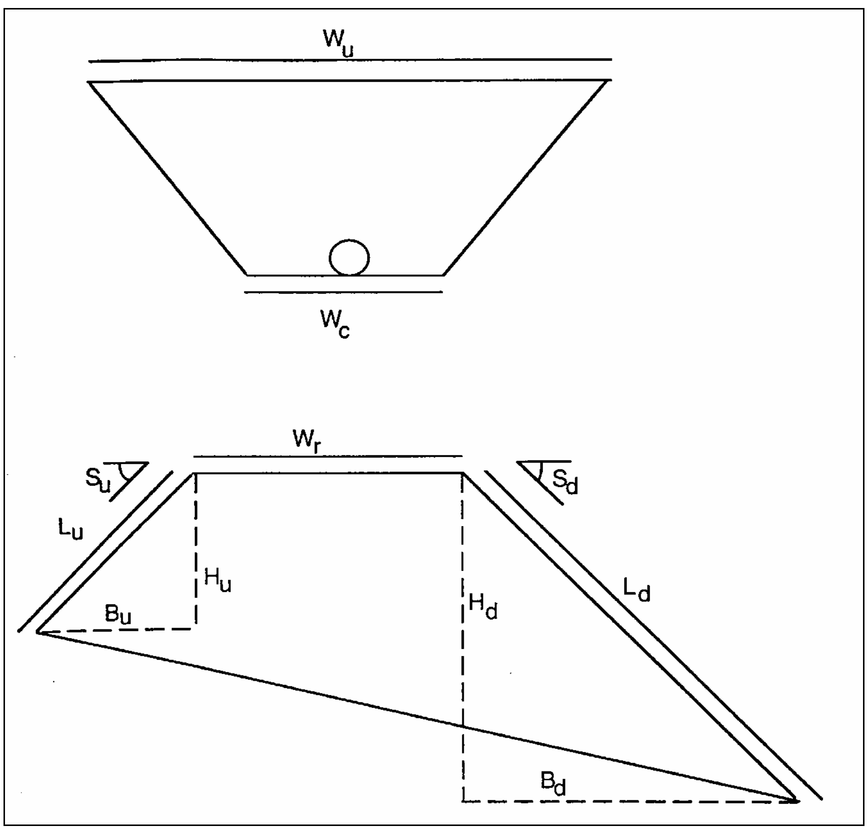

Figure 1. Fill measurements – solid lines were measured values, dashed lines were calculated.

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 in either a bound, waterproof, field notebook; or 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.

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, in press-2001).

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) 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.

FishXing used the survey elevation and culvert specifications to evaluate passage for each species and lifestages of salmonids known to currently or historically reside in the Mendocino County streams of interest. The swimming abilities and passage criteria used for each species and lifestage are listed Table 2. Although many individual fish will have swimming abilities surpassing those listed below, swim speeds were selected to ensure stream crossings accommodate passage of weaker individuals within each age class.

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

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

Table 2. Fish species and lifestages used in the fish passage along with associated swimming abilities and passage criteria. Passage flows are based on current adult salmonid criteria combined with observational data from northern California coastal streams.

Fish Species/Age Class	**Adult Steelhead, Chinook, and Coho**	**Juvenile steelhead and resident rainbow trout 2+ years old**	**Juvenile steelhead and resident rainbow trout 1+ years old**	**Juvenile steelhead, coho, and resident rainbow trout young-of-year**
Fish Length	500 mm	200 mm	130 mm	80 mm
Prolonged Mode				
Swim Speed	6.0 ft/s	2.8 ft/s	2.4 ft/s	2.0 ft/s
Time to Exhaustion	30 min	30 min	30 min	30 min
Burst Mode				
Swim Speed	10.0 ft/s	6.4 ft/s	4.5 ft/s	3.0 ft/s
Time to Exhaustion	5 s	5 s	5 s	5 s
Velocity Reduction Factors**	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	Inlet = 0.8 Barrel = 0.6 Outlet = 0.8
Maximum Leaping Speed	12.0 ft/s	6.4 ft/s	4.5 ft/s	3.0 ft/s
Minimum Required Water Depth	0.8 ft	0.5 ft	0.3 ft	0.2 ft
Upper Passage Flow	2% flow (Nov-April)	10% flow (Nov-April)	10% flow (Nov-April)	10% flow (Nov-April)
Lower Passage Flow	95% flow (Nov-April)	95% flow (Nov-April)	95% flow (Nov-April)	95% flow (Nov-April)

** 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.

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 gaged on most small streams, it must be estimated using techniques that required hydrologic information about the stream crossing's contributing watershed, including:

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

Drainage area and basin elevations were calculated from a 1:24,000 USGS topographic map. Mean annual precipitation (MAP) and potential evapotranspiration (PET) were 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, 2000). 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. Undersized crossings can also adversely effect sediment transport and downstream channel stability, creating conditions that hinder fish passage, degrade habitat, and may cause damage to other stream crossings 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 and box culverts. Capacity 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 5-year, 10-year, 25-year, 50-year, and 100-year peak flows. Regional flood estimation equations developed by Waananen and Crippen (1977) were used to estimate peak flows for the various recurrence intervals. The equations incorporate drainage area, MAP, and mean basin elevation as variable to predict peak flow in 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 five "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. or less than the 10-year flow.

These 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 (NMFS 2000; 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 (NMFS, 2000).

The NMFS guidelines designate the **lower fish passage flow (Q_{lp})** for adult, resident, and juvenile fish as the 95% exceedence flow (the flow equaled or exceeded 95% of the time) during the migration period. The **upper fish passage flow for adult salmonids ($Q_{hp\text{-}adult}$)** is defined as the 2% exceedence flow during the period of migration. Due to a lack of a well-defined upper passage flow for migrating juvenile and resident fish, the 10% exceedence flow ($Q_{hp\text{-}juvenile}$) for the migration period was chosen based on fish observations at stream crossings throughout northwestern California.

For coastal Mendocino County, upstream salmonid migration was assumed to occur between November and April. Between the lower and upper passage flows stream crossings should allow unimpeded passage of all adult salmonids.

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 lifestage of concern. Identifying the 2% and 95% exceedence flows required obtaining average daily stream flow data from nearby gaged basins. Daily average flow data for small streams in coastal Mendocino County were available from the USGS and the US Forest Service Redwood Science Lab (RSL).

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

1. Obtained flow records from local stream gages that met the following requirements:
   - At least 5-years of recorded daily average flows (do not need to be consecutive years);
   - A drainage area less than 50 square miles, and preferably less than 10 square miles; and,
   - Unregulated flows (no upstream impoundments or water diversions) during the migration season.

2. Discarded flows that fell outside of the migration period (November – April).

3. Estimated the average daily flow ($Q_{ave.}$) for both the gaged stream and the stream crossings using a regional runoff equation:

$$R = MAP - 0.40\,(PET) - 9.1$$ (from Rantz, 1968)

and; $$Q_{ave}\,[cfs/cfs] = 0.0736 \times (A) \times (R)$$

Where;

R = Average annual runoff, in inches/year
MAP = Mean annual precipitation, in inches/year
PET = Potential evapotranspiration, in inches/year
A = drainage area, in square miles.

4. Divided the flows for each gaged stream by its estimated average daily discharge to normalize the data. Then created a flow duration table containing exceedence values and associated flows (Q/Q_{ave}).

