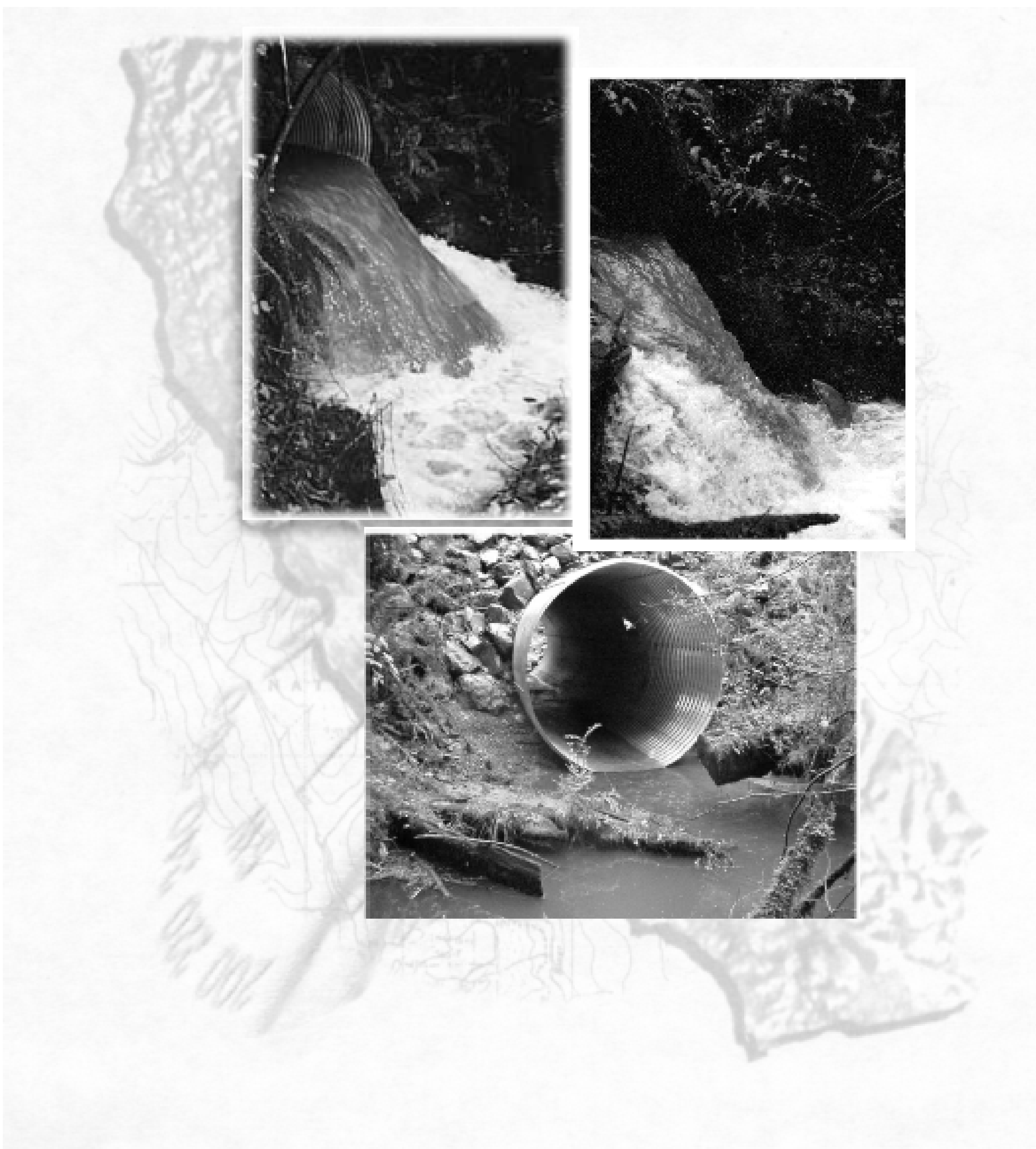
PART IX

FISH PASSAGE EVALUATION AT STREAM CROSSINGS



Disclaimer

This manual describes many methods and techniques used with varying degrees of success by habitat restoration specialists. The methods and techniques described here represent only a starting point for project design and implementation. They are not a surrogate for, nor should they be used in lieu of, a project design that has been developed and implemented according to the unique physical and biological characteristics of the site-specific landscape.

The techniques and methods described in this manual are not a surrogate for acquiring the services of appropriate professionals, including but not limited to licensed professional engineers or licensed professional geologists, where such expertise is called for by the Business and Professions Code section 6700 et seq. (Professional Engineers Act) and/or section 7800 et seq. (Geologists and Geophysicists Act).

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ACKNOWLEDGMENTS

The primary authors for Part IX, *Fish Passage Evaluation at Stream Crossings* were Ross N. Taylor and Michael Love. Ross N. Taylor, Ross Taylor and Associates, is a private consulting fishery biologist, with his business based in McKinleyville, California. He has completed an inventory and fish passage evaluation for culverts located within fish bearing streams in Humboldt, Mendocino, Del Norte, Siskiyou, and Trinity Counties and is currently working on similar inventories for tributaries to the Russian River. Michael Love, Michael Love and Associates, specializes in hydrologic and hydraulic analysis for natural resources management. Michael has completed projects involving the design of stream crossings for fish passage, road and culvert assessments, effectiveness monitoring of stream crossings for fish passage, and flow frequency analysis for fish passage design. Michael is also a co-author of the *FishXing* software for analysis of fish crossings. Ross and Michael, under contract with the For Sake of Salmon program completed five fish passage workshops in the fall of 2001. Funding for the development of Part IX was provided by the Salmon and Steelhead Trout Restoration Account Citizen Advisory Committee (SB 271) and the Coastal Salmon Recovery Program Advisory Committee.

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The editors want to thank Ross Taylor and Michael Love for the use of the title page photos. The photo on the upper left shows the old five-foot culvert on Morrison Gulch, on November 20, 1998. The upper right photo shows a salmon trying to pass the culvert. The lower photo is of the nine-foot culvert installed in the summer of 2001.

INTRODUCTION

A stream crossing is any human-made crossing over or through a stream channel including paved roads, unpaved roads, railroads, trails, and paths. Stream crossings include culverts, bridges, and low-water crossings such as paved and unpaved fords. A stream crossing encompasses any structure or device designed to pass stream flow, and includes the approach and surface fill material within the crossing prism. The distinction between types of stream crossings is not as important as the effect the crossing has on the form and function of the stream.

An individual stream crossing may impact a relatively short length of upstream anadromous fish habitat, sometimes one or two miles or less. Throughout California, possibly thousands of stream crossings functioning as barriers exist. The cumulative effect of blocked habitat is thought to be substantial. Many stream crossings create temporal, partial, or complete barriers for adult anadromous salmonids during spawning migrations and create flow barriers for juvenile salmonids during seasonal movements (Table IX-1).

Barrier Category	Definition	Potential Impacts
Temporal	Impassable to all fish at certain flow conditions (based on run timing and flow conditions).	Delay in movement beyond the barrier for some period of time.
Partial	Impassable to some fish species, during part or all life stages at all flows.	Exclusion of certain species during their life stages from portions of a watershed.
Total	Impassable to all fish at all flows.	Exclusion of all species from portions of a watershed.

Table IX-1. Definitions of barrier types and their potential impacts (adapted from Robison et al. 2000).

At temporal barriers, the delay imposed by a stream crossing can limit the distance adult fish migrate upstream before spawning. This may result in under-utilization of upstream habitat and superimposition of redds in lower stream reaches. Even if stream crossings are eventually negotiated by adult fish, excess energy expended may result in their death prior to spawning, or reductions in viability of eggs and offspring. Migrating adults and juveniles concentrated below impassable stream crossings are vulnerable to predation by a variety of avian and mammalian species, and to poaching by humans. In addition, this reduction in stream habitat creates competition for space and food among adult and juvenile salmonids and other aquatic species, year round.

Both resident and anadromous salmonids make upstream and downstream migrations. Juvenile coho salmon spend approximately one year in freshwater before migrating to the ocean, and juvenile steelhead trout may rear in freshwater up to four years. Thus, both species are highly dependent on stream habitat throughout the year. Seasonal upstream movement into tributaries by juvenile salmonids has also been observed during the summer. These fish are thought to be seeking cool water refugia from stressful or lethal temperatures in larger river channels. A common strategy for over-wintering juvenile coho salmon is to migrate from large rivers into smaller tributaries during late-fall and early-winter storms to seek refuge from high water velocities and 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). Shapovalov and Taft (1954) reported seasonal movements by juvenile steelhead trout both upstream and downstream. Recent research conducted in coastal northern California suggests that juvenile salmonids migrate into smaller tributaries in the fall and winter to feed on eggs deposited during spawning, and on the flesh of adult carcasses (Roelofs, personal communication). Direct observation at numerous culverts in northern California confirmed similar upstream movements of three year-classes of juvenile steelhead trout (Taylor 2000).

Recent studies in coastal Washington streams documented the movement of juvenile coho salmon, steelhead trout, and coastal cutthroat trout and determined that movers grew faster than non-movers. Most summer, fall, and winter movement occurred in an upstream direction; however some marked individuals moved more than once and in both directions. Movement of juvenile salmonids is also a vital life history strategy in streams that naturally de-water during the summer, triggered by declining discharge (Kahier et al. 2001).

Characteristics of stream crossings with poor fish passage include:

- Crossings that constrict the natural channel width
- Crossings with hardened bottoms lacking diverse stream substrate
- Paved crossing invert set above the channel bottom
- Crossings not in alignment with stream channel
- Crossings requiring baffles or weirs inside to meet hydraulic criteria
- Channel bed and banks showing signs of instability upstream or downstream
- Crossings with projecting culvert inlets
- Crossings with trash rack installed at culvert inlet.

Such characteristics cause these typical types of passage problems (Figure IX-1):

- Excessive water velocities within a culvert
- Excessive drop at the outlet, resulting in a too high entry leap, or too shallow of a jump pool below a crossing
- Lack of water depth within culvert or over crossing
- Excessive water velocity or turbulence at a culvert inlet
- Debris accumulation at a culvert inlet or within a culvert barrel.

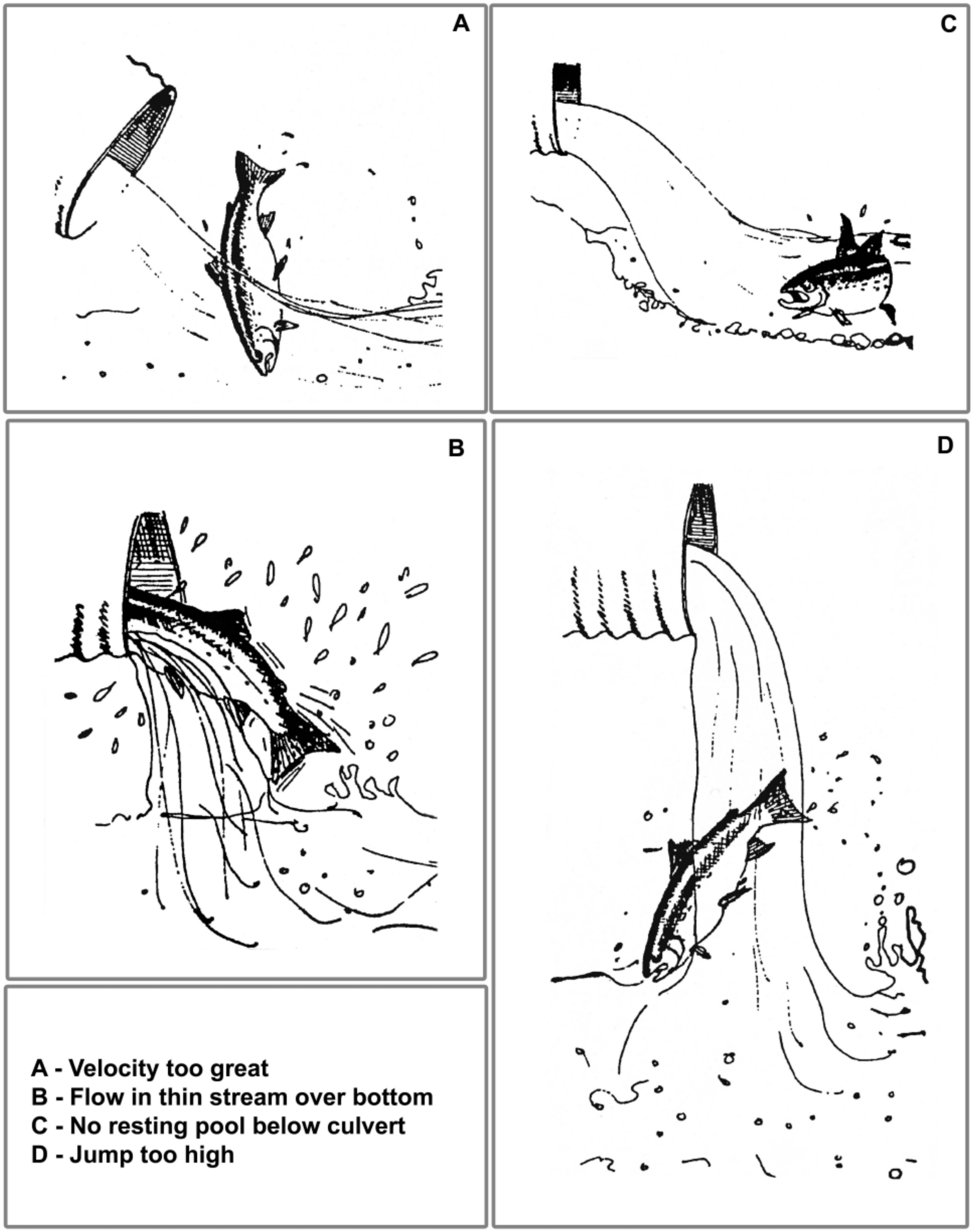


Figure IX-1. Common conditions that block fish passage.

Current state and federal guidelines for new crossing installation aim to provide unimpeded passage for both adult and juvenile salmonids (Appendix IX-A and IX-B). However, many existing crossings are barriers to anadromous adults, more so to resident and juvenile salmonids whose smaller size significantly limits their leaping and swimming abilities. For decades, these existing crossings have effectively disrupted the spawning and rearing behavior of all four species of anadromous salmonids commonly found in California: chinook salmon, coho salmon, steelhead trout, and coastal cutthroat trout.

Characteristics of fish friendly crossings include:

- Crossing width at least as wide as the active channel. This reduces the constriction of flows at the inlet
- Culvert passes a 100-year storm flow at less than 100 percent of the culvert's height. This allows for passage of other watershed products (large wood, debris, and substrate) during extremely high flows
- Crossing bottom buried below the streambed
- Natural bed material accumulated along the bottom of the crossing
- The water surface within the crossing blends smoothly with upstream and downstream water surfaces without excessive drops
- Obvious turbulent conditions are not present
- No obvious signs of excessive scour of the tailwater pool
- Stable streambanks upstream and downstream of the crossing.

OBJECTIVE

The objective of Part IX is to provide the user with:

- Consistent methods for collecting and analyzing data to evaluate passage of juvenile and adult salmonids through stream crossings (pages IX-8 to IX-44)
- Ranking criteria for prioritizing stream crossing sites for treatment according to the degree to which the barrier impedes species life stages trying to negotiate them, and considers the quality and quantity of available habitat upstream of the crossing (pages IX-45 to IX-47)
- Treatment options to provide unimpeded fish passage for all adult and juvenile age classes (page IX-47)
- A stream crossing remediation project checklist (page IX-49)
- Guidance measures to minimize impacts during stream crossing remediation construction (pages IX-50 to IX-52)
- Methods for monitoring effectiveness of corrective treatments (page IX-54).

OVERVIEW OF EVALUATION PROCESS

The fish passage evaluation protocol provides consistent methods for evaluating fish passage through culverts at stream crossings, and will aid in assessing fish passage through other types of stream crossings, such as bridges, and paved or hardened fords. Consistent evaluation of stream crossings enables managers to rank and prioritize sites for treatment. This is not a design protocol for constructing replacement structures. However, general aspects of design options, permits, water management, and measures to minimize construction impacts to salmonids and stream habitat are included.

The stream crossing inventory and fish passage evaluation is generally conducted as a series of tasks completed in the following order (Figure IX-2):

- Location of stream crossings and identification of crossing sites for passage evaluation (page IX-8)
- Completing *Fish Passage Inventory Data Sheet* (pages IX-18 and IX-21)
- First-phase passage evaluation using the filtering process to assist in identifying sites which either meet or fail to meet fish passage criteria (the filtering process reduces the number of crossings which require an in-depth passage evaluation) (pages IX-31 to IX-34)
- Estimation of stream-specific hydrology, flow capacity of crossings, and fish passage flows (pages IX-34 to IX-39)
- In-depth passage analysis at sites identified by the first-phase passage evaluation as possible temporal or partial barriers (pages IX-41 to IX-44)
- Collection and interpretation of existing habitat information (page IX-44)
- Ranking of sites for corrective treatment (pages IX-45 to IX-47).

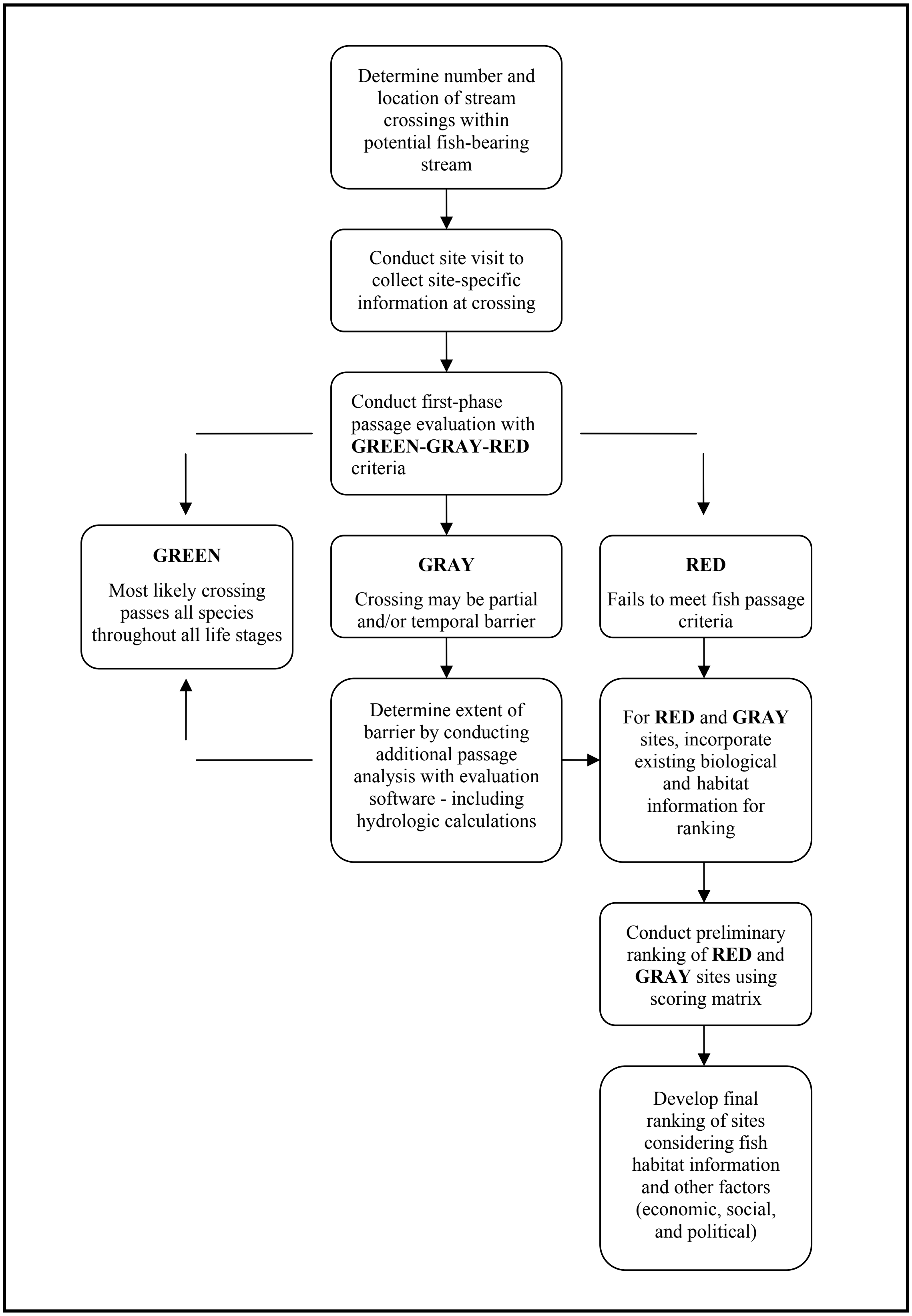


Figure IX-2. Framework for inventory and evaluation of fish passage through stream crossings.

FISH PASSAGE EVALUATION FIELD PREPARATION

Prior to conducting field inventories, the project manager must consider special training requirements, minimum crew-size restrictions, and permits that may be required to legally work within road easements or confines of culverts. Always obtain landowner permission before accessing private property. Use proper safety equipment and carefully assess the site-specific characteristics of each stream crossing before conducting longitudinal surveys.

At each site place bright orange safety cones with signs marked “Survey Party” to alert oncoming traffic from both directions. Crewmembers should wear bright orange vests to increase visibility to traffic. Two-way radios with headsets enable effective communication between crewmembers in spite of noise from road traffic and stream flow.

Use extreme caution when wading through culverts. In older corrugated steel culverts, check the floor carefully for rusted-through areas and/or jagged edges. A hard hat with a chin strap, protective footwear, and flashlight should be required items for any crewmembers that enter a culvert.

Prior to initiating stream crossing inventories field crews should become familiar with the protocol by participating in a DFG-sponsored or approved training session. Project supervisors should assure quality control of data collected by crews.

Tools and Supplies Needed

Prior to conducting field inventories, the following equipment and supplies should be assembled:

- Maps marked with site locations
- Names and phone numbers of property owners, along with copies of access agreements
- Data collection sheets, printed on water-proof paper
- Pencils
- Global Positioning System (GPS) unit (optional)
- Safety vests, signs, and cones
- Hard hat with chin strap
- Flashlight or headlamp
- Two-way radios with headset
- Waders, hip boots, and wading shoes (non-slip soled)
- Survey-level, auto-level equivalent, r better (such as total station)
- Tripod, domed head preferred
- Tapes (one each): 300' and 100' in 0.1' increments
- Clamps to secure tapes for longitudinal profiles and cross-section surveys
- Leveling rod: 25' in 1/100' increments

- Pocket leveling rod - to measure breaks-in-slopes within small diameter culverts
- Compass
- Clinometer - for measuring road prism slopes
- Camera, film (or discs for digital), and extra batteries
- Machete or pruners for clearing brush
- First-aid kit
- Poison oak protection.

FISH PASSAGE EVALUATION

The fish passage evaluation protocol is designed for conducting consistent evaluation of stream crossings. Evaluation results identify fish passage problems, and considering additional fish habitat information, rank or prioritize treatment recommendations for the project area. This protocol was designed to be used in conjunction with *FishXing* software (Love 1999).

Location of Stream Crossings

The first task is to locate and define the number of existing stream crossings on fish-bearing stream reaches within the watershed or area of interest. Preliminary watershed assessment for potential crossing locations requires an examination of the road system from aerial photos or topographic maps, and identification of stream crossings on known historic and present fish-bearing stream reaches.

Seek input from people with intimate knowledge of the road systems and watersheds of concern including road supervisors, maintenance and construction crews, fisheries biologists, restoration groups, watershed groups, public land managers, and/or private landowners. Before entering private lands, access permission must be obtained from all private landowners.

Anadromous fish-bearing stream reaches may be initially identified from topographic maps by considering the limit of anadromy up to a sustained channel slope of eight to ten percent. Resident trout reaches are defined as channels with gradients up to 20 percent (Robison et al. 2000, SSHEAR 1998). DFG biologists or land managers may have knowledge of anadromy limits due to local features such as falls, debris jams, small dams, or other stream crossings that may act as migration barriers.

Site Visit

A site visit at the stream crossing is conducted to collect physical measurements affecting fish passage. This information is recorded on the *Fish Passage Inventory Data Sheet*. Additional information collected for stream crossings include:

- A description of the type and condition of each crossing
- Qualitative comments describing stream habitat immediately above and below each crossing
- GPS waypoints

- Site sketch and photographs.

When in the field, to the extent feasible, search for stream crossings that failed to appear on the maps. Note any locations where these additional crossings exist, as well as stream reaches not examined. If stream crossings on maps are classified as culverts, bridges, or fords, it is recommended to field verify each of these structures. It is not uncommon for large culverts to be labeled as bridges. If maps are outdated, record locations on the topographic map and assign a GPS waypoint where a crossing has been installed or replaced with another type of stream crossing.

FISH PASSAGE INVENTORY DATA SHEET

The *Fish Passage Inventory Data Sheet* (pages IX-29 to IX-30) is completed for all stream crossings visited. Culverted stream crossings will require more data taken. Most field time is spent traveling to and from stream crossing locations. Therefore, at each location fill out the appropriate information which includes: determining active channel width, calculating a fill estimate, surveying a longitudinal profile and a tailwater cross-section, making a site sketch and taking photographs.

Active Channel Widths

The active channel stage or ordinary high water level is the elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence on the landscape. Evidence of the active channel stage includes:

- The bank elevation at which cleanly scoured substrate of the stream ends and terrestrial vegetation begins
- A break in rooted vegetation or moss growth on rocks along stream margins
- Natural line impressed on the bank
- Shelving or terracing
- Changes in soil character
- Presence of deposited organic debris and litter
- Natural vegetation changes from predominantly aquatic to predominantly terrestrial.

An active channel discharge is less than a bankfull channel discharge. Figure IX-3 provides a basic sketch of active versus bankfull channel locations. Figure IX-4 illustrates an example of both active and bankfull channel margins; however in many situations these indicators are less apparent. Many culvert design guidelines utilize active channel widths in determining the appropriate widths of new crossing installations (DFG 2002; Robison et al. 2000; NOAA 2001; Bates et al. 1999).

Take at least five channel width measurements to determine the active channel width. The best measurement sites are above the crossing in a channel reach visually beyond any influence the crossing may have on channel width. If it is not possible to measure active channel width above the crossing, downstream measurements may be taken beyond the influence of the crossing. An average of these measurements should account for natural variations in channel width.

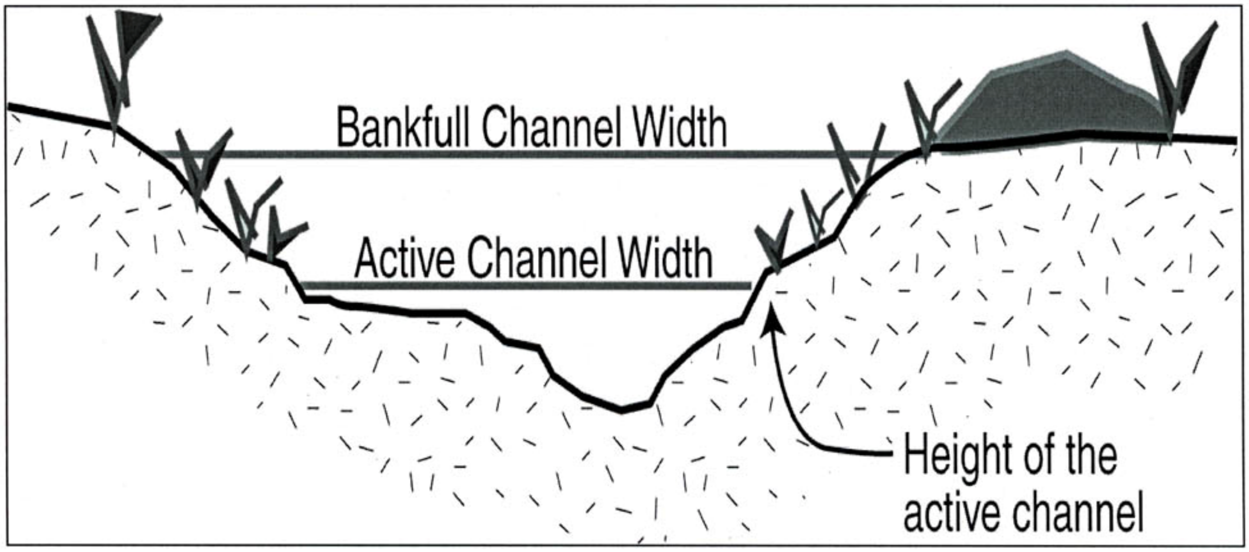


Figure IX-3. Active channel width versus bankfull channel width.

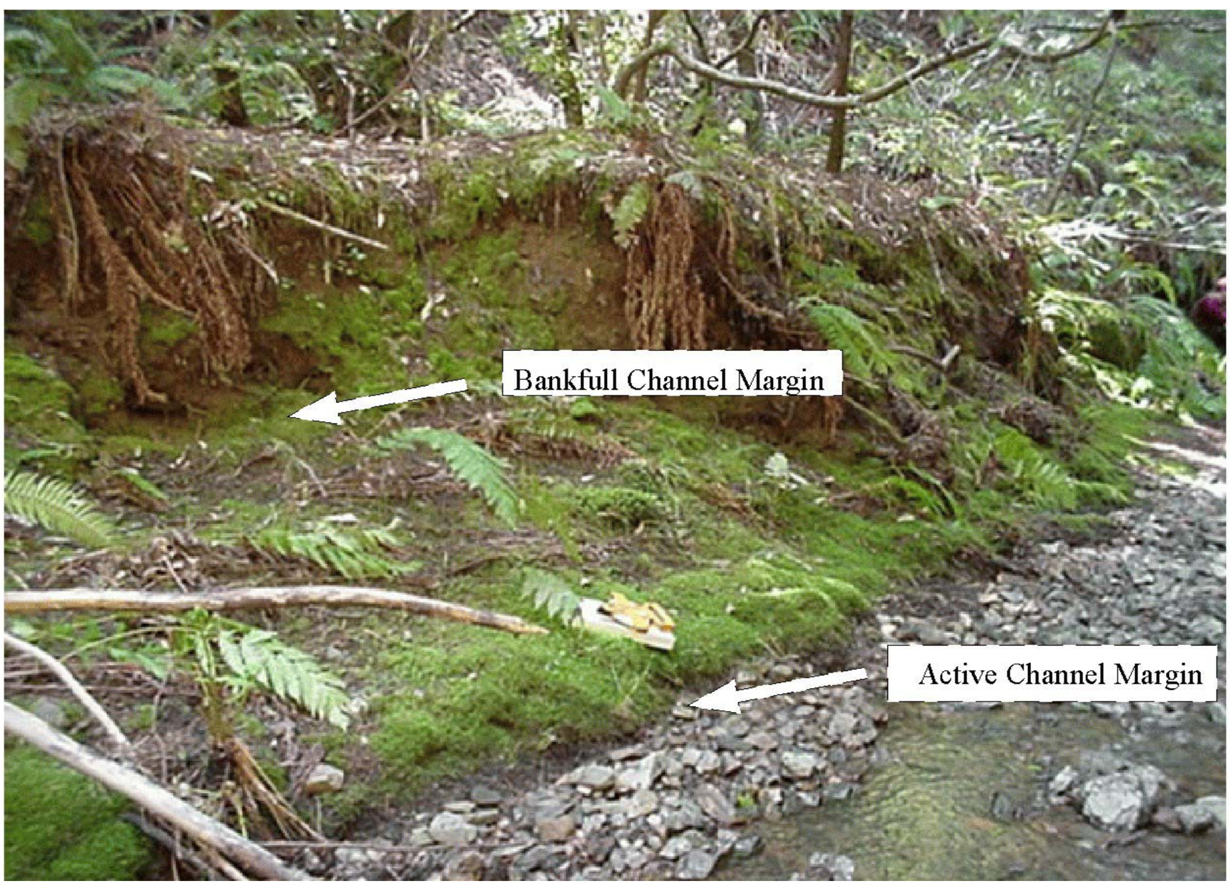


Figure IX-4. Example of active and bankfull channel margin.