5. Created a regional flow duration curve by averaging the exceednece flows (Q/Q_{ave}) of the gaged streams (Appendix C).

6. Determined the upper and lower passage flows for each stream crossing using the regional flow duration curve and the estimate of Q_{ave} for 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 2000). For the ranking matrix, at each road crossing, the extent of the migration barrier was determined for each salmonid species and lifestage presumed present. Junvenile and resident trout passage was also determined between Q_{lp} and $Q_{hp;}$ however Q_{hp} was defined as the 10% exceedence flow instead of the 2% exceedence flow.

Site Visits for Fish Migration Observations

During late-fall and winter storms, some sites were visited in order to observe salmonids attempting to migrate through culverts. These visits were limited to culverts with perched outlets because turbid conditions of most streams during winter migration flows allowed only observation of jump attempts.

The purpose of these visits was to:
1. confirm upstream migration of adult and/or juvenile salmonids;
2. record numbers of successful and failed attempts at specific culverts;
3. observe behavior of jump attempts;
4. identify locations with high levels of migration;
5. better understand the timing of fish migration as related to storm hydrographs; and
6. measure velocities through culverts and jump heights during migration flows.

Migration observation data were not intended for use in the ranking matrix for several reasons:
1. observations were made at a subset of culvert locations;
2. observations were conducted sporadically at various locations and flow levels; and
3. total observation time (in minutes) accounted for a small fraction of total migration period.

However, this information provided valuable insight of fish behavior at culverts and served as an important component of professional judgement in the final ranking of priority locations. The protocol used for conducting observations at perched culverts is located in Appendix E.

Habitat Information

Because this project addressed fish passage in many tributaries of several watersheds, plan development was based both on prior assessment and evaluation; and on conducting habitat assessment and evaluation as part of the project. Habitat conditions upstream and downstream of culvert locations relied on previously conducted habitat typing or fisheries surveys. These surveys also provided information on past, present, and future land uses within watersheds that flow through culverts on the Mendocino County road system.

Communication with agency and private-sector biologists, watershed groups, coordinators, restorationists, and large landowners assisted in acquiring additional information on watershed assessment and evaluation (Bell, Downie, Flosi, Harris pers. comm. and Jones, 2001). Habitat information and fish distribution data were used from reports on file at CDFG offices in Fortuna, Fort Bragg and Willits; as well as reports, surveys, and memos summarized by Jones (2001).

Professional judgment from on-site inspection of culverts 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 road crossings on private roads.

Length of potential salmonid habitat upstream of each county culvert was estimated off of digitized USGS 7.5 Minute Series topographic maps (Terrain Navigator, Version 3.01 by MapTech). The upper limit of anadromous habitat was considered when the channel exceeded an eight degree slope.

The presence of additional road crossings, above and below each county-maintained site, was also considered when evaluating potential habitat gains. In many cases, additional road crossings existed, either private-maintained or state (CALTRANS). These crossings were not evaluated in detail (with FishXing), but were examined for visual estimates of length, slope, and presence of perched outlets.

Initial Ranking of Stream Crossings for Treatment

Methods for ranking stream crossings were developed after carefully reviewing criteria used in Oregon (Robison et at. 2000) and Washington (SSHEAR 1998). The two protocols are fairly similar except for how stream habitat information was utilized. Robison et al. (2000) relied mostly on potential species diversity of the fish-bearing channel above a culvert site and did not factor in a “score” for habitat quality.

The Oregon method segregated culverts into five priority types, based on:

- Degree of barrier – partial or complete.
- Risk of failure – flow capacity.
- Species diversity of upstream habitat (in descending order) – coho salmon and others, steelhead and cutthroat, any gamefish, non-fish-bearing but flows into fish-bearing reach.

Once a cursory ranking of culverts was completed, the Oregon method used the input of fisheries professionals with knowledge of the stream’s biological significance. The Oregon method also acknowledged numerous social, economic, and technical aspects often influences the ultimate order of treatment locations (and treatment options – replacement versus modification of existing crossing).

Washington used a complex equation which calculates the quadratic root of numerous factors, including discrete values assigned to habitat parameters (both physically measured and visually estimated). The equation analyzed passage for each species and lifestage of salmonid which may be present and sums the results for a “score”. Thus for each culvert a specific numbered score (and rank) was generated. Initially, the method appears quite objective in nature, yet many of the habitat parameters assigned a discrete value were actually generated from subjective (unrepeatable) estimates. The method also attempted to quantify (and rank) gains in spawning and rearing habitat by assuming all pooltails and riffles are viable spawning habitat. The Washington method has merit, but seemed too complex for the task of determining a first-cut of high, medium, and low priority culvert locations.

The need for extensive habitat information collected in a consistent manner is also time consuming and expensive to generate. Detailed information was not available for many Mendocino County watersheds and conducting surveys was beyond the scope (and budget) of this project. 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 judgement 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 Mendocino County intends on treating culvert sites identified as "high-priority" by submitting proposals to various fisheries restoration funding sources, additional opportunities for re-evaluating the biological merit of potential projects will occur through proposal review committees composed of biologists from CDFG and other agencies. The methods for ranking 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.

Ranking Criteria

The method developed and utilized, assigned a score or value for the following parameters at each culvert location. The total score is the sum of five criteria: species diversity, extent of barrier, sizing, current condition, and 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, chinook salmon, and steelhead = **2** points.

2. **Extent of barrier:** for each species and lifestage known to occur, 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. For adults, assign **each** species a barrier extent score – this provides additional weight to road crossings that are barriers on streams with multiple (listed) salmonid species present. For a total score, sum scores given to each species and lifestage.

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.

4. **Current condition:** for each culvert, assign one of the following values. **Score:** **1** = good condition. **2** = fair, showing signs of wear. **3** = poor, floor rusting through, crushed by roadbase, etc. **4** = extremely poor, floor rotted-out, severely crushed, damaged inlets, collapsing wingwalls, slumping roadbase, etc.

5. **Habitat quantity:** above each crossing, length in feet to sustained 8% gradient. **Score:** Starting at a 500' minimum; 0.5 points for each 500' length class (**example**: **0** points for <500'; **1** point for 1,000'; **2** points for 2,000'; **3.5** points for 3,500'; and so on).

6. **Habitat quality:** for each stream, assign a "multiplier" of quality (relative to other streams in inventory) after reviewing available habitat information.

- **Score: 1.0 = Excellent-** Relatively undeveloped, "pristine" watershed conditions. Habitat features include dense riparian zones with mix of mature native species, frequent pools, high-quality spawning areas, cool summer water temperatures, complex inchannel habitat, 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 inchannel habitat, 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 inchannel complex habitat, floodplain intact or slightly modified). Presence of migration barrier(s) is probably 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 inchannel habitat, floodplain severely modified with levees, riprap, and/or residential or commercial development. Other limiting factors within watershed are most likely of a higher priority for restoration than remediation of migration barriers.

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

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 judgement 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 characterized as complete migration barriers with significant amounts of upstream habitat for several species of anadromous salmonids. Medium-priority sites were characterized as limited in upstream habitat gains, limited species diversity, and/or were only barriers to juvenile migration. Low-priority sites were either limited in 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.

Mendocino County DOT 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 Mendocino County DOT 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.

RESULTS

Initial Site Visits

Initial site visits were conducted at a total of 54 stream crossings on roads in Mendocino County (Table 3). However, only **28** of 54 crossings were surveyed and **26** sites included in the fish passage evaluation and site ranking. The reasons for excluding 28 sites in the evaluation varied and are listed in the right-hand column of Table 3. Most site visits and surveys were conducted during fall or spring low flows, which provided safer wading conditions in streams and through culverts. A table of the 28 culvert sites inventoried and their location information is provided in Appendix A.

Site-specific characteristics, site photographs, maps, and habitat descriptions for the 26 sites evaluated for passage are provided in a "Catalog of Coastal Mendocino County Culverts" (Appendix B). The following list is an overview of the culvert inventory:

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

2. Many culverts were in poor condition (11 sites or 39%) and are due for replacement. Another eight culverts (28.6%) were described as in "fair" condition, and starting to show signs of deterioration.

3. Most culverts were undersized when compared to recently released NMFS guidelines that recommend stream crossings pass the 100-year storm flow at less than 100% of inlet height. Only two sites (Windem Creek/Branscomb Road and Mill Creek #1/Fish Rock Road) were sized to pass more than a 100-year storm discharge. This is mostly likely because many county road crossings were constructed prior to the development of these conservative guidelines. Another four crossings were sized close to the NMFS guidelines: Ornbaun Creek #1/Ornbaun Road (96-years); Hotel Gulch/Usal Road (94-years); Taylor Creek/Branscomb Road (83-years); and Bear Creek/Branscomb Road (82-years). Ten of the remaining culverts were extremely undersized, overtopping on less than a ten-year storm flow (Table 4).

Table 3. List of 54 stream-crossing locations visited in coastal Mendocino County.

BASIN NAME	STREAM NAME	ROAD NAME	COUNTY MAP #	STATUS OF SITE
South Fork Eel River				
Hollow Tree Ck.	Mule Creek	Westside Road	2F	Private road
Rattlesnake Ck	Cummings Creek	Bell Springs Road	2F	Under Hwy 101
Tenmile Ck	Mill Creek	North Road	2F45	Private road
	Cahto Creek	Branscomb Road	2F45	Ditch
	Jack of Hearts Creek	Wilderness Lodge Road	2F	Bridged
	Deer Creek	Wilderness Lodge Road	2F	**X**
	Little Charlie Creek	Wilderness Lodge Road	2F	No
	Bear Creek	Branscomb Road	2F	**X**
	Taylor Creek	Branscomb Road	2F	**X**
	Windem Creek	Branscomb Road	2F	**X**
Mainstem Eel River				
Outlet Creek	Dutch Henry Creek	Sherwood Road	3F	No channel
	Dutch Henry Creek	Poppy Drive	3G22	No channel
	Dutch Henry Creek	Fox Road	3G22	No channel
	Rowes Creek	Sherwood Road	3F	No channel
	Ryan Creek	Ryan Creek Road	3G22	**X**
	Upp Creek	Madrone Road		**X**
Berry Creek	Alder Creek	Canyon Road	3G	Not fish-bearing
Davis Creek	Fulweiter Creek #1	Eastside Road	3G32	**X**
	Fulweiter Creek #2	Eastside Road	3G32	Not fish-bearing
	Moore Creek	Ridgewood Road	3G	No access
Tomki Creek	Tomki Creek	Hearst-Willits Road	3G	Bridged
	Cave Creek	Tomki Road	3G	Check fords
	Unnamed Cave Ck trib.	Tomki Road	3G	No crossing
	Big Canyon Creek	Canyon Road	3G	Extensively modified
Coastal Watersheds				
Usal Creek	South Fk Usal Creek	Westside Road	2F	Private road
	Shady Dell	Usal Road	2F	**X**
	Hotel Gulch	Usal Road	2F	**X**
	Low Gap Creek	Briceland Road	2F	**X**
Mattole River	Ancestor Creek	Briceland Road	2F	**X**
	Upper Mattole River	Briceland Road	2F	Bridged
Tenmile Creek				
South Fork Tenmile	Smith Creek	Little Valley Road	2G	Private road
	Campbell Creek	Camp Tenmile Road	2G	Private road

Table 3 (continued). List of 54 stream-crossing locations visited in coastal Mendocino County.

BASIN NAME	STREAM NAME	ROAD NAME	COUNTY MAP #	STATUS OF SITE
Big River	Dark Gulch	Orr Springs Road	3G	**X**
	Johnson Creek	Orr Springs Road	3G	**X**
	Unnamed trib.	Orr Springs Road	3G	**X**
Albion River				
	North Fork Albion River	Comptche-Ukiah Road	2G	No culvert
	Albion River	Flynn Creek Road	2G	**X**
	Marsh Creek	Flynn Creek Road	2G	**X**
Navarro River				
Anderson Creek	Witherell Creek	Anderson Valley Way	3H22	**X**
	Graveyard Creek	Anderson Valley way	3H22	No, ditch
	Ornbaun Creek #1	Ornbaun Road	3H22	**X**
	Ornbaun Creek #2	Ornbaun Road	3H22	**X**
Garcia River	Mill Creek	Fish Rock Road #1	3H	**X**
	Mill Creek	Fish Rock Road #2	3H	**X**
Coastal Watersheds	Mill Creek	Westwood Drive	2G23	**X**
	Virgin Creek	Airport Road	2G23	**X**
	Digger Creek	Ocean Drive	2G-1B	**X**
	Mitchell Creek	Mitchell Creek Road	2G33	**X**
	Mitchell Creek	Ocean Drive	2G-1B	Private road
	Doyle Creek	Point Cabrillo Drive	2G-1B	Bridged
	Irish Gulch	Pomo Lake Drive	2H-1B	Above anadromy
	Spanish Creek	Crispin Road	2H34	**X**
	Hathaway Creek	Windy Hallow Road	2H34	**X**
	Moat Creek	Curley Lane	2H44	**X**

Table 4. Hydraulic capacity of 26 coastal Mendocino County road 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).

Stream Name	Road Name	Drainage	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)
Marsh Creek	Flynn Creek Road	Albion River	363	788	**3.2**	**30**
Albion River	Flynn Creek Road	Albion River	1,342	1,634	**21**	**48**
Ornbaun Creek #1	Ornbaun Road	Anderson Creek - Navarro River	77	271	**1.4**	**23**
Ornbaun Creek #2	Ornbaun Road	Anderson Creek - Navarro River	231	447	**96**	**>250**
Witherell Creek	Anderson Valley Way	Anderson Creek - Navarro River	231	542	**2.6**	**40**
Dark Gulch	Orr Springs Road	Big River	340	1,021	**1.8**	**22**
Johnson Creek	Orr Springs Road	Big River	861	1,212	**30**	**155**
Un-named tributary	Orr Springs Road	Big River	930	1,230	**23**	**79**
Spanish Creek	Crispen Lane	Brush Creek	64	183	**1.1**	**5.6**
Virgin Creek	Airport Road	Coastal	112	174	**1.7**	**3.6**
Mitchell Creek	Mitchell Creek Road	Coastal	135	523	**3.3**	**>250**
Digger Creek	Ocean Drive	Coastal	93	200	**1.6**	**7.1**
Mill Creek #1	Fish Rock Road	Garcia River	1,200	1,600	**134**	**>250**
Mill Creek #2	Fish Rock Road	Garcia River	650	1,000	**37**	**>250**
Hathaway Creek	Windy Hollow Road	Garcia River	177	299	**1.5**	**3.6**
Ancestor Creek	Briceland Road	Mattole River	259	315	**8.4**	**13**
Tributary to Mill Creek	Westwood Drive	Mill Creek	77	271	**7.4**	**>250**
Ryan Creek	Ryan Creek Road	Outlet Creek - Eel River	430	1,600	**11.7**	**>250**

Table 4 (continued). Hydraulic capacity of 26 coastal Mendocino County road crossings.