Fill Estimate

At each culvert, the volume of road fill is estimated from field measurements. These fill volume estimates are then incorporated into the ranking criteria for treatment and can assist in:

- Calculating culvert flood capacity at the headwater depth (HW) /culvert height (diameter, D) equal to one, HW/D =1 (Figure IX-5)
- Determining potential volume of sediment delivered to the stream if the stream crossing fails
- Developing rough cost estimates for barrier removal by estimating equipment time required for fill removal and disposal site space needed.

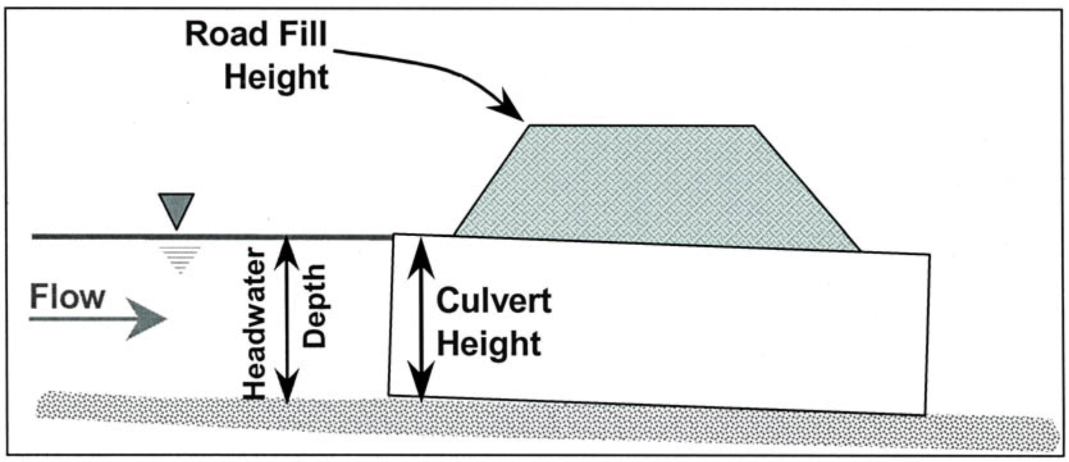


Figure IX-5. Headwater depth and culvert height, HW/D=1.

Road fill volume is estimated using procedures outlined in Flannigan et al. (1998). The following measurements are taken to calculate the fill volume (Figure IX-6):

- Upstream and downstream fill slope lengths (L_u and L_d)
- Percent slope of upstream and downstream fill slopes (S_u and S_d)
- Width of road prism (W_r)
- Top fill length (W_f)
- Base fill width (W_c).

The fill measurements included in the *Fish Passage Inventory Data Sheet* generate rough fill volumes for comparison between sites while minimizing the amount of time required to collect the information. These volume estimates can contain significant error and should not be used for designing replacement structures.

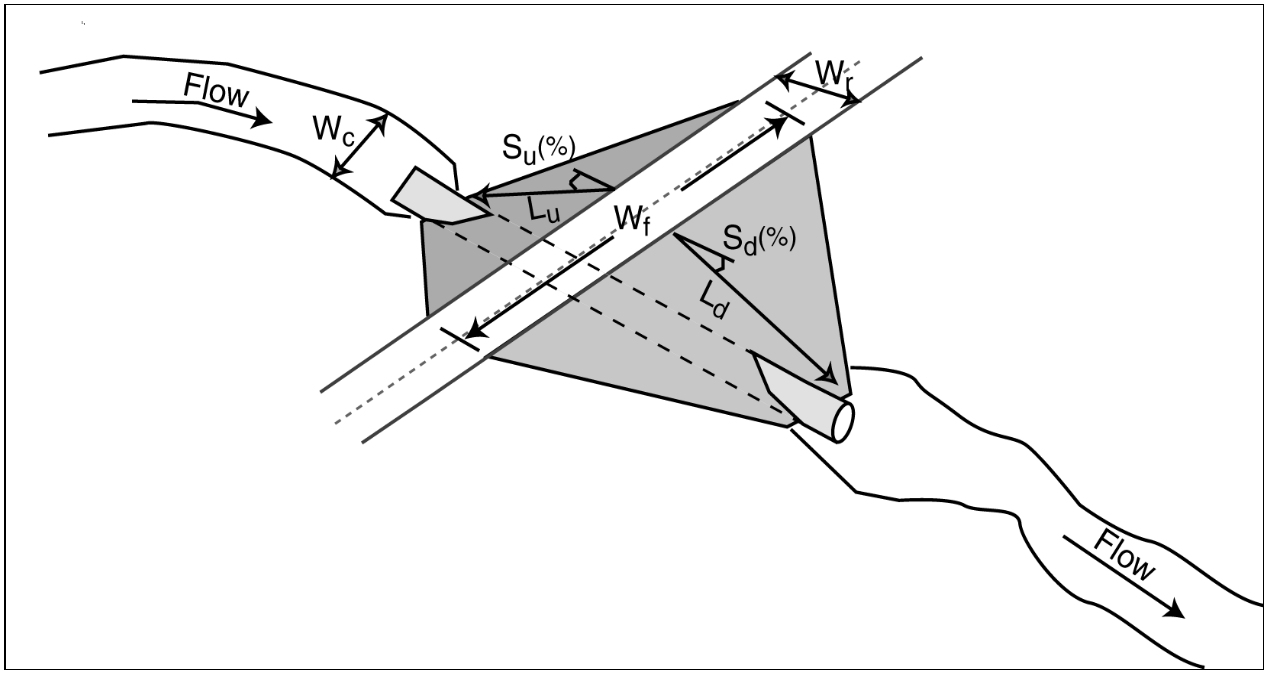


Figure IX-6. Measurements taken to calculate fill volume.

Equations (1) through (4) below are used to calculate the fill volume. To use the fill volume equations, convert slope from percent to degrees. This is accomplished by using the arc tangent function.

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:

$$V = V_u + V_d + V_r$$

Longitudinal Survey

A longitudinal survey is performed at each stream crossing to provide accurate elevation data for fish passage analysis. *Stream Channel Reference Sites: an Illustrated Guide to Field Technique* (Harrelson et al. 1994) provides basic surveying techniques. Because of the sensitivity of slope measurements when evaluating passage, slopes must be measured with surveying equipment that can accurately measure changes in elevation to 0.01 foot. It is not adequate to measure slopes with a handheld sight level or clinometer. The following steps should be followed when doing longitudinal surveys:

- Secure the end of a 300-foot tape on the upstream side of the crossing, usually at the tailwater control of the first resting pool above the crossing (Figure IX-7). This would be considered the first available resting habitat for fish after negotiating the crossing. The first resting pool location can be near the crossing inlet or a considerable distance upstream.
- Set the tape down the approximate center of the stream channel to reflect any major changes in channel direction. Continue the tape through the culvert or down the length of the crossing if possible. An elevation is recorded at the tailwater control of the pool immediately below the crossing. If several downstream weirs create “stair-stepped” pools, take the elevation of the tailwater control of the most downstream pool. Extend the longitudinal tape downstream from the tailwater control until there is a noticeable change in slope or channel width. This channel reach often extends downstream to termination of the riffle below the outlet pool. Record the elevation at the downstream end of the channel reach selected. Record the station locations at the tailwater control and the end of the channel reach (to determine distance). The change in elevations divided by the distance, multiplied by 100, calculates the percent channel slope below the tailwater control.
- Pull the tape taut along the length of the crossing. For culverts, clamp the tape securely to the culvert inlet and outlet for accurate length measurements. In situations where it is not feasible to lay the tape through the culvert, such as at small diameter or severely rusted culvert, attempt to measure the culvert length as accurately as possible from the road surface. Make note of where these measurements were taken and attempt to verify length from existing road databases or as-built plans.
- Set the survey-level in a location to minimize or eliminate the number of times it must be moved to complete the survey. If possible, a location on the road surface is optimal, allowing a complete survey from a single location. However, at sites with high road fills or with breaks-in-slope within the culvert, the best location for the survey-level and tripod is within the stream channel or culvert.
- Establish and survey a temporary benchmark (TBM).
- Place the leveling rod in the thalweg at various stations along the center tape to capture visible breaks in slope along the stream channel and through the stream crossing.

At all stream crossings, a minimum of six elevations and corresponding stations along the center tape are required (Figure IX-7). These are:

- Culvert inlet, or upstream end of the crossing
- Culvert outlet, or downstream end of the crossing
- Maximum depth within five feet downstream of the culvert
- Maximum depth of outlet pool
- Outlet pool's tailwater control
- Active channel margin between the culvert outlet and the outlet pool's tailwater control. This elevation should correspond to the height of flow during an active channel discharge event.

On a site-specific basis, the following additional survey points provide useful information for evaluating fish passage:

- Steep changes in the stream channel profile immediately upstream of the culvert inlet or at the upstream end of the crossing. Measure the elevation at the tailwater control of the first upstream resting pool to estimate the channel slope upstream of the crossing (Figure IX-7). In some cases, a fish may negotiate a culvert only to encounter a velocity barrier upstream of the inlet entrance.
- Slope of inlet and outlet aprons. To increase flood capacity and prevent scour, some crossings have concrete aprons lining the stream channel at the upstream and/or downstream end. These aprons are often steep, creating velocity and lack of depth barriers. Measure elevations at upstream and downstream ends of each apron and the length of the apron to calculate slope.
- Apparent breaks in slope within the crossing: Older culverts can sag when road fills slump, creating steeper sections within a culvert. If only inlet and outlet elevations are measured in a sagging culvert, steeper sections that may act as barriers will be missed.

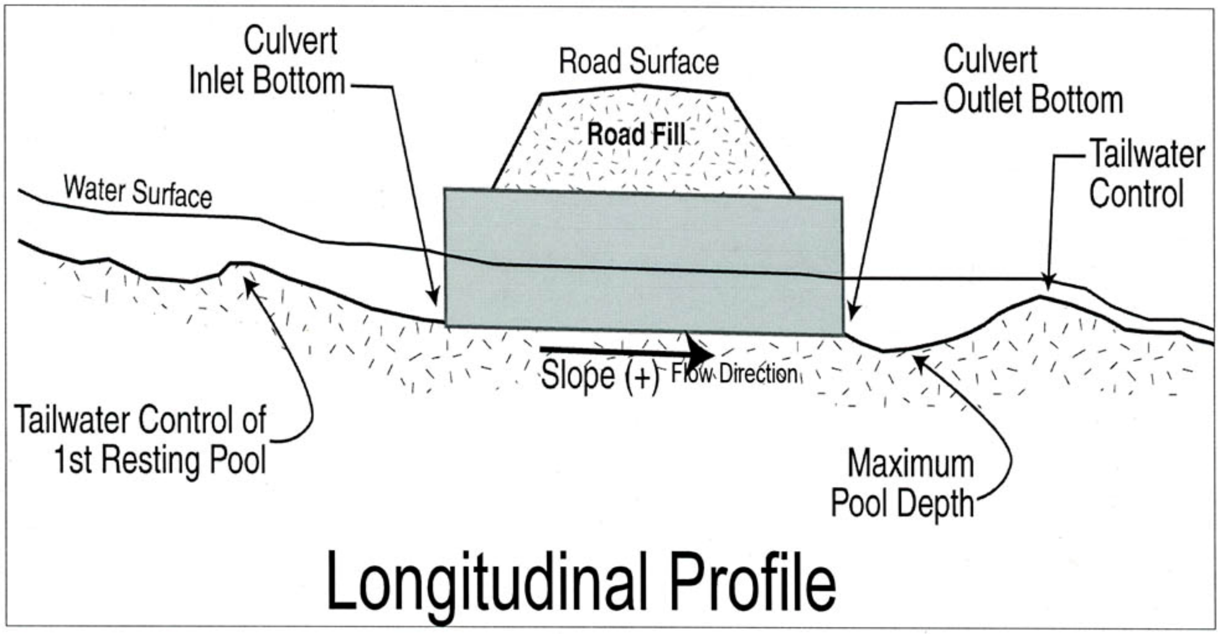


Figure IX-7. Diagram of required survey points for a longitudinal profile through a culvert.

Measure all elevations to the nearest 0.01' and enter each surveyed point with a corresponding station location (distance along tape) to the nearest 0.1 foot. Conventional survey standards start with station 0.0' at the downstream end of the tape; however, it is usually more feasible to work through a culvert from an upstream-to-downstream direction.

Tailwater Cross-Section

Although not required, in some cases a cross-section survey across the bankfull channel width at the downstream tailwater control increases the accuracy of passage analysis. Space is provided on the *Fish Passage Inventory Data Sheet* to conduct this survey. For more detail, please refer to the extensive “Help files” provided with *FishXing* (Love 1999).

With no apparent outlet pool, locate the cross-section three feet from the culvert outlet, perpendicular to the channel. For slightly perched culverts, locate the cross-section at the tailwater control, perpendicular to the stream channel. Cross-sections typically start (station 0.0N) on the left bank (looking downstream). Securely place the 100-foot tape across the channel. If feasible, conduct cross-section survey with survey level still set in place for the longitudinal survey, otherwise a turning point is required.

Locate the first survey point at approximately the bankfull channel margin. Proceed to survey from left to right, taking elevations at obvious breaks in slope. Record the station number of each surveyed point (distance indicated on cross tape). Record points of interest such as location of bankfull channel margin, active channel margin, tailwater control, mid-channel bar formation, and/or wetted edges.

Site Sketch

A site sketch of the stream crossing should be included on the back of the *Fish Passage Inventory Data Sheet*. Figure IX-8 illustrates a typical site sketch. Features to consider in site sketches include:

- A "North Arrow". Use a compass to determine direction of north. Orient the sketch so that north is towards the top of data sheet
- Direction of stream flow, road name, and stream name
- TBM location and type
- Location(s) where survey level and tripod were placed to complete the longitudinal survey
- Locations of photo points
- Orientation of stream channel to culvert inlet
- Unique features such as wingwalls, riprap for bank armoring or jump pool formation, baffles, debris jams, location of any bends in the culvert, etc.

Photography

Take photographs of all stream crossing locations, including the inlet and outlet of each culvert. Photograph any unique site features, such as steep drops at inlets, perched outlets, breaks-in-slope, poor or damaged crossings, outlet pool conditions, debris blocked inlets, and/or habitat conditions above and below the site.

Photograph the outlet pool and tailwater control while facing in a downstream direction to capture stream bank configuration and channel slope. These photos provide a clear picture of the crossing's tailwater control to aid in passage evaluation.