Stream Name	Road Name	Drainage	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)
Davis Creek tributary	Eastside Road	Outlet Creek - Eel River	878	1,307	**143**	**>250**
Fulweiter Creek	Eastside Road	Outlet Creek - Eel River	112	185	**3.4**	**6.7**
Deer Creek	Wilderness Lodge Rd	South Fork Eel River	259	474	**5.6**	**19**
Taylor Creek	Branscomb Road	South Fork Eel River	508	1,449	**83**	**>250**
Bear Creek	Branscomb Road	South Fork Eel River	557	731	**82**	**>250**
Windem Creek	Branscomb Road	South Fork Eel River	860	1,200	**177**	**>250**
Hotel Gulch	Usal Road	Usal Creek	250	247	**7.3**	**7.3**
Shady Dell	Usal Road	Usal Creek	143	162	**3.8**	**5.0**

Passage Analyses

Of the 28 culverts included in the inventory, 26 were evaluated for passage with FishXing. Two sites were dropped from the inventory after further investigation ruled out the probability of these creeks supporting anadromous fishes:

1. Low Gap Creek/Briceland Road. Channel between ocean and county road is extremely steep (overall slope = 14.6%). Past CDFG surveys have found no fish in this creek. Approximately 500' of channel on each side of Low Gap Road was examined during the initial site visit: no fish were observed; channel was steep, confined, and boulder/bedrock dominated.

2. Moat Creek/Curley Lane. Mouth of Moat Creek at beach is clogged by an extensive woody debris jam. It is unlikely that anadromous access is available on an annual basis. Past CDFG surveys confirmed lack of salmonids in Moat Creek. No fish observed during initial site visit.

FishXing proved an extremely useful tool in identifying where passage problems occurred and probable causes. However, like most models which attempt to predict complex physical and biological processes with mathematics, there were limitations and assumptions that must be acknowledged.

Field surveys to numerous culverts within the Five-Counties region during migration flows revealed some confounding results generated by FishXing:

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

2. Adult salmonids successfully migrating through depths considered "too shallow".

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' jumping and swimming abilities at a culvert may change as numerous attempts are made. We observed individual fish become fatigued over repetitive attempts, and conversely documented other fish gaining access to culverts after numerous failed attempts (Taylor 2000; Love pers. comm.).

Passage results generated by FishXing are displayed as "percent passable" for the range of migration flows calculated for each stream crossing location within the four watershed categories (Eel River, Navarro River/Garcia River, Albion River/Big River, and Mattole River/smaller coastal tributaries) (Figures 2-5).

For each site, by species and lifestage, FishXing evaluation results are provided in Appendix C. The "Comments" column in Appendix C lists assumptions made concerning specific sites while running FishXing.

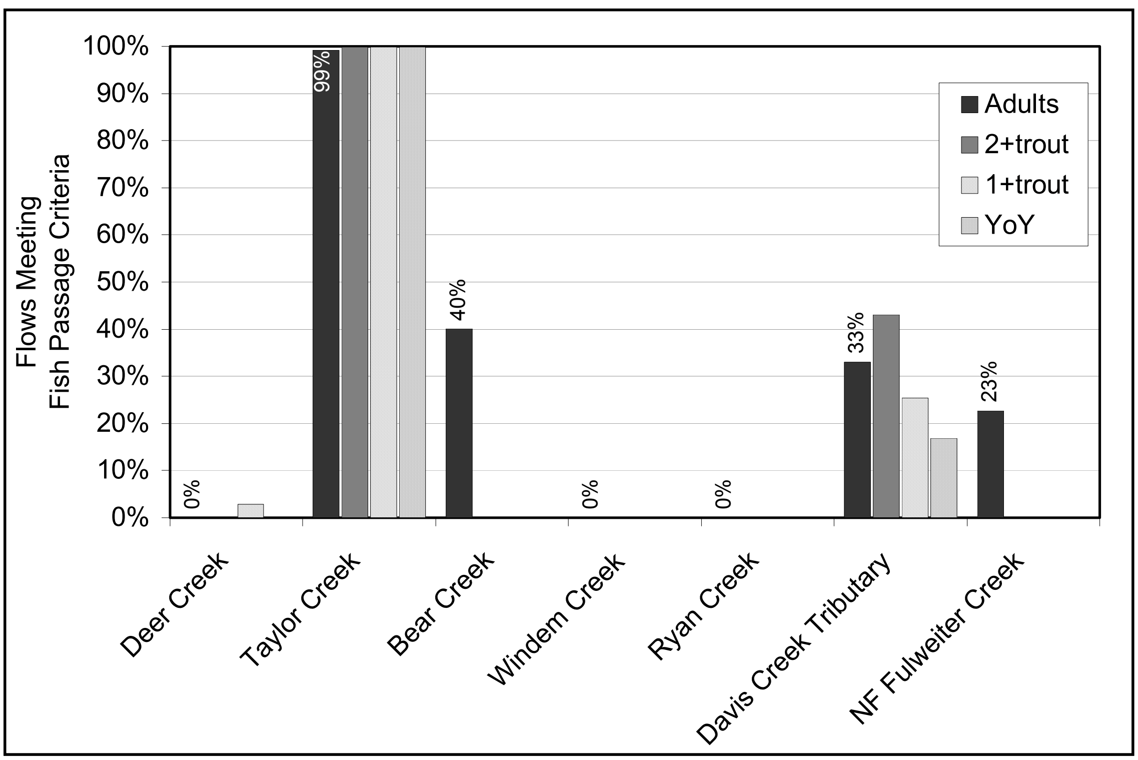

Figure 2. Percent passable as estimated by FishXing for seven coastal Mendocino County road crossings within the Eel watershed, by salmonid species and lifestage.

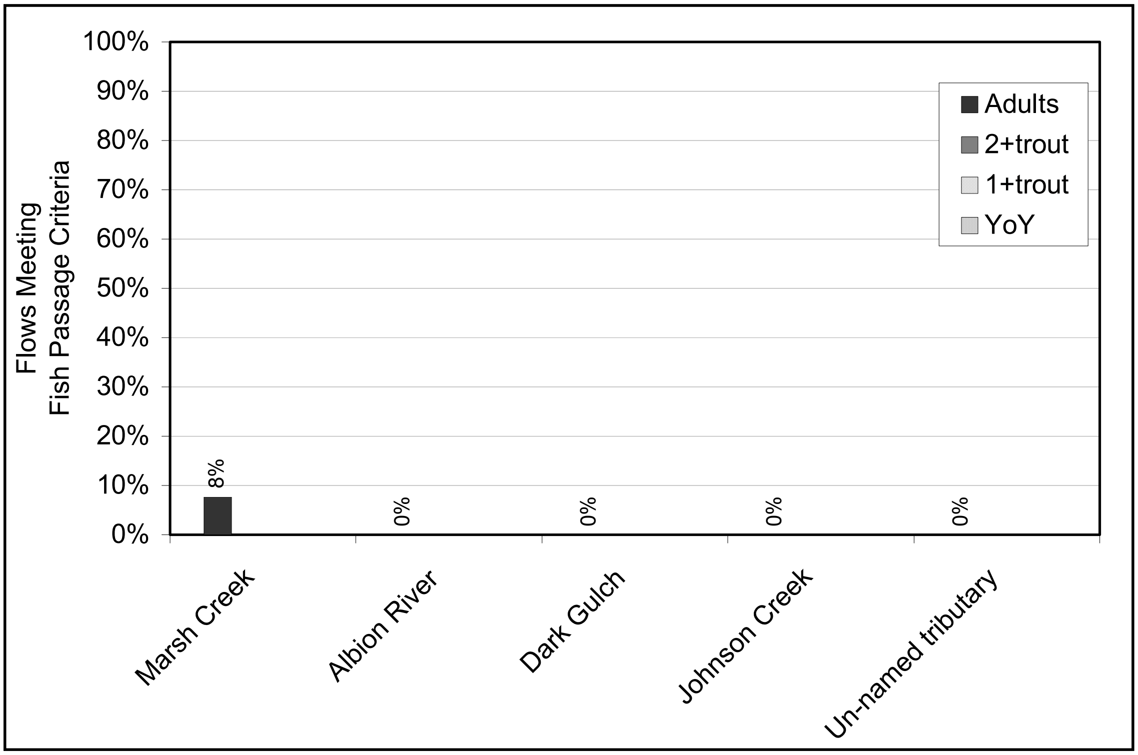

Figure 3. Percent passable as estimated by FishXing for five coastal Mendocino County road crossings within Albion River and Big River watersheds, by species and lifestage.

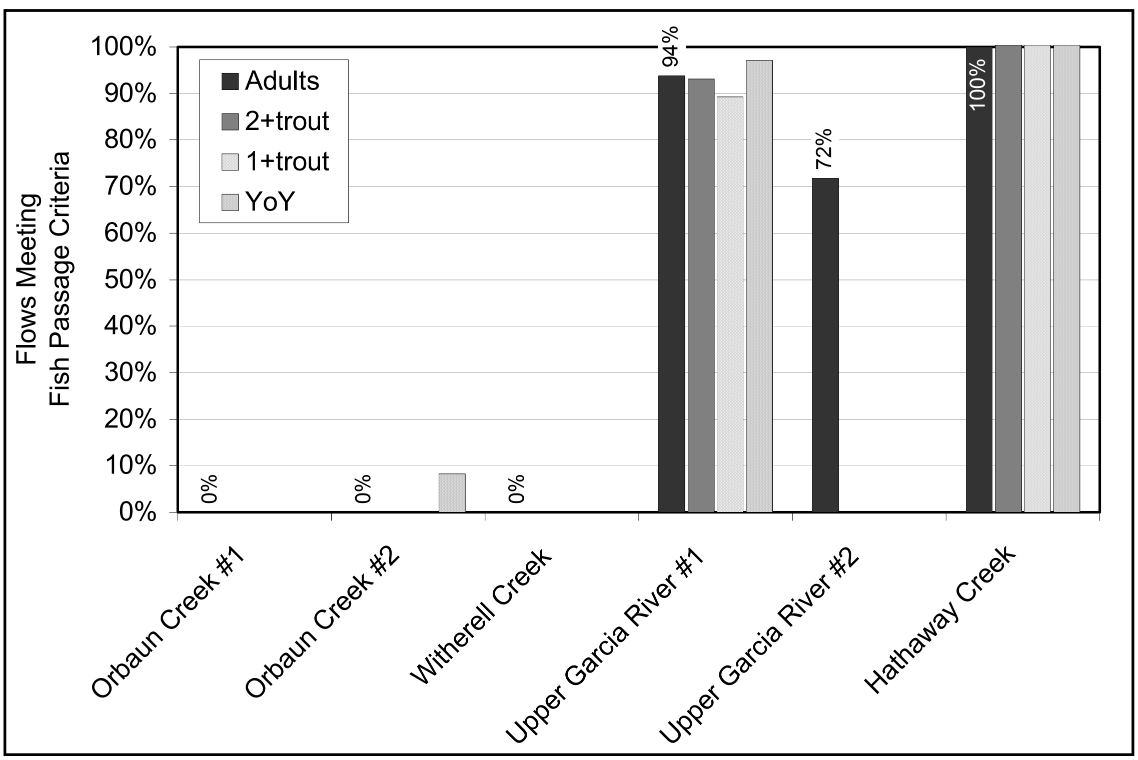

Figure 4. Percent passable as estimated by FishXing for six coastal Mendocino County road crossings within the Navarro River and Garcia River watersheds, by species and lifestage.

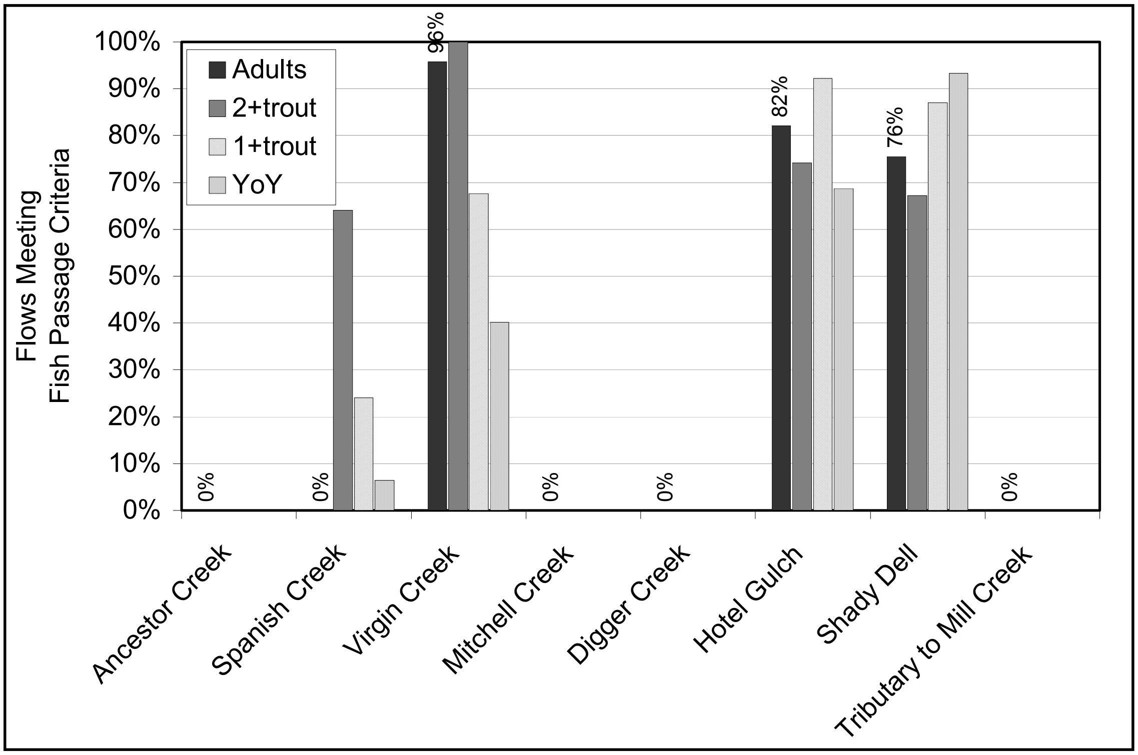

Figure 5. Percent passable as estimated by FishXing for eight coastal Mendocino County road crossings within the Mattole River and smaller coastal watersheds, by species and lifestage.