Digital cameras are highly recommended, especially models with a variable aperture setting and flash. Digital technology allows preview of pictures while at the site. Delete and re-take unsuccessful photos.

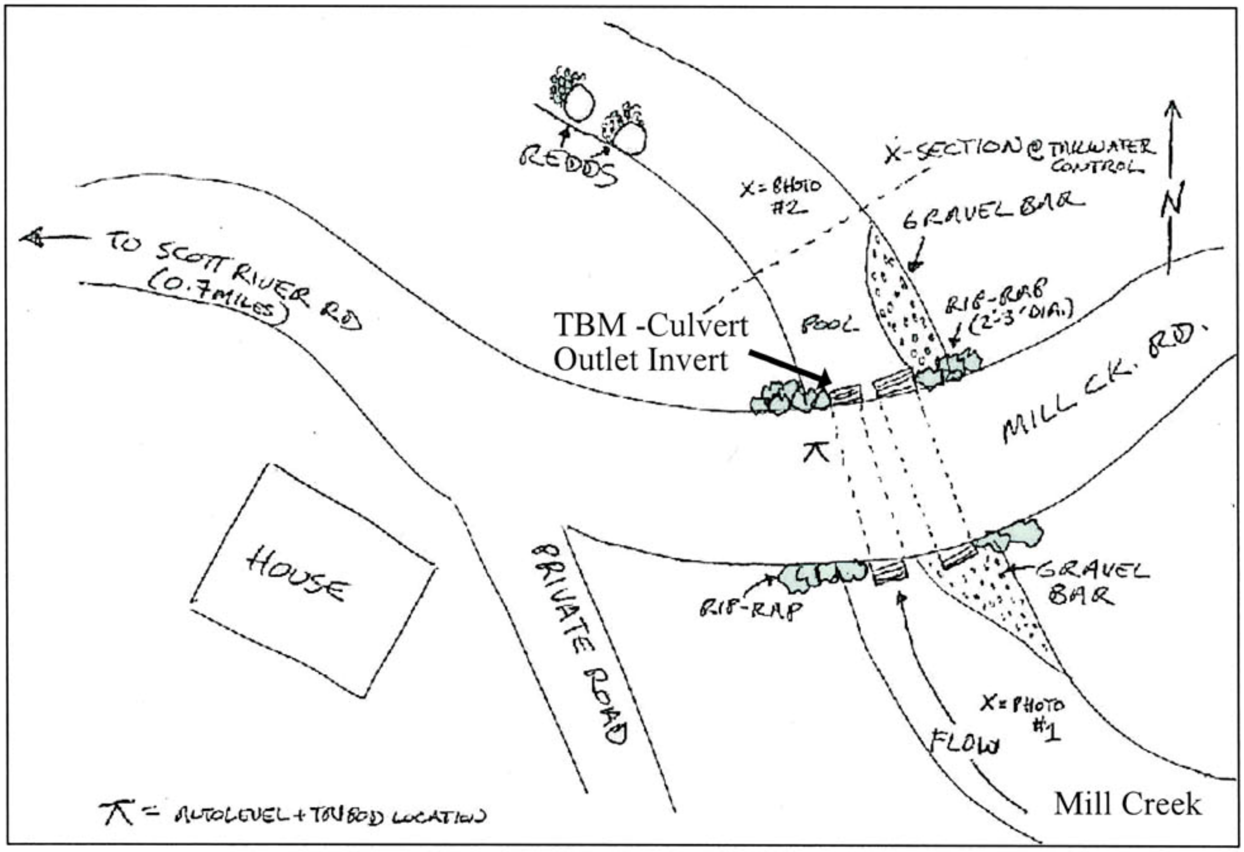


Figure IX-8. Site sketch example.

INSTRUCTIONS FOR COMPLETING THE FISH PASSAGE INVENTORY DATA SHEET

***Stream Crossing Type*:** Check bridge, ford, culvert, or other. If other, describe the type of stream crossing.

***Date*:** Enter the day's date (mm/dd/yy).

***Surveyors*:** Enter the names of people operating the surveying-level (scope) and leveling rod.

***Culvert* #____ of _____:** Required if a stream crossing is comprised of multiple pipes or a box culvert with two or more bays. Number from the left bank to the right bank (determined when facing downstream).

***Road*:** Enter road name and/or number.

***Mile Post*:** Enter the mile post where crossing is located. If the mileage is not posted at the crossing, use the vehicle's odometer to estimate the mile post to the nearest 0.1 mile by driving to the nearest posted mile-marker or the beginning of the road. Also record the direction driven.

***Crossroad*:** Enter the name, direction and distance (0.1 mile) to the nearest named or numbered crossroad.

***Stream Name*:** Enter the stream name as it appears on the 7.5-Minute United States Geological Survey (USGS) quadrangle. If the stream is unnamed, enter *unnamed.* If a road crosses a stream in multiple locations, assign a number to the stream name with the stream #1 crossing located farthest downstream.

***Tributary to*:** Enter the name of the receiving stream, river, lake or ocean.

***Basin*:** Enter the main drainage system.

Quad: Enter the name of the USGS 7.5-Minute Series Quadrangle where the stream crossing is located.

T-R-S: From the USGS quadrangle, enter the Township, Range and Section the stream crossing is located in.

Lat/Long: Enter the latitude and longitude coordinates of stream crossing location in decimal degrees to the five figures right of the decimal place. DFG datum standard is NAD27. If the datum is other than NAD27, such as WSG84, record the horizontal datum used in the comments section. Determine location with either a global positioning system unit at the site, or later with a digitized, geo-referenced USGS quadrangle.

***Flow Conditions During Survey*:** Check the box that best describes the flow conditions.

Fisheries Information

Fish Presence Observed During Survey: When initially approaching the crossing, carefully look for salmonids in the stream above and below the crossing. Check the appropriate choices.

Location: Upstream and/or downstream, or none;

Age classes: Adults, juveniles;

Species: Steelhead trout, coho salmon, chinook salmon, coastal cutthroat, resident trout species, or unknown;

Juvenile Size Classes: <3", 3" - 6", >6"

Number of Fish Observed: Estimate the number of fish observed.

Stream Crossing Information

Inlet Type: Check the box that best describes inlet configuration (Figure IX-9).

Projecting: Culvert barrel projects upstream out of the road fill.

Headwall: Culvert barrel is flush with road prism, often set within a vertical concrete or wooden headwall.

Wingwall: Concrete walls that extend out from the culvert inlet in an upstream direction. In a downstream direction, wingwalls taper towards the inlet and usually increase a crossings flow capacity

Mitered: Culvert inlet is cut on an angle similar to angle of the road prism, increasing the size of the opening and the flow capacity.

Flared: Flared inlet secured to culvert in increase capacity.

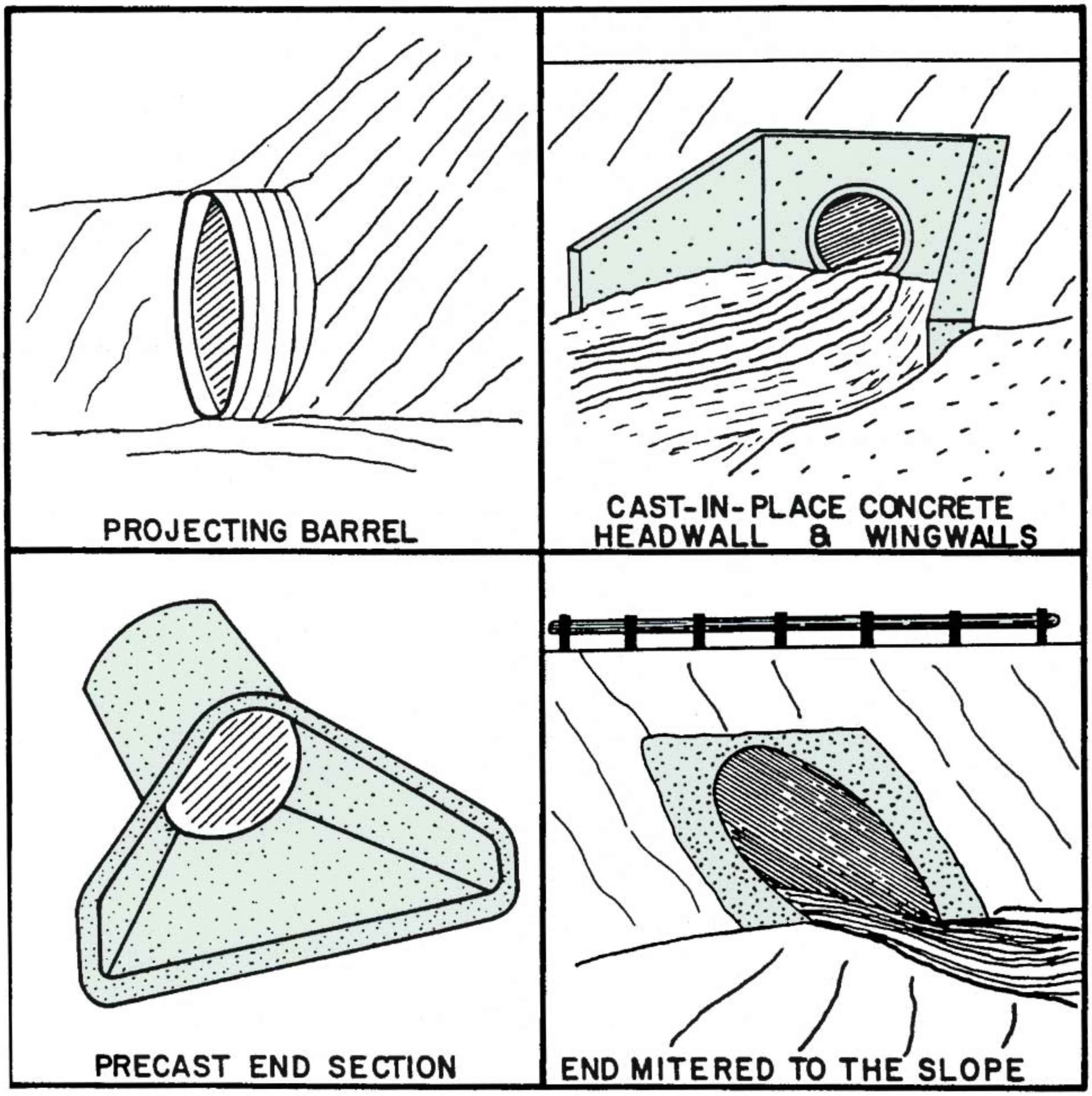


Figure IX-9. Four standard inlet types (Norman et al. 1985).

Alignment: While standing at the inlet and looking upstream, estimate the stream channel approach angle with respect to the inlet. Check: <30°, 30° - 45°, >45°. Include this feature in the site sketch. Channel approach angles greater than 30° may increase the likelihood of a stream crossing plugging with debris during storm flows, which impedes fish passage and can result in catastrophic failure of the stream crossing and road prism. In some instances, poor channel alignment creates adverse hydraulic conditions that inhibit or prevent fish passage.

Inlet Apron: Check appropriate choice. If an apron exists, provide a brief description. Measure and record length, width, and slope, and include in the site sketch. Aprons are usually constructed of concrete and are installed to increase flow capacity and prevent or reduce erosion at the toe of the stream crossing fill.

Outlet Configuration: Check box that best describes culvert outlet.

At Stream Grade: A swim through culvert that has no drop at the outlet.

Free-fall Into Pool: Culvert outlet is perched directly over the outlet pool. Requires migrating fish to leap into culvert from outlet pool.

Cascade Over Riprap: Culvert outlet is perched above the downstream channel and exiting water flows (or sheets) over riprap, concrete, and/or bedrock.

Outlet Apron: Follow same instructions as provided for inlet aprons.

Tailwater Control: Defined as the channel feature which influences the water surface immediately downstream of the crossing. Check the box that best describes the tailwater control.

Pool Tailout: Commonly referred to as the riffle crest. Deposition of substrate downstream of the outlet pool controls the pool elevation.

Full-Spanning Log or Debris Jam: Naturally deposited pieces of wood or trees that influence the outlet pool elevation.

Log, Boulder, or Concrete Weirs: These structures are often placed downstream of perched culverts to raise tailwater elevation and reduce the leap height required by migrating fish to enter a culvert.

Other: Describe the pooltail conditions if none of the above choices accurately classifies the feature influencing the outlet pool elevation. Include details in site sketch and photograph the feature.

No Control Point (Channel Cross-Section Recommended): Describes situations where there is no outlet pool, allowing water to flow unimpeded downstream. In this situation the channel roughness, slope, and cross-sectional shape govern the water elevation downstream of the outlet. When surveying a cross-section at these sites, it should be located within five feet of the outlet.

Upstream Channel Widths: Measure and record five active channel widths. The active channel is identified by locating the height of annual scour along banks developed by annual fluctuations of stream flow and indicated by the following physical characteristics:

- Natural line impressed on the streambanks
- Shelving
- Changes in soil character
- Absence of terrestrial vegetation
- Presence of deposited organic debris and litter (Figure IX-4).

Space the five measurements out over approximately a 100N stream reach, well above any influence the stream crossing may have on channel width or tributaries. Avoid obvious discontinuities, such as a large root wad or boulder. Record the *Average Width*. Undersized culverts can influence the active channel width for several hundred feet upstream as a result of ponding storm runoff, causing substrate deposition.

Culvert Information

Culvert Type: Check the appropriate type of culvert. Figure IX-10 depicts the end-sections of four common culvert types. *Other* may include either bridge or ford.

Diameter (ft): For circular culverts measure to the nearest 0.1 foot of the culvert's inside diameter. If corrugated, measure from the outside edge of the corrugations. In some cases circular pipes are installed as slightly oval (elliptical) to compensate for settling, if so, measure rise and span as in a pipe arch culvert.

Height or Rise (ft): While inside the culvert, measure the culvert's height or rise, to the nearest 0.1 foot, measured vertically from inside the corrugations. If the culvert bottom is completely covered with bedload (embedded), estimate culvert height based on shape (e.g. assume height = width for circular culverts). For open-bottom arches and box culverts that appear bottomless, measure the rise from the streambed to top of culvert.

Width or Span (ft): Measure and enter the culvert's maximum width or span to the nearest 0.1 foot.

***Length (ft)*:** Measure and record the culvert length from inlet to outlet to the nearest 0.1 foot.

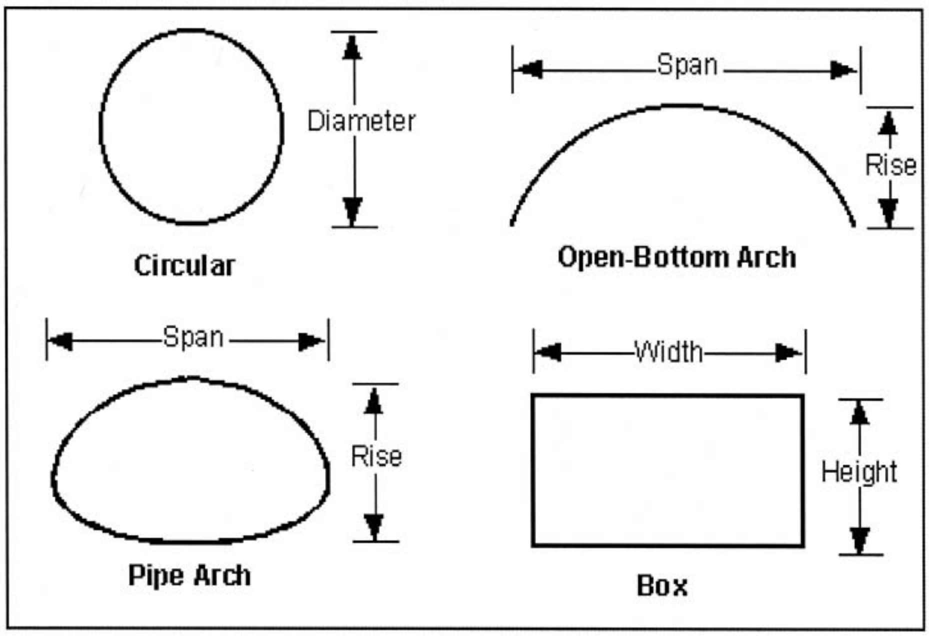


Figure IX-10. Culvert type and dimensions.

Material: Check the box that most accurately describes the culvert's construction material. If none of the choices accurately describes the culvert material, provide a brief description of construction material and characterize the roughness of the material (a photograph is also recommended). Check multiple boxes if the culvert is a composite of two or more materials. Include a length measurement for each section of varying material.

*Structural Steel Plate (*SSP*):* Or "multi-plate" pipes constructed of multiple plates of corrugated galvanized steel, bolted together.

Corrugated Steel Pipe: (CSP) Pipes constructed of a single sheet of corrugated galvanized steel. Also referred to as corrugated metal pipes (CMP).

Aluminum: Corrugated aluminum, these pipes do not develop rustlines.

Plastic: Constructed of various types of high-impact plastics, usually with shallow corrugations.

Concrete: Most box culverts on county and state roads are constructed with concrete. However, some circular and arch pipes are made of concrete, generally with no corrugations.

Log/Wood: Includes old log stringer bridges and Humboldt crossings, but occasionally some box and old circular pipes too.

Other: Provide a brief description if none of the materials accurately describes the culvert.

Corrugations: Measure (in inches) and select the one of the standard corrugation dimensions (width x depth): 2bO x ½O; 3O x 1O; 5O x 1O; 6O x 2O or enter measurements if dimensions are not standard (Figure IX-11).

Spiral: Check the appropriate choice if culvert has spiral (helical) corrugations because these reduce roughness.

Other: Describe corrugations if other than spiral.

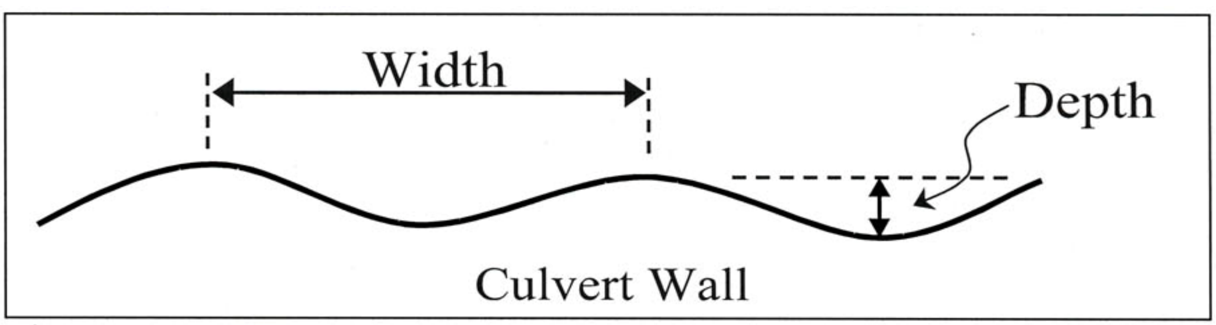


Figure IX-11. Measuring corrugations.

Pipe Condition*:* Check the box that most accurately describes the culvert's condition. Also provide a brief description, if necessary. Photos of damaged crossings are recommended.

Good: No apparent damage, possibly slight rusting occurring.

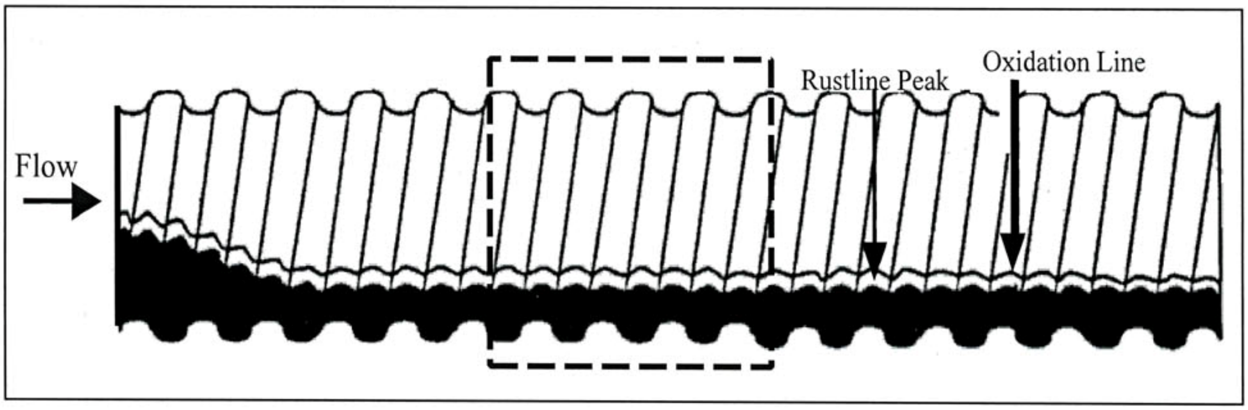
Fair: Noticeable wear or rusting has occurred, but not rusted through the bottom yet.

Poor: Rusted or worn through, substantial leakage through bottom.

Extremely Poor: Culvert floor is rusted through, sections are missing, crushed, slumping, or road fill is being undermined. High potential for imminent failure.

Describe Condition: Briefly describe any other type of apparent damage to culvert and/or road prism.

Rustline Height: If present, measure height (nearest 0.1N) of rustline peak inside culvert away from noticeable differences in rustline height affected by the inlet, outlet, baffles, or weirs (Figure IX-12). If no rustline is apparent enter *not present (NP)* (new CSP or SSP) or *not applicable (NA)* (concrete, aluminum, plastic).



Oxidation line is whitish or silver line, not to be confused with the rustline.
(Adapted from Flannigan).

Figure IX-12. Rustline measurements.

Embedded: Check yes if the culvert has substrate retained within at least a third of its length. Measure the depth of the substrate at the inlet and the outlet. If substrate is retained throughout the culvert, the start and end stations will be at the inlet and outlet. If substrate cover is partial, record the depth as 0.0N at the appropriate location. For example, if the substrate coverage just begins within the culvert and continues through to the outlet, record the depth at the outlet and enter 0.0N for the inlet depth. Record station location of start and end of deposition (Figure IX-13).

Describe the substrate: As boulder, cobble, gravel, sand, silt/clay or bedrock (see Part III for substrate classifications).

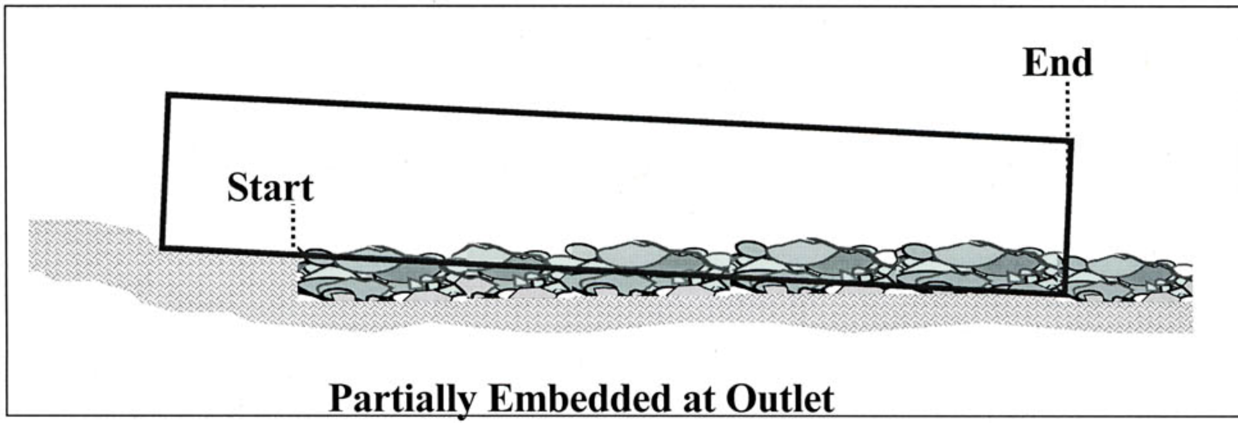


Figure IX-13. Measurements taken at embedded culverts.

Barrel Retrofit: If culvert contains baffles or weirs inside the culvert, record the type, size, number, and placement of the structures (see Part VII for baffle types).

Outlet Beam: If the stream crossing contains a beam within the outlet.

Notched: Note if structure is notched.

Breaks-in-Slope: Note the number and survey all noticeable breaks-in-slope between the culvert inlet and outlet. Record in the additional survey elevations section. Also note the station at which the break is located. In smaller culverts a pocket leveling rod is required. Surveying breaks-in-slope allows evaluation of the crossing in distinct sections to account for water velocities and depths influenced by the differing slopes.

Fill Volume*:* Seven measurements are required to generate a rough fill volume estimate (Figure IX-14).

1. *Length of Upstream Fill (L_u):* Measure and record to the nearest 0.1' the length of the road fill. To measure, one person stands at edge of road with tape held at waist level and the second crew member stands in channel at the toe of the road fill with tape at waist level.
2. *Percent Slope of Upstream Fill (S_u):* The crew member on the road surface shoots from their eye-level to the eye-level of the crew member standing in channel at the toe of the fill.
3. *Road Width (W_r):* Measure and record to the nearest 0.1N the width of the road prism. Measure across the road surface at each edge where the break-in-slope down the fill prism occurs, this may include the paved road and/or shoulders and turn-outs on either side of the road.
4. *Length of Downstream Fill (L_d):* Same as measurement of L_u, but on downstream side of stream crossing fill slope.
5. *Percent Slope of Downstream Fill (S_d)* Same as measurement of S_u, but on downstream side of stream crossing fill slope.
6. *Top Fill Length (L_f):* Measure and record to the nearest 0.1N the length of the road fill as it extends from left bank to right bank of the natural valley wall confinement of the stream channel.

7. *Base Fill Width (W_c):* Use the average active channel width calculated on the front of the data sheet.

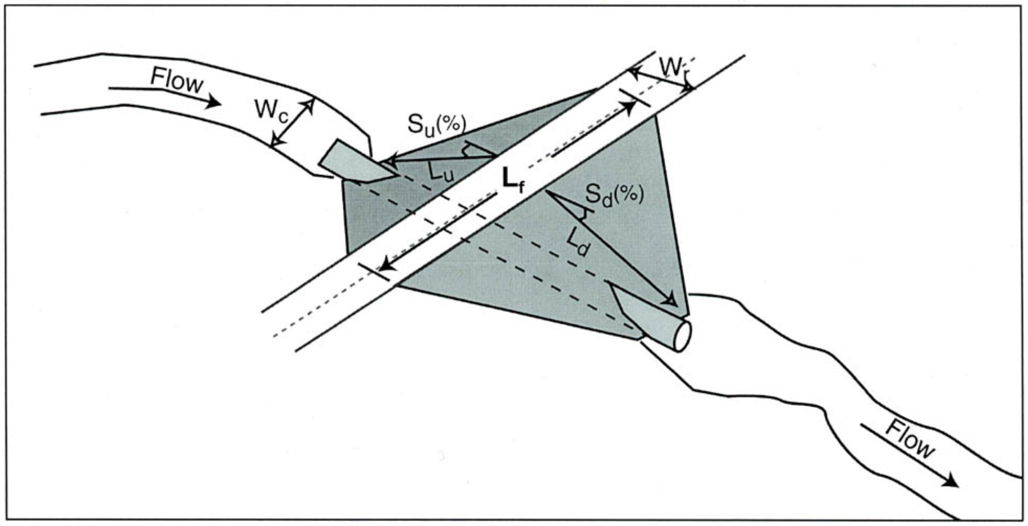


Figure IX-14. Measurements required to generate a rough fill volume estimate.

Longitudinal Surveyed Elevations /Additional Surveyed Elevations: Record corresponding distance along tape (Station) with each survey point to the nearest 0.1 foot. Described below are the required survey points (Figure IX-15). If the channel is wetted at time of survey, measure water depths at all surveyed points and record in the Station Description column. The elevations of the backsight (BS), height of instrument (HI) and foresight (FS) in the longitudinal survey to the nearest 0.01 foot.

***Temporary Benchmark* (TBM):** Record assigned elevation.

Tailwater Control of First Resting Habitat Upstream of Inlet: Elevation at the start of the tape.

Inlet Apron/Riprap: If these features exist, survey the top of inlet apron and survey the toe of outlet aprons (even if submerged). Together with the elevations of the culvert's inlet and outlet, these points may be used to calculate the slopes of the inlet and outlet aprons.

Inlet Depth: Survey this point at the center of the culvert inlet. In embedded culverts, survey two elevations; at the center and at the channel thalweg. Use the "Additional Surveyed Elevations" section of the data sheet to enter the inlet thalweg data.

Outlet Depth: Survey this point at the center of the culvert outlet. In embedded culverts, survey two elevations; at the center and at the channel.

Outlet Apron/Riprap: If these features exist. See above Inlet Apron/Riprap instructions.

Maximum Depth Within Five Feet of Outlet: Survey the maximum pool depth occurring within five feet of the culvert outlet. During migration flows, most adult salmonids will attempt their leaps within five feet of the outlet.

Maximum Pool Depth: Survey the deepest point of the outlet pool. Record depth at this point in addition to the maximum depth within five feet of outlet. If culvert is perched, this data determines if pool depth is adequate.

Tailwater (TW) Control: Survey the thalweg at the tailwater control (refer back to tailwater control for description). If no discernable control point exists, survey the channel thalweg within five feet of the culvert outlet. If concrete, boulder, or log weirs are in place, survey the lowest point along the weir. Photograph outlet pool and tailwater location to assist the data analyst running *FishXing*.

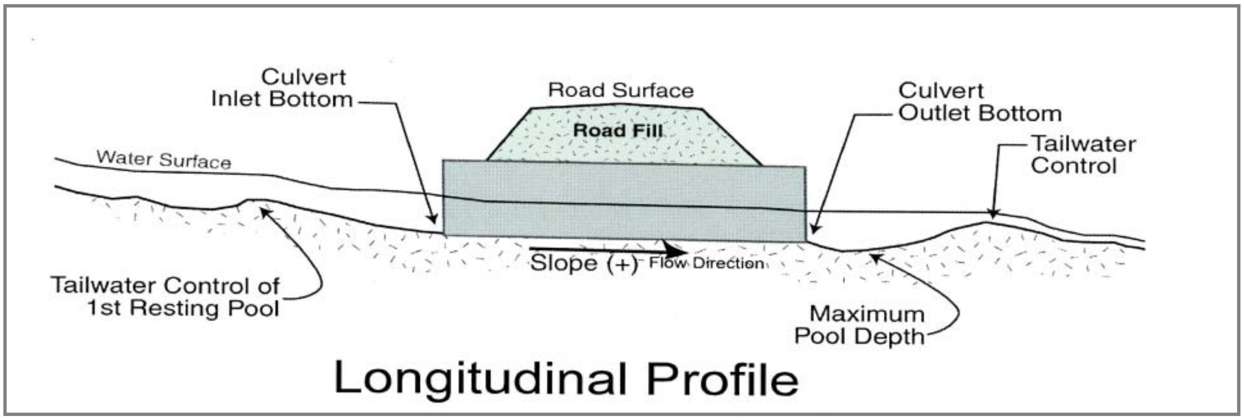


Figure IX-15. Surveyed elevations.