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. Only two sites were evaluated as allowing unimpeded (100%) access for all adults at the entire range of migration flows (Hathaway Creek/Windy Hollow Road and Taylor Creek/Branscomb Road). However, Taylor Creek was evaluated assuming that all 12 baffles were functioning properly when several have recently failed.

Most culverts, 24 of 26 (92%), evaluated were at least temporary or partial barriers to adults salmonids. Eighteen of the 26 culverts (69%) were considered total barriers to all adult and juvenile salmonids.

By species, 10 of 26 sites within the 13 streams presumed to support coho salmon were estimated to be significant adult barriers (not passable on >60% of estimated migration flows) which block migration to 19.9 miles of upstream habitat.

For steelhead (within 24 streams presumed to support steelhead), 18 of 26 sites were estimated to be significant adult barriers (not passable on >60% of expected migration flows) which block migration to 26.4 miles of upstream habitat

Most culverts were some form of barrier to juvenile salmonids, more so for young-of-year (y-o-y's) than one-year old (1+) juveniles. For 1+ fish, 18 of 26 (or 69%) culverts were total barriers and seven more culverts were classified as temporal barriers. Only Hathaway Creek/Windy Hollow Road allowed for unimpeded juvenile upstream migration over the entire range of estimated migration flows.

For young-of-year juveniles, 20 of 26 (or 77%) culverts were classified as total migration barriers over the range of expected migration flows.

For both age classes of juveniles, their extremely small size renders them most vulnerable to perched culverts or those with velocities during migration flows exceeding two to four feet per second. Passage evaluation scores are provided in the Culvert Ranking Matrix (Appendix D).

Fish Observations

Fish observations were conducted at 11 culverts during the winter of 1999-2000, for a total of 420 minutes (Table 5). In coastal Mendocino County very little migration was observed. This may be due to either low numbers of fish and/or that our visits were limited to just two days out of the entire period of winter migration (November-April). However, on Hotel Gulch and Mill Creek (upper Garcia River) extensive reaches of stream were surveyed for spawning adults or redds constructed by earlier spawners – none were observed even though conditions and timing appeared optimal.

During earlier passage studies within the Five-Counties region, numerous observations have provided valuable insight into salmonid migration, including:

1. Most upstream migration occurred during the falling limb of storm hydrographs.

2. Regardless of jumping abilities cited in literature, most perched culverts were migration problems for adult salmonids. Site-specific hydraulics at culvert outlets appeared to create confusing flow patterns to migrating salmonids.

3. When individual fish made repeated jump attempts, these often occurred at regular intervals spaced about five to 12 minutes apart and often occurred at the same location. Individuals were rarely observed attempting leaps from a variety of locations at an outlet.

4. Although most literature on fall/winter, upstream movement of juvenile salmonids concerned only coho salmon, we observed upstream movement of three year-classes of either juvenile coastal cutthroat trout or steelhead (young-of-year, 1+, and 2+) at several culverts.

Table 5. Observations of salmonid migration at 11 culverts on the Mendocino County road system, November 1999 – March 2000.

Stream Name	# of Visits	Total Obs. (minutes)	Adult Successful Attempts	Adult Failed Attempts	Juvenile Successful Attempts	Juvenile Failed Attempts	Comments
Hotel Gulch at Usal Road	1	40	0	0	0	0	Walked approximately 3,000' above culvert – no fish or redds observed.
Shady Dell at Usal Road	1	40	0	0	0	0	Walked approximately 1,000' upstream. No fish or redds observed. Natural falls about 500' above Usal Road may block juvenile migration.
Mill Creek tributary at Westwood Drive	1	20	0	0	0	0	Checked mouth at beach – some flow into surf with 100's of seagulls.
Albion River at Flynn Creek Road	2	60	0	0	0	0	Newly emerged fry observed in pools above and below culvert (3/30/00).
Marsh Creek at Flynn Creek Road	2	60	0	0	0	3	Measured surface velocity = 8.1 ft/sec through culvert on 2/24/00. Observed 7" steelhead leaping at outlet on 3/30/00.
Spanish Creek at Crispin Lane	2	60	0	0	0	0	Measured surface velocity = 5.6 ft/sec on 2/25/00. Excessive velocity at channel drop into culvert inlet. Removed debris at inlet on 2/25/00.
Ornbaun Creek #1 at Ornbaun Road	1	20	0	0	0	0	Removed debris jam that was plugging primary culvert on 2/25/00. Noticed lack of depth below culvert to attempt 2.2' leap.

Table 5. Observations of salmonid migration at six culverts on the Mendocino County road system, November 1999 – February 2000.

Stream Name	# of Visits	Total Obs. (minutes)	Adult Successful Attempts	Adult Failed Attempts	Juvenile Successful Attempts	Juvenile Failed Attempts	Comments
Ornbaun Creek #2 at Ornbaun Road	1	20	0	0	0	0	Measured surface velocity = 4.7 ft/sec on 2/25/00.
Mill Creek #2 at Fish Rock Road	2	40	0	0	0	0	Walked approximately 3,000' of channel between both county culverts – no fish or redds observed.
Deer Creek at Wilderness Lodge Road	1	20	0	0	0	0	No migration attempts observed, but on 3./30/00 outlet pool contained numerous juveniles salmonids (three age classes).
Ryan Creek at Ryan Creek Road	1	40	0	0	0	0	No migration attempts observed, but on 3/31/00 numerous juveniles salmonids in outlet pool - confirmed several coho. Also, observed adult Pacific lamprey digging a redd below culvert.

Ranking Matrix

The 26 Coastal Mendocino County culvert locations were sorted by "Total Scores", the sum of the five ranking criteria (Appendix D). The final list of the Mendocino County culverts reflects changes made due to professional judgement (Table 6).

Table 6. Ranking for 26 culvert locations on the Mendocino County road system.

Final Rank	Stream Name	Road Name	Initial Rank	Comments to Final Ranking
1	Albion River	Flynn Creek Road	**1**	Top-priority site due to: severity of barrier (100% for all species and lifestages); quantity and quality of upstream habitat; and sizing and condition of current crossing. Along Mendocino coast, upper Albion River is vital coho salmon spawning and rearing habitat. Access should be a high priority.
2	Ryan Creek	Ryan Creek Road	**2**	High-priority due to: severity of barrier (100% for all species and lifestages); species diversity of watershed (adult coho, chinook, steelhead, and Pacific lamprey all recently observed in outlet pool) (Harris, pers. comm.); condition and sizing of current culvert; and quantity/quality of upstream habitat. CALTRANS intends to evaluate two Highway 101 crossings in their 2001 pilot road crossing inventory.
3	Ancestor Creek	Briceland Road	**3**	High-priority due to: severity of barrier (100% all species and lifestages); known coho and steelhead stream; quantity and quality of upstream habitat. Current culvert is undersized and in poor condition, with other problems associated with road drainage. Upper Mattole River tributaries are vital coho salmon spawning and rearing areas.
4	Marsh Creek	Flynn Creek Road	**4**	High-priority due to: severity of barrier (100% for all species and lifestages); and potential habitat gains (either 4,900' or 12,900' depending on presence/absence of upstream mill pond noted on USGS topographic map). Current culvert is undersized and in poor condition. Marsh Creek lacks a biological assessment (Jones, 2001). Two age classes of juveniles observed at outlet during winter site visits.
5	Johnson Creek	Orr Springs Road	**7**	High-priority due to: severity of barrier (100% for all species and lifestages); good habitat quality and significant length of upstream habitat gain (1.7 miles). Both coho salmon and steelhead historically utilized creek for spawning and rearing. Culvert barrier at mouth on Orr Springs Road first noted in a 1959 CDFG stream survey. Moved up in rank because of higher biological importance than Digger Creek and Dark Gulch – initial total score was lower due to low sizing and condition values.