Active Channel Stage: Surveyed anywhere in the outlet pool between the culvert outlet and the tailwater control location. Identify the active channel stage markings in at least two locations and compare elevations. A third elevation may be warranted if the first two are greater than 0.3N apart. This elevation provides the minimum data required to roughly estimate the height of the outlet pool during upper migration flows (Figures IX-3 and IX-4).

***Downstream Channel Percent Slope*:** Using the field inventory data, calculate the percent slope of the channel downstream of the stream crossing.

Tailwater Cross-section: (Optional) This cross-section is used to estimate tailwater elevation at varying flows by constructing a flow-versus-tailwater elevation rating curve. This method is most appropriate for stream crossings with little or no outlet pool resulting in essentially unimpeded flow downstream of the outlet. A tailwater cross-section is also useful at sites with slightly perched outlets (less than 2.0N high).

Substrate at Cross-section: Describe the streambed substrate composition at, and immediately downstream of the cross-section. Substrate composition will determine the Manning's roughness coefficient (Appendix H).

Suspected Passage Assessment: Based on your field observations and the definitions given in Table IX-1, check the boxes that in your judgment best describes the impact the stream crossing has on adult and juvenile salmonid fish passage.

Culvert Slope (%): Using the field inventory data, calculate percent culvert slope:

[(Elevation of Inlet Invert - Elevation of Outlet Invert)/(Culvert length)] X 100 = % Slope

FISH PASSAGE INVENTORY DATA SHEET

Stream Crossing Type: ☐ **bridge** ☐ **ford** ☐**culvert** ☐ **other**__________________ **Date:**____/____/____
Surveyors: Scope:_________________________________**Rod:**____
Culvert #_____**of**______**(left bank to right bank)**

Road:	**Mile Post:**	**Crossroad:**
Stream Name:	**Tributary to:**	**Basin:**
Quad:	**T:** **R:** **S:**	**Lat/Long:**

Flow Conditions During Survey: ☐ continuous ☐ isolated pools ☐ dry

Fisheries Information

Fish Presence Observed During Survey: Location: ☐ upstream ☐ downstream ☐ none
Age Classes: ☐ adults ☐ juveniles Species: ____ ☐ unknown
Juvenile Size Classes: ☐ <3" ☐ 3"-6" ☐ >6" Number of Fish Observed:

Stream Crossing Information

Inlet Type: ☐ projecting ☐ headwall ☐ wingwall ☐ mitered ☐ flared
Alignment (deg): ☐ <30° ☐ 30°-45° ☐ >45° **Inlet Apron:** ☐ yes ☐ no
Describe:____
Outlet Configuration: ☐ at stream grade ☐ free-fall into pool ☐ cascade over rip rap
Outlet Apron: ☐ yes ☐ no **Describe:**____
Tailwater Control: ☐ pool tailout ☐ full-spanning log or debris jam ☐ log weir ☐ boulder weir
☐ concrete weir ☐ other_______________________☐ no control point (complete a channel cross-section)
Upstream Channel Widths (ft): (1) (2) (3) (4) (5) Average Width:

Culvert Information

Culvert Type: ☐ circular ☐ pipe arch ☐ box ☐ open-bottom arch ☐ other__________________
Diameter (ft):_______ **Height or Rise (ft):**________ **Width or Span (ft):**_______ **Length (ft):**________
Material: ☐ SSP ☐ CSP ☐ aluminum ☐ plastic ☐ concrete ☐ log/wood ☐ other_________
Corrugations (width x depth): ☐ 2 2/3" x ½ ☐ 3" x 1" ☐ 5" x 1" ☐ 6" x 2" ☐ spiral
☐ other__________
Pipe Condition: ☐ good ☐ fair ☐ poor ☐ extremely poor
Describe:____
____
Rustline Height (ft):___________ ☐ NP (new CSP or SSP) ☐ NA (concrete, aluminum, plastic)
Embedded: ☐ yes ☐ no
Depth (ft): inlet_____ outlet_____ Station (ft): start:________ end:_______
Describe Substrate:____
____
Barrel Retrofit (weirs/baffles): ☐ yes ☐ no
Type: ☐ steel ramp baffles ☐ Washington ☐ corner ☐ other:________________________________
Describe (size, number, placement, materials):____
____
Outlet Beam: ☐ yes ☐ no **Notched:** ☐ yes ☐ no
Breaks-in-Slope: ☐ yes ☐ no Number:
Fill Volume: L_u (ft):_____ S_u (%):_____ W_r (ft): _____ L_d (ft): _____ S_d (%):_____ L_f (ft):_____
W_c (use average channel width) (ft):______

FISH PASSAGE INVENTORY SURVEYED ELEVATIONS

Longitudinal Surveyed Elevations					Station Description and Water Depth (**Bold** = Required)	Tailwater Cross-section (optional)					
Station (ft)	**BS (+)**	**HI (ft)**	**FS (-)**	**Elevation (ft)**		Station (ft)	BS (+)	HI (ft)	FS (-)	Elevation (ft)	Notes
					TBM:						
					TW Control of 1st resting habitat u/s of inlet						
					Inlet Apron/Riprap						
					Inlet Depth=						
					Outlet Depth=						
					Outlet Apron/Riprap						
					Max. Depth within =						
					Max. Pool Depth						
					TW Control Depth=						
					Active Channel Stage						
					Downstream Channel Slope (%):	**Substrate at X-Section:**					

Additional Surveyed Elevations (including Breaks-in-Slope)						
						Suspected Passage Assessment: Adults: ☐ 100% barrier ☐ partial barrier ☐ no barrier Juveniles: ☐ 100% barrier ☐ partial barrier ☐ no barrier
						Culvert Slope:_______%

Qualitative Habitat Comments:

PASSAGE ANALYSIS

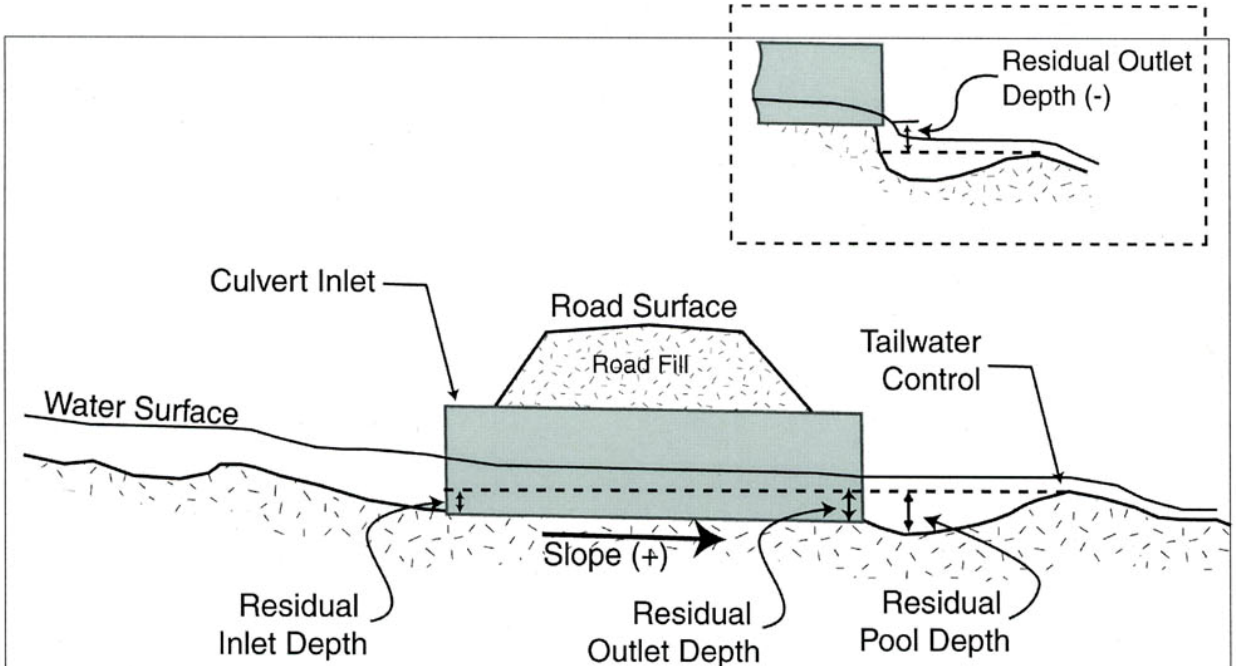
Enter data from the *Fish Passage Inventory Data Sheet* into a database or spreadsheet. From this, various calculations can be completed.

PASSAGE EVALUATION FILTER: GREEN-GRAY-RED

A filtering process can be used to assist in identifying sites which either provide, or fail to provide, fish passage for all fish species and their life stages. From the *Fish Passage Inventory Data Sheet*, calculate average active channel width, culvert slope, residual inlet depth, and residual depth at the outlet (Figure IX-16). The passage evaluation filter (Figure IX-17) is used to reduce the number of crossings which require in-depth passage evaluation using *FishXing*. The filter classifies crossings into one of three categories:

- **GREEN:** Condition assumed adequate for passage of all salmonid life stages or throughout all salmonid life stages.
- **GRAY:** Condition may not be adequate for all salmonid species at all their life stages. *FishXing* is used to determine the extent of barriers for each salmonid life stage.
- **RED:** Condition fails to meet DFG and NOAA passage criteria (Appendix IX-A and Appendix IX-B) at all flows for strongest swimming species presumed present. Analysis of habitat quantity and quality upstream of the barrier is necessary to assess the priority of this crossing for treatment.

Some stream crossings have characteristics which may hinder fish passage, yet they are not recognized in the filtering process, such as breaks in-slope, inlet and outlet aprons, crushed inlets, or damage to the crossing invert. For crossings meeting the GREEN criteria, a review of the inventory data and field notes is necessary to ensure no unique passage problems exist before classifying the stream crossings as "passable".



Residual Pool Depth = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Pool Bottom}})$

Residual Outlet Depth = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Culvert Outlet}})$ (If Residual Outlet Depth is less than zero it is referred to as the Residual Outlet Drop)

Residual Inlet Depth = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Culvert Inlet}})$

Figure IX-16. Measurements used in filtering criteria.

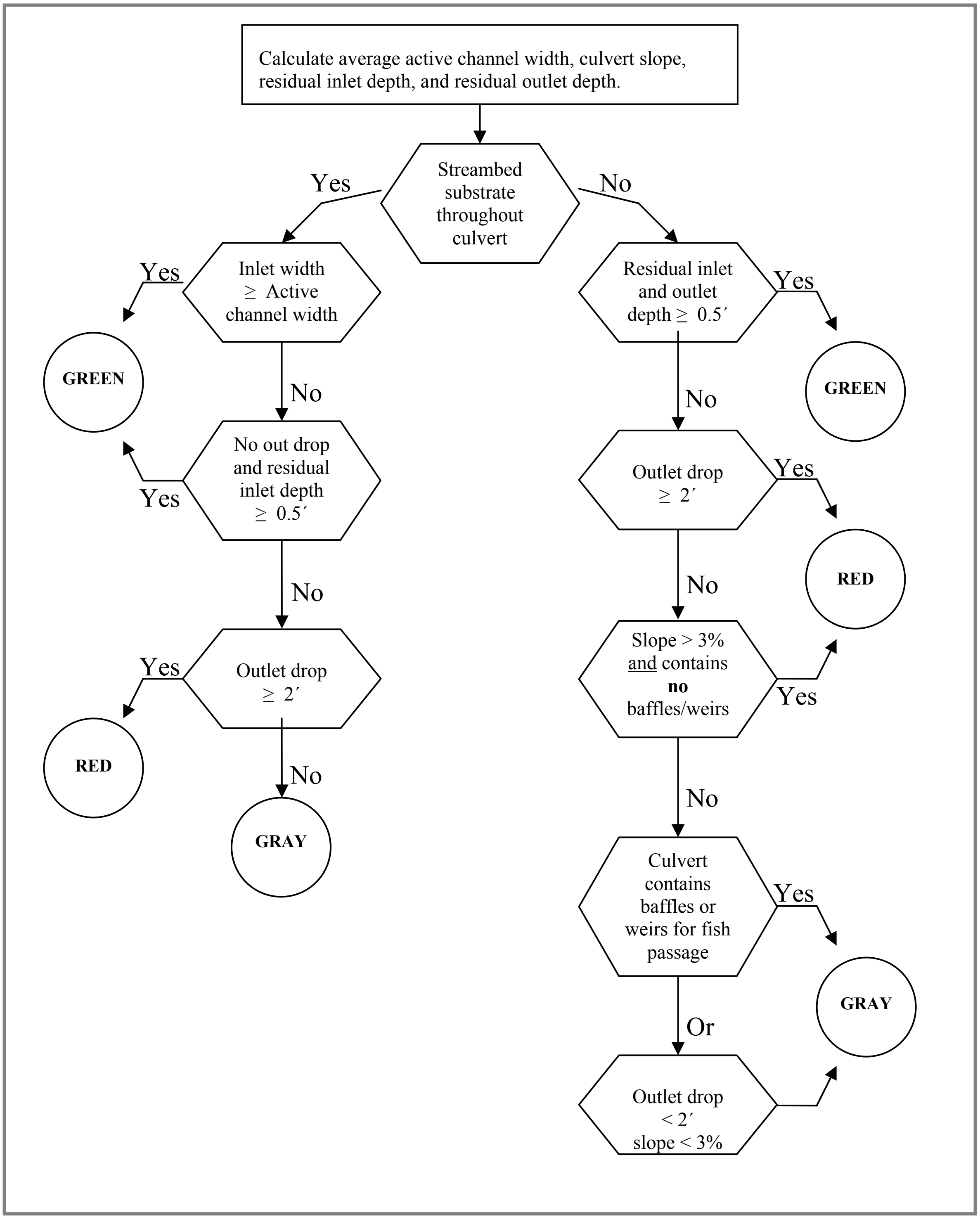


Figure IX-17. GREEN-GRAY-RED first-phase passage evaluation filter.

Hydrology And Flow Requirements

When examining stream crossings for fish passage, three specific flows are considered: the peak flow capacity of the crossing, and the upper and lower fish passage flows. Peak flow capacity defines the ability of a crossing to accommodate a one-hundred year flow event, while fish passage flows define the upper and lower migration flows at the crossing. Fish passage flows will vary by species and lifestage so a complete analysis of a culvert often involves deriving several pairs of these high and low fish flows.

Because flow is not gaged on most small streams, it must be estimated using techniques that often require hydrologic information about the stream crossing's contributing watershed. Information needed includes:

- Drainage area
- Mean annual precipitation
- Average basin elevation.

Most of this information can be obtained from USGS topographic maps, precipitation records, and water resources publications by various agencies.

Flow Capacity

Determination of peak flow capacity at a crossing can assist in prioritizing sites for treatment. Undersized crossings have a higher risk of catastrophic failure, which often results in the immediate delivery of sediment from the road fill to the downstream channel. Undersized crossings can also adversely affect sediment transport and downstream channel stability through frequent ponding of water upstream of the crossing and excessive scour of the downstream channel bed. This often leads to conditions that hinder fish passage and degrade habitat, such as upstream sediment deposition, perched crossing outlets, and downstream bank erosion.

Estimate the flow capacity of the stream crossing. Capacity is generally a function of the shape and cross-sectional area of the inlet. Additionally, the flow capacity increases as water ponds and the headwater depth increases. For existing stream crossings, determine the flow capacity at a headwater depth equal to the height of the culvert (Figure IX-5). This is commonly referred to as a headwater-to-diameter ratio equal to one (HW/D = 1).