Table 6 (continued).

Final Rank	Stream Name	Road Name	Initial Rank	Comments to Final Ranking
6	Digger Creek	Ocean Drive	**5**	Moderate-priority due to: severity of barrier, and migration barriers downstream of Ocean Drive are being treated (2001 and 2002). CALTRANS intends to evaluate Highway 1 box culvert in 2001. Historic coho-bearing stream that has potential to educate public about watershed restoration (60,000 visitors annually at Mendocino Coast Botanical Gardens and Fort Bragg residents).
7	Dark Gulch	Orr Springs Road	**6**	Moderate-priority due to: a total barrier to all species and lifestages with nearly one mile of upstream habitat. Initial efforts to raise pool elevation with boulder weir appear ineffective. Large amount road fill will make this an expensive replacement project.
8	Deer Creek	Wilderness Lodge Road	**8**	Moderate priority due to: only 3,900' spawning and rearing habitat upstream of crossing. Raised slightly in ranking because culvert is a total barrier and is extremely undersized. Deer Creek may provide thermal refugia during summer months. Deer Creek would benefit from a stream survey to better assess biological significance (Jones, 2001).
9	Mill Creek #2 (Garica River)	Fish Rock Road	**9**	Moderate priority due to: impedes mostly juvenile migration and habitat starts to degrade upstream of State Park boundary. However, both coho and steelhead rear year-round in Mill Creek.
10	Unnamed Tributary to South Fork Big River	Orr Springs Road	**10**	Moderate-priority due to: although a total barrier to all species and lifestages; there is limited upstream habitat (2,900'). However, over a mile of low-gradient channel is located above reach with 10% slope for 400'. No surveys exist to accurately determine extent of anadromy.
11	Spanish Creek	Crispen Lane	**11**	Moderate-priority due to: although culvert is a total barrier, upstream habitat appears degraded by current landowner. However, a substantial length of habitat (10,000') is above culvert. DOT who recently replaced this culvert (within past five years) should look at this site to learn what NOT to do with future replacements. New culvert is undersized and set at a steep slope.
12	Bear Creek	Branscomb Road	**18**	Moderate-priority due to: although a total migration barrier only steelhead are presumed to use tributary. Moved up in ranking because of good summer water quality and treatment of retrofitting existing culvert is cost-effective.

Table 6 (continued).

Final Rank	Stream Name	Road Name	Initial Rank	Comments to Final Ranking
13	Windem Creek	Branscomb Road	**19**	Moderate-priority due to: although a total migration barrier only steelhead are presumed to use tributary. Moved up in ranking because of good summer water quality and treatment of retrofitting existing site is cost-effective.
14	Taylor Creek	Branscomb Road	**26**	Moderate-priority due to: amount of upstream habitat. Site was moved up in ranking because site was evaluated as if all 12 baffles were in good condition (and providing passage). However, three failed baffles are creating migration barriers (and nine others are in fair to poor condition).
15	Mitchell Creek	Mitchell Creek Road	**12**	Low-priority due to: poor quality of upstream habitat; additional potential barriers upstream and downstream; and limited presence of salmonids within watershed. High cost of fill removal also was reason to drop site in final ranking.
16	Witherell Creek	Anderson Valley Way	**15**	Low-priority due to: poor quality of upstream habitat; additional potential barriers upstream and downstream; and limited presence of salmonids within watershed. High cost of fill removal also was reason to drop site in final ranking.
17	Tributary to Mill Creek (coastal)	Westwood Drive	**13**	Low-priority due to: limited amount of poor-quality, upstream habitat. Past CDFG surveys confirm decades of poor habitat and distribution of salmonids (in very low numbers) limited to Mill Creek channel downstream of this tributary.
18	Ornbaun Creek #1	Ornbaun Road	**14**	Low-priority due to: limited amount of upstream habitat, poor condition of upstream habitat, and presence of additional upstream migration barrier (Ornbaun Creek #2).
19	Ornbaun Creek #2	Ornbaun Road	**17**	Low-priority due to: limited amount of upstream habitat, poor condition of upstream habitat, and presence of additional downstream barrier (Ornbaun Creek #1).
20	Fulweiter Creek	Westside Drive	**17**	Low-priority due to: limited amount of upstream habitat, and poor condition of upstream habitat. Site should be periodically inspected for condition. Culvert is undersized, when needed, replace with a properly-sized crossing.
21	Mill Creek #1 (Garcia River)	Fish Rock Road	**20**	Low-priority due to: current crossing allows for unimpeded adult and juvenile migration. Current crossing is also in good condition and is adequately-sized.

Table 6 (continued).

Final Rank	Stream Name	Road Name	Initial Rank	Comments to Final Ranking
22	Hathaway Creek	Windy Hollow Road	**21**	Low-priority due to: current crossing allows adult and juvenile migration on most flows. However, culvert is undersized. Hathaway Creek supports steelhead, plus historically a known coho stream (Bell, pers. comm.)
23	Davis Creek tributary	Westside Drive	**22**	Low-priority due to: limited amount of upstream habitat, and poor condition of upstream habitat.
24	Virgin Creek	Airport Road	**23**	Low-priority due to: current crossing allows for adult and juvenile passage; also, upstream habitat is degraded. Site should be periodically inspected for condition. Culvert is undersized, when needed, replace with a properly-sized crossing.
25	Hotel Gulch	Usal Road	**24**	Low-priority due to: current crossing allows for adult and juvenile passage on most migration flows. Site should be periodically inspected for condition. Culvert is undersized, when needed, replace with a properly-sized crossing.
26	Shady Dell	Usal Road	**25**	Low-priority due to: current crossing allows for adult and juvenile passage on most migration flows. Site should be periodically inspected for condition. Culvert is undersized, when needed, replace with a properly-sized crossing.

Site-Specific Treatments and Scheduling

<u>High-Priority Sites</u>

During the past few years, several sources of restorations funds have been available for treating priority culverts – SB271, California Coastal Salmon Recovery Program (CCSRP), and Proposition 13 (Clean Water Bond). As of March, 2001, Mendocino County has already submitted proposals to treat the two of the top-ranked sites. Proposals for the remaining three high-priority sites are being submitted to CDFG-administered funding sources on May 17, 2001.

For all five "high-priority" sites, recommendations are for replacements. Because most of the inventoried culverts were under-sized, very few are candidates for modification of existing crossing. retrofitting a crossing with baffles will further decrease the flow conveyance capacity of already under-sized structure and increase the likelihood of debris clogging.