Several methods are available for determining flow capacity of culverts, depending on the culvert shape and the level of accuracy required. Tables IX-2 through IX-4 offer flow capacity estimates at HW/D = 1 for standard metal circular, metal pipe-arch, and concrete box culverts. These values assume an unimpeded stream flow through the crossing with no reduction in velocity from outlet controls. Flow capacity for other types of stream crossings can be estimated using nomographs presented in the *Hydraulic Design of Highway Culverts* manual by the US Federal Highways Administration (Normann et al. 1985), available on-line at http://www.fhwa.dot.gov.

Diameter (inches)	Area (ft^2)	Flow Capacity[1]		
		Projecting (cfs)	Mitered (cfs)	Headwall (cfs)
24	3.1	11	12	14
30	4.9	20	22	24
36	7.1	31	34	38
42	9.6	46	51	55
48	12.6	64	71	77
54	15.9	86	95	104
60	19.6	112	123	135
66	23.8	142	157	171
72	28.3	177	195	213
78	33.2	216	238	260
84	38.5	260	286	313
90	44.2	309	340	372
96	50.3	363	400	437
102	56.7	422	465	509
108	63.6	487	536	587
114	70.9	557	614	672
120	78.5	634	698	763
132	95	804	886	969
144	113	1,000	1,101	1,204

[1] Flow capacity using equations presented in (Piehl et al. 1998).

Table IX-2. Flow capacity for circular metal culverts at HW/D=1.

Span IX Rise (feet - inches)	Area (ft^2)	Flow Capacity[1]		
		Projecting (cfs)	Mitered (cfs)	Headwall (cfs)
3-0 IX 1-10	41.3	16	17	18
3-7 IX 2-3	6.4	26	28	29
4-2 IX 2-7	8.5	37	40	42
4-10 IX 3-0	11.4	55	59	61
5-5 IX 3-4	14.2	70	77	79
6-0 IX 3-8	17.3	90	98	100
6-1 IX 4-7	22	130	138	142
7-0 IX 5-1	28	170	182	190
8-2 IX 5-9	38	240	258	270
9-6 IX 6-5	48	330	350	370
11-5 IX 7-3	63	470	520	550
12-10 IX 8-4	58	650	720	800
15-4 IX 9-3	107	920	980	1,020

1. Flow capacity estimated from Chart 34 in *Hydraulic Design of Highway Culverts* (Normann et al. 1985).

Table IX-3. Flow capacity for metal pipe-arch culverts at HW/D = 1.

Box Height (ft^2)	Flow Capacity[1]	
	Headwall (cfs/ft)	Wingwall (cfs/ft)
2	7.2	8.2
3	13	15
4	20	23
5	29	33
6	38	44
7	48	55
8	59	68
3	70	80
10	81	93
11	93	107
12	108	123

[1] Flow capacity estimated from Chart 34 in *Hydraulic Design of Highway Culverts* (Normann et al. 1985).

Table IX-4. Flow capacity for concrete box culverts at HW/D = 1.

To calculate flow capacity, multiply value in the table by the culvert width.

Estimate the peak flows at each crossing. Peak flows are often reported in terms of a recurrence interval. The recurrence interval defines the average length of time between occurrences of a specific peak flow. For example, a 100-year peak flow has a 1 percent chance of occurring in any given year and occurs, on average, once in 100-years.

Current guidelines recommend all stream crossings pass the flow associated with the 100-year flood without causing structural damage (DFG 2002; NOAA 2001). Because of the high potential for debris clogging, infrequently maintained culvert crossings should accommodate the 100-year flood without overtopping the culverts inlet. The ranking analysis requires estimating the 5-year, 10-year, 25-year, 50-year, and 100-year peak flows. Three methods are commonly employed:

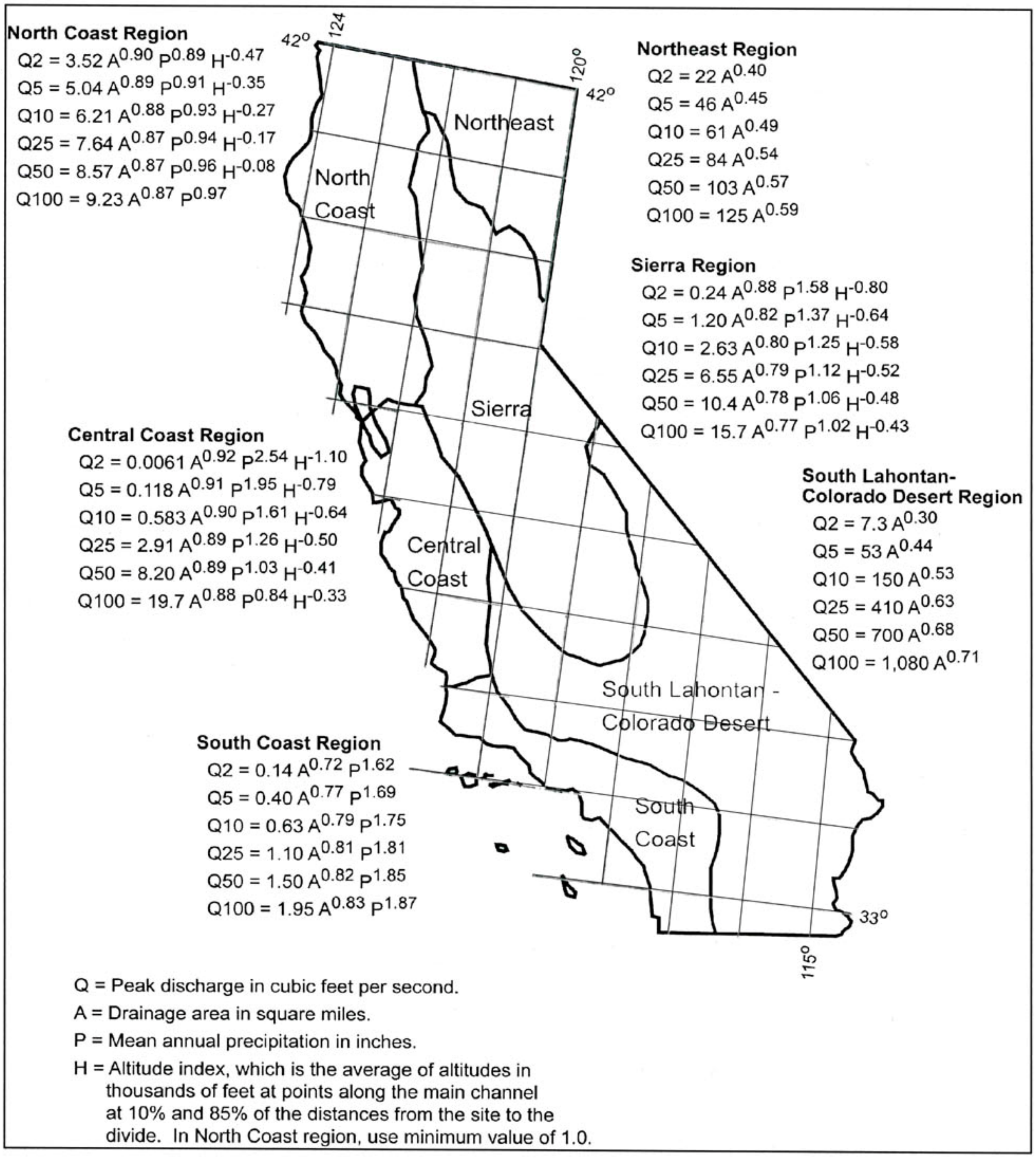
- Regional flood estimation equations for various recurrence intervals
- The rational method
- Estimates using local stream gaging data.

Flood estimators have been developed for regions throughout California by the USGS, the USDA Forest Service, California Department of Water Resources, and many county and city planning agencies. In some cases, flood estimations have a high degree of error, as much as a 40 percent to 50 percent mean standard error of estimate. These equations typically require general hydrologic information pertaining to the watershed, such as drainage area and mean annual precipitation.

Figure IX-18 contains the flood estimation equations developed by the USGS for regions throughout California. To determine if newer or more reliable flood estimation equations have been developed for a region, consult with local road managers and water resources professionals.

Compare the stream crossing’s flow capacity to peak flow estimates. To assess the risk of failure, compare the stream crossing’s flow capacity with the estimated peak flow for each recurrence interval. Then place each crossing into one of six categories:

- Flow capacity equal to or greater than the 100-year flow
- Between the 50-year and 100-year flows
- Between the 25-year and 50-year flows
- Between the 10-year and 25-year flows
- Between the 5-year and 10-year flows
- Less than the 5-year flow.



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).

Figure IX-18. California regional regression equations.

Fish Passage Flows

Although adult anadromous salmonids typically migrate upstream during higher flows triggered by hydrologic events, it is presumed that migration is naturally delayed during extreme large flood events. Conversely, during low flow periods water depths within the channel can become impassable for adult and/or juvenile salmonids (Figure IX-19). It is widely agreed that designing stream crossings to pass fish at high flood flows is impractical (Robison et al. 2000; SSHEAR 1998). 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 (Table IX-5, DFG 2002).

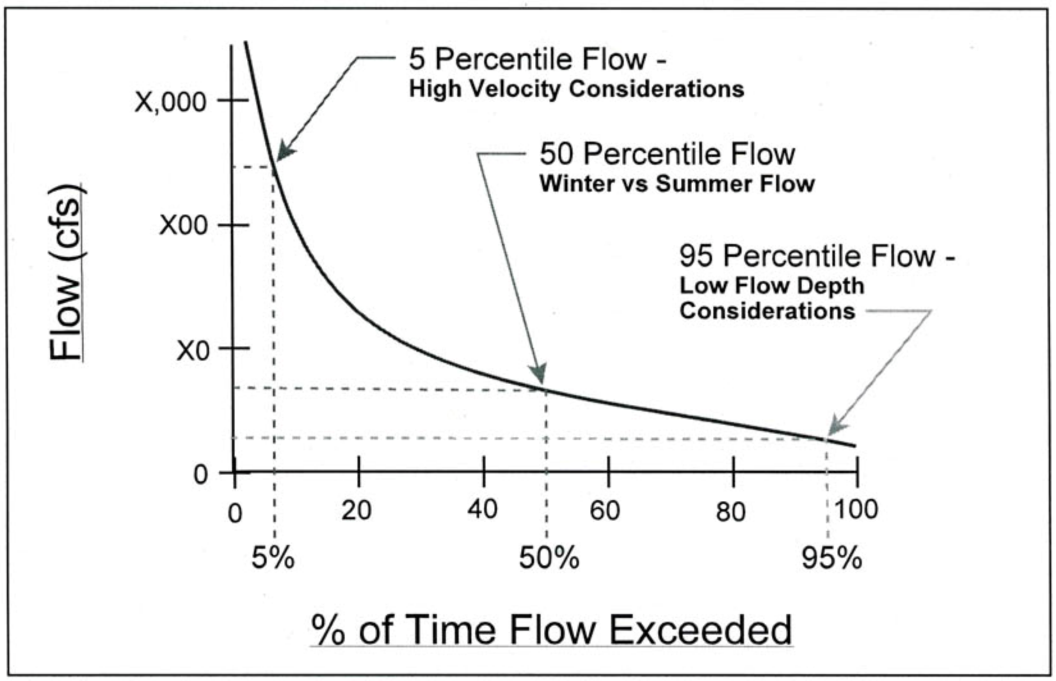


Figure IX-19. Example of a flow duration curve.

The upper fish passage flow limit for adult anadromous salmonids (Q_{hp}) is defined as the 1 percent exceedance flow (the flow equaled or exceeded 1 percent of the time) during an average year. For all adult salmonids, the lower fish passage flow (Q_{lp}) equals the 50 percent exceedance flow. Table IX-5 lists the upper and lower passage flows for all species and life stages. Between the lower and upper passage flows stream crossings should allow unimpeded passage.

Fish passage flows are required for assessing passage at the GRAY stream crossings. To evaluate the extent to which a crossing is a barrier to fish, passage is assessed between the lower and upper passage flows for each fish species and lifestage of concern.

Species/Lifestage	Upper Passage Flow	Lower Passage Flow	
	Exceedance Flow	Exceedance Flow	Alternate Minimum Flow (cfs)
Adult Anadromous Salmonids	1%	50%	3
Adult Non-Anadromous Salmonids	5%	90%	2
Juvenile Salmonids	10%	95%	1
Native Non-Salmonids	5%	90%	1
Non-Native Species	10%	90%	1

Table IX-5. Upper and lower fish passage flows for stream crossings (DFG 2002).

Identifying exceedance flows requires obtaining average daily stream flow data from nearby gaged basins. Most stream gages are operated by the USGS and the California Department of Water Resources, with much of the data available on-line. Use the following steps to estimate the needed upper and lower passage flows (see Appendix IX-C for a sample calculation):

Obtain flow records from local stream gages that meet the following requirements:

- At least 5-years of recorded daily average flows, and preferably more than 10-years (do not need to be consecutive years)
- A drainage area less than 50 square miles, and preferably less than 10 square miles
- Unregulated flows (no upstream impoundment or water diversions). If feasible, use several gaged streams to determine which ones have flow characteristics that best resemble stream flows observed throughout the project area.

Rank the flows from highest to lowest (a rank of i = 1 given to the highest flow). The lowest flow will have a rank of *n*, which equals the total number of flows considered.

To identify the rank associated with a particular exceedance flow, such as the 50 percent and 1 percent exceedance flows ($i_{50\%}$ and $i_{1\%}$ respectively), use the following equations:

$i_{50\%} = 0.50(n+1)$ $\qquad$ $i_{1\%} = 0.01(n+1)$

Round to the nearest whole number. The flows corresponding to those ranks are the 50 percent and 1 percent exceedance flows for the gaged stream.

To apply these flows to the ungaged stream, multiply the flows obtained in above step, $Q_{50\%}$ and $Q_{1\%}$, by the ratio of the gauged stream's drainage area (*DA*) to the drainage area of the ungaged stream at the stream crossing. Multiplying by this ratio adjusts for the differences in drainage area between watersheds. Other methods for determining exceedance flows for ungaged streams can also be used. These methods typically take into account differences in precipitation between watersheds.

In *FishXing* analysis, these flows will be 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 percent passable.

When flows from several different gaging stations are available, use knowledge of the local hydrology and rainfall patterns to decide which one offers the best estimate. For inventory and assessment purposes, the method described above is often sufficient. More detailed or accurate flow measurement techniques may be necessary in the design of new or replacement stream crossings.

FishXing Analysis

The subset of stream crossings identified as GRAY will require additional analysis to determine the extent to which they are barriers. At these stream crossings, water depths, velocities and outlet conditions should be calculated between the lower and upper passage flows to ascertain whether fish passage requirements are being met. Fish passage conditions can be analyzed using *FishXing*, a computer software program developed by the Six Rivers National Forest Watershed Interactions Team (USDA Forest Service 1999). *FishXing* models culvert hydraulics (including open-bottom structures) and compares the predicted values with data regarding swimming and leaping abilities and minimum water depth requirements for numerous fish species. *FishXing* is available on-line at: http://www.stream.fs.fed.us/fishxing/.

FishXing inputs are divided into two categories:

1. Swimming capabilities and requirements for the fish species of concern
2. Site-specific information about the stream crossing.

The following are general instructions for using *FishXing* to analyze passage conditions at a stream crossing. For detailed instructions and background information about using the software, consult the "Help Files" contained within *FishXing* and available from the home-page in a user manual format.