The following general guidelines draw from design standards used in Oregon and Washington, and should be consistent with NMFS draft guidelines for culvert installations (NMFS 2000). However, site-specific characteristics of the crossing 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.

Bates et al. (1999) is recommended as an excellent reference to use when considering fish-friendly culvert installation options. Robinson et al. (2000) provides a comprehensive review of the advantages and disadvantages of the various treatment alternatives as related to site-specific conditions.

Order of Preferred Alternatives

1. Bridge.

2. Open bottom arch culverts.

3. Culvert set below stream grade (countersunk or embedded).

4. Culvert set at grade with baffles installed to allow low-flow passage and reduction of velocities during higher migration flows.

5. Culvert perched with outlet pool weirs and baffles throughout culvert. Entry jumps should never exceed 1.0 feet for adults or 0.5 feet for juveniles.

Design Criteria for Proper Sizing and Alignment

1. Pass a 100-year storm flow at less than 100% of the culvert's height. This allows for passage of woody debris during extremely high flows.

2. Culvert width sized at least equal to active channel width – base winter flow, about at line of vegetation growth. Should reduce constriction of flows at the inlet associated with fish migration. (NMFS may recommend sizing to a wider channel width).

3. Avoid projecting culvert inlets.

4. Align culvert with the general direction of channel – avoid sharp bends in channel at approach to inlet.

5. Avoid installing trash racks at culvert inlets.

Moderate-Priority Sites

The "moderate-priority" tier of culvert locations requiring treatment to improve fish passage includes nine locations with ranks #6-14. Several sites have already received restoration funding for treatment or have had proposals submitted. These sites are:

1. Windem, Bear, and Taylor Creeks on Branscomb Road were funded by SB271 as a package proposal. These sites will be treated by modifying the existing culverts with baffles, outlet beams, and/or outlet pool weirs.

2. Digger Creek on Ocean Drive. Mendocino County submitted a proposal to Prop. 13 to replace this under-sized pipe-arch. The County is treating this barrier because a downstream landowner (Mendocino Coast Botanical Gardens) is replacing both of their barrier culverts with bridges in 2001 and 2002. CALTRANS will be assessing their box culvert under Highway 1 (above Ocean Drive) in summer of 2001.

3. Mill Creek #2 on Fish Rock Road. Mendocino County DOT is submitting proposal to replace this crossing to CDFG on May 18, 2001.

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

1. Mendocino County has a large task of completing the scheduling, contracting, permitting, and implementation required to treat the first 10 locations submitted for funding. The County should focus on completing these higher priority projects with properly designed and constructed treatments before addressing the next tier of sites.

2. Mendocino County is a participant in the Five-Counties Salmon Group, which plans to acquire treatment funds for passage problems in all five counties (Mendocino, Trinity, Siskiyou, Del Norte, and Humboldt). Thus, the remaining "moderate-priority" tier of Mendocino County culverts should be ranked and evaluated with respect to priority culverts located in the other four counties. Culvert inventories are currently underway in Siskiyou county; and will be started in Trinity County in spring of 2001. Mendocino and Sonoma County culverts in the Russian River will also be inventoried in 2001-2002.

3. When addressing the "moderate-priority" tier of culverts, the current biological condition and/or importance (such as quantity) of the streams starts 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

The remaining sites, ranked #15-26, are of “low-priority”. These sites either allow 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 fill amount. All future replacements with county maintenance funds should include properly sized crossings that permit unimpeded passage of adult and juvenile salmonids.

The four most common activities impacting these Mendocino County streams are timber harvesting, agriculture, unfenced grazing, and residential 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, the County should carefully examine this list and determine which locations may be treated with existing maintenance funds.

For example, Mendocino County DOT 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, Mendocino County DOT and Water Agency should utilize this report to explain why the replacement should be a larger and higher-quality crossing (for both fisheries and future-flood benefits).

LITERATURE CITED

Bates, K; B. Barnard; B. Heiner; P. Klavas; and P. Powers. 1999. Fish passage design at road culverts: a design manual for fish passage at road crossings. WA Department of Fish and Wildlife. Olympia, Washington. 44 p.

Cederholm, C.J. and W.J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981, p. 98-110. *In* E.L. Brannon and E.O. Salo, editors. Proceedings of the Salmon and Trout Migratory Behavior Symposium. School of Fisheries, University of Washington, Seattle, WA.

Flannigan, S.A.; T.S. Ledwith; J. Ory; and M.J. Furniss. 1997. Risk assessment of culvert installations of forest roads. Water-roads Interactions Project, Six Rivers National Forest. 28 p.

Flosi, G. and F.L. Reynolds. 1994. California salmonid stream habitat restoration manual. Inland Fisheries Division, CDFG, Sacramento, California.

Jones, W. 2001. California coastal salmon and steelhead current stream habitat distribution table. NMFS California Anadromous Fish Distributions. 180 p.

Nickelson, T.E., J.D. Rogers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Aquat. Sci. 49: 783-789.

Normann, J. L., R. J. Houghtalen, and W. J. Johnston. 1985. Hydraulic Design of Highway Culverts. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design Series No. 5, 272 pp.

Piehl, B. T., M. R. Pyles, and R. L. Beschta. 1988. Flow Capacity of Culverts on Oregon Coast Range Forest Roads. Water Resources Bulletin. Vol. 24, No. 3. pp 631-637.

Rantz, S.E. 1968. Average annual precipitation and runoff in North Coastal California. USGS, Menlo Park, CA. 3 accompanying maps. 4 p.

Robison, E.G.; A. Mirati; and M. Allen. 1999. Oregon road/stream crossing restoration guide: spring 1999. Advanced Fish Passage Training Version. 75 p.

Scarlett, W.J. and C.J. Cederholm. 1984. Juvenile coho salmon fall-winter utilization of two small tributaries of the Clearwater River, Jefferson County, Washington, p. 227-242. *In* J.M. Walton and D.B. Houston, editors. Proceedings of the Olympic Wild Fish Conference, March 23-25, 1983. Fisheries Technology Program, Peninsula College, Port Angeles, WA.

SSHEAR. 1998. Fish passage barrier assessment and prioritization manual. Washington Department of Fish and Wildlife, Salmonid Screening, Habitat Enhancement, and Restoration (SSHEAR) Division. 57 p.

Skeesick, D.B. 1970. The fall immigration of juvenile coho salmon into a small tributary. Res. Rep. Fish Comm. Oregon 2: 90-95.

Taylor, R.N. 2000. Humboldt County culvert inventory and fish passage evaluation. Final Report, CDFG Agreement #FG 7068 IF. 39 p.

Taylor, R.N. and M. Love. In press. Fish passage evaluation at road crossings. Section 10 of the California Salmonid Stream Habitat Restoration Manual, CDFG Agreement #P9985035.

Tripp, D. and P. McCart. 1983. Effects of different coho stocking strategies on coho and cutthroat trout production in isolated headwater streams. Can. Tech. Rep. Fish. Aquat. Sci. 40: 452-461.

Tschaplinski, P.J. and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for over-wintering survival. Can J. Fish Aquat. Sci. 40: 452-461.

Waananen, A.O. and J.R. Crippen. 1977. Magnitude and frequency of floods in California. U. S. Geological Survey, Water Resources Investigation 77-21, Menlo Park, CA. 96 p.

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