Fisheries Inputs

For each stream crossing that was placed in the GRAY category, conduct a separate passage analysis for all salmonids and their life stages. At many sites this may include different life stages of anadromous salmonids and resident trout. For each lifestage, a prolonged and burst swim speeds must be entered into the software. Prolonged swim speeds can be sustained for extended periods of time, ranging from one to sixty minutes. Fish often swim in this mode when passing through the barrel of a culvert. Burst swim speeds are higher than prolonged but can only be sustained for a few seconds. Fish swim in burst mode when faced with challenging situations, such as the inlet and outlet regions of a typical culvert. Minimum water depth requirements and swimming and leaping ability inputs for *FishXing*. lists swimming and leaping speeds along with corresponding endurance times for several salmonid life stages.

Species or Lifestage	Minimum Water Depth	Prolonged Swimming Mode		Burst Swimming Mode		
		Maximum Swim Speed	Time to Exhaustion	Maximum Swim Speed	Time to Exhaustion	Maximum Leap Speed
Adult anadromous salmonids	0.8 feet	6.0 ft/sec	30 minutes	10.0 ft/sec	5.0 sec	15.0 ft/sec
Resident trout and juvenile steelhead trout >6”	0.5 feet	4.0 ft/sec	30 minutes	5.0 ft/sec	5.0 sec	6.0 ft/sec
Juvenile salmonids <6”	0.3 feet	1.5 ft/sec	30 minutes	3.0 ft/sec	5.0 sec	4.0 ft/sec

(These values are used to assist in prioritizing stream crossing for treatment and do not represent whether or not a stream crossing currently meets DFG or NOAA passage criteria).

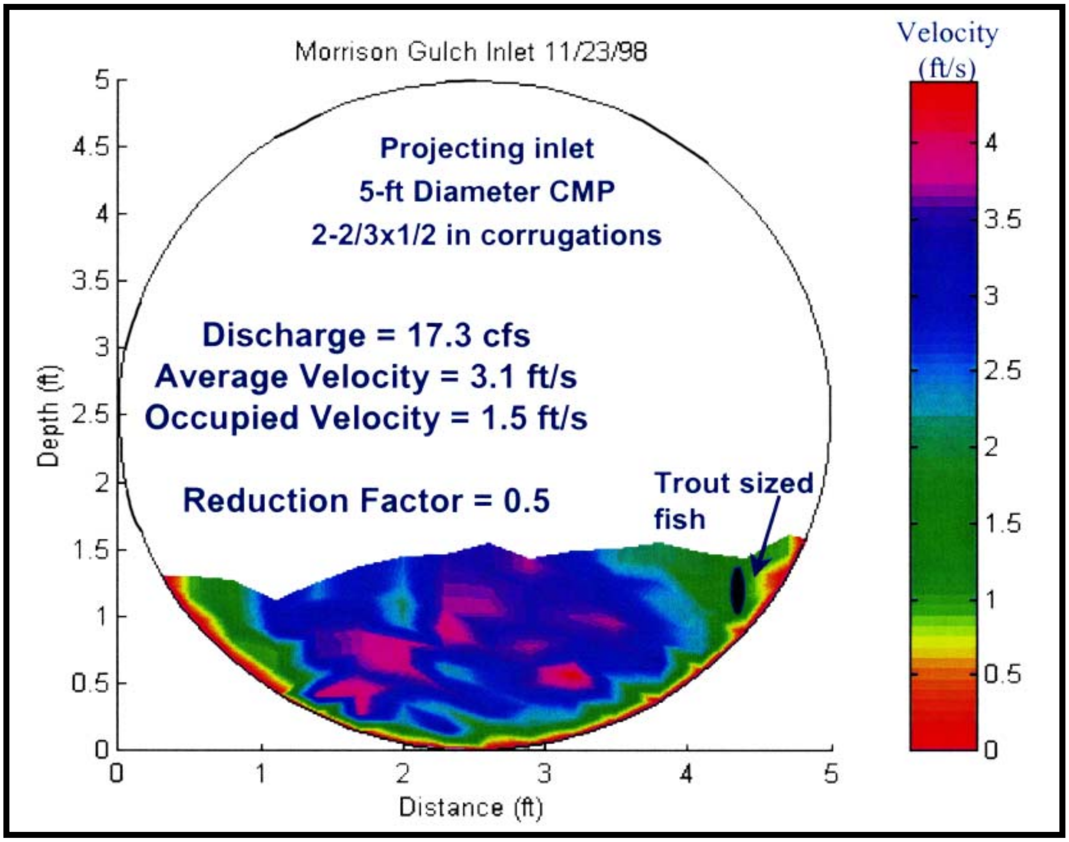
Table IX-6. Minimum water depth requirements and swimming and leaping ability inputs for *FishXing*.

FishXing and other hydraulic models report the average cross-sectional water velocity, not accounting for spatial variations. Stream crossings with natural substrate or deep corrugations will have regions of reduced velocities that can be utilized by migrating fish (Figure IX-20). These areas are often too small for larger fish to use, but can enhance juvenile passage success. *FishXing* allows the use of reduction factors that decrease the calculated water velocities proportionally. Accounting for areas of reduced velocities may be appropriate for the analysis of juvenile passage through certain types of stream crossing structures. *FishXing* also requires a lower and upper fish passage flow. To calculate these flows refer to the previous “Hydrology and Flow Requirements” section.

Stream Crossing Inputs

During the site visit, all required stream crossing information will have been collected for the passage analysis. Input the appropriate stream crossing type, material and length, whether it’s embedded, corresponding roughness values, and the bottom elevations of the inlet and outlet.

Next, define the tailwater elevation with respect to the stream crossing outlet. The tailwater elevation often determines whether the culvert is a barrier. A high tailwater can backwater the culvert for easy passage. Too low of a tailwater elevation will leave the outlet perched above the downstream channel. There are three different methods to choose from, depending on the type of information collected during the field survey (Table IX-7).



On Quarry Road at Morrison Gulch, tributary to Jacoby Creek, Humboldt Bay watershed.

Figure IX-20. Varying velocity measurements within a culvert.

Method	Description	Advantages	Disadvantages
Constant Tailwater	Enter one tailwater elevation, often the height of the active channel margins at the tailwater control downstream of the culvert.	Requires least amount of data and may be adequate for first-cut assessments.	Does not accurately describe conditions at most sites.
Tailwater Rating Curve	Generates curve relating tailwater elevation to flow, requiring a minimum of two points. For the first point, set the flow equal to zero and enter the tailwater control elevation. The second point is approximated at the adult high passage flow using the surveyed elevation of active channel. A more accurate curve can be constructed by taking actual flow measurements.	Approximating the rating curve requires less data than Cross-sectional Analysis, but is more accurate than Constant Tailwater method.	Requires making assumptions about tailwater elevation or taking direct measurements of stream flow.
Cross-sectional Analysis	Creates a tailwater-rating curve using a channel cross-section surveyed at the tailwater control, the downstream channel slope, and an estimate of channel roughness.	Creates a rating curve that adequately describes tailwater conditions.	Data intensive and requires estimate of channel roughness.

Table IX-7. Alternative methods available in *FishXing* for defining tailwater elevation below a stream crossing.

Interpreting Results

Run *FishXing* at the lower, middle and upper passage flows. After running the model, use the "Water Surface Profile" (WSP) results to determine if the stream crossing is passable at the lower, middle, and upper flows. Use the "Barrier Code" to identify potential passage problems. The "Uniform Flow" results can be used to identify crossings with outlets perched too high for fish passage. Refer to the *FishXing* Help Files for additional information on interpreting results. Because "Uniform Flow" results do not account for backwatering nor depth and velocity changes at the inlet and outlet, these results should only be used to identify potential vertical barriers.

If results indicate desired conditions for passage do not exist at the lower or upper passage flow, use a trial-and-error approach (by changing input flows) to identify the flows that are passable, if any. Record these cut-off flows and note the passage requirement(s) that are not being met.

To assess the extent to which the crossing is a barrier to adult anadromous, resident, and juvenile salmonids compare the actual range of passable flows to the desired range (the upper and lower passage flows) and calculate the "percent passable". These values are utilized in the matrix for ranking sites for treatment. Additionally, on a site-by site basis, the identified range of passage flows can aid in developing treatment options.

Analysis of Retrofitted Stream Crossings

Evaluating passage conditions at crossings that have been retrofitted with baffles or weirs to increase water depths and decrease velocities is difficult and beyond the capabilities of *FishXing*. These sites require field monitoring during migration flows. Visit the site at several different flow conditions and observe the hydraulics within the crossing. Measure water depths between the baffles or weirs within the culvert and at the inlet and outlet. Water velocities can be estimated using a timed float. Also note if there appear to be insufficient resting areas behind baffles, excessive turbulence, debris clogging, or other conditions that may help or hinder passage of adult and juvenile fish. Based on these observations, for each fish species and lifestage present, estimate whether the crossing meets the passage criteria at migration flows. If the stream crossing provides adequate passage conditions for adults but not juveniles, then it would be considered 100 percent passable for adults and 0 percent passable for juveniles.

The observation of fish upstream does not necessarily indicate the stream crossing meets desired fish passage criteria. The crossing may remain a barrier at most flows or to most life stages, allowing passage for only a limited number of fish. Salmonids observed above a suspected barrier may also be resident fish.

FISH HABITAT INFORMATION

When ranking stream crossings for treatment, both quality and quantity of upstream habitat should be considered so that restoration funds are devoted to the greatest benefit of the fisheries resource. Following are fish habitat criteria to be considered.

Assessment of habitat conditions upstream and downstream of stream crossings can rely on previously conducted habitat typing or fisheries surveys. Communication with agency and private-sector biologists, watershed groups, coordinators, restorationists, and large landowners may assist in acquiring additional information on watershed assessment and evaluation. Historical information is often available in reports on file at DFG offices; check with the local DFG biologists or watershed planners for assistance in obtaining recent habitat information. If the road system intersects streams lacking recent habitat inventory information, field reconnaissance may be utilized to quantify habitat quality and quantity.

To estimate length of potential salmonid habitat upstream of each stream crossing use:

- Completed stream inventory reports (see Part III)
- Stream inventory as a part of the fish passage inventory
- USGS 7.5-Minute Series topographic maps to define the upper limit of anadromous habitat when the channel exceeds a sustained eight to ten percent slope for approximately 1,000 feet. Upper limits of resident fish habitat may include channel reaches with slopes up to 20 percent. Consult with the local DFG biologist for additional guidance. This method should be considered a rough estimate. If possible verify results in the field.

RANKING OF STREAM CROSSINGS FOR TREATMENT

The primary objective of the ranking is to arrange stream crossings classified as GRAY and RED in order from high to low priority, using fish habitat information as the primary criteria. This should be done using site-specific information weighted heavily towards the biological and physical habitat considerations. The rankings generated are categorical and not intended to be absolute in deciding the exact order of scheduling remediations. Professional judgment plays an important part in deciding the order of treatment. As noted by Robison et al. (2000) numerous social and economic factors influence the exact order of sites to be treated, as well as treatment options considered.

Ranking Criteria

The ranking method assigns scores or values for the following five parameters at each GREEN, GRAY and RED stream crossing location:

1. *Species Diversity* - Number of salmonid species currently present (or historically present which could be restored) within the stream reach at each crossing location.
   - **Score** - For each federally or state listed salmonid species; Endangered = 4 points; Threatened or Candidate = 2 points; not listed = 1 point. Consult DFG or NOAA for historic species distribution and listing status information.
2. *Extent of Barrier* - Over the range of estimated migration flows, assign one of the following values from the "percent passable" results generated with *FishXing*. GREEN crossings are considered 100 percent passable for all fish, while RED crossings are considered 0 percent passable for all fish. Do this for adult anadromous, resident, and juvenile salmonids for each culvert.
   - **Score** - 0 = 80% or greater passable; 1 = 79-60% passable; 2 = 59-40% passable; 3 = 39-20% passable; 4 = 19% or less passable; 5 = 0% passable (RED). For a total score, sum the values for all three.
3. *Habitat Value* - Multiply habitat quantity score by habitat quality score.

   Habitat Quantity - Above each crossing, length in feet to a sustained 8% gradient or field-identified limit of anadromy.

- **Score:** 0.5 points for each 500 feet of stream (example: 0.5 points for <500N; 1 point for 1,000N; 2 points for 2,000N; and 5.5 points for 5,500N). The maximum possible score for Habitat Quantity is 10.

Habitat Quality - For each stream, assign a score of quality after reviewing available habitat information. Consultation with local DFG biologists to assist in assigning habitat quality score is recommended.

- Score:

***1.0** = Excellent* - Relatively undeveloped, with 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 instream habitat, floodplain relatively intact.

***0.75** = Good* - Habitat is mostly intact but erosional processes or other factors have altered the watershed with a likelihood of continued occurrence. Habitat includes dense riparian zones of native species, frequent pools, spawning gravels, cool summer water temperatures, complex instream habitat, floodplain relatively intact.

***0.5** = Fair* - Erosional processes or other factors have altered the watershed with negative affects on watershed processes and features, with the likelihood of continued occurrence. Indicators include:

a) riparian zone lacking mature conifers

b) infrequent pools

c) sedimentation evident in spawning areas (embeddedness ratings of 3)

d) summer water temperatures periodically exceed stressful levels for salmonids

e) sparse instream complex habitat, and floodplain intact or slightly modified.

0.25 = Poor - Erosional processes or other factors have significantly altered the watershed. There is a high likelihood of increased erosion and apparent effects to watershed processes. Habitat impacts include riparian zones absent or severely degraded, little or no pool habitat, excessive sedimentation evident in spawning areas (embeddedness ratings of 4), stressful to lethal summer water temperatures common, lack of instream habitat, floodplain severely modified with levees, riprap, and/or residential or commercial development.

4. *Sizing (risk of failure)* - For each crossing, assign one of the following values as related to flow capacity.

    - **Score:** 0 = sized for at least a 100-year flow, low risk; 1 = sized for at least a 50-year flow, low/moderate risk; 2 = sized for at least a 25-year flow, moderate risk of failure; 3 = sized for at least a 10-year flow, moderate/high risk of failure; 4 = sized for less than a 10-year flow, high risk of failure; 5 = sized for less than a 5-year flow, extreme risk of failure.

5. *Current Condition* - For each crossing, assign one of the following values.

    - **Score:** 0 = good condition; 1 = fair, showing signs of wear; 3 = poor, floor rusting through, crushed by roadbase, etc.; 4 = extremely poor, floor rotted-out, severely crushed, damaged inlets, collapsing wingwalls, slumping roadbase, etc.

For each stream crossing, enter criteria values into a spreadsheet, sum the five ranking criteria values, and compute the total scores. Then sort the list of crossings by total scores to determine a first-cut ranking for the project area.

Additional Ranking Considerations

The results of the ranking matrix provide a rough, first-cut evaluation of GRAY and RED stream crossings. There are other important factors that should be considered when deciding the exact scheduling of remediation efforts.

The following list provides guidance that should assist in rearranging the first-cut ranking. On a site-specific basis, some or all of these factors should be considered:

- *Presence or absence of other stream crossings* - In many cases, a single stream may be crossed by multiple roads. If migration barriers exist at multiple stream crossings, a coordinated effort is required to identify and treat them in a logical manner, generally in an upstream direction starting with the lowest crossing in the stream.
- *Fish observations at crossings* - Sites where fish are observed holding during migration periods should receive high consideration for remediation. Identify the species present, count the number of fish, and record failed versus successful passage attempts. Consider the potential for predation and/or poaching. Sites with holding fish are areas where immediate recolonization of upstream habitat is likely to occur.
- *Amount of road fill* - At stream crossings that are undersized and/or in poor condition, consider the volume of fill material within the road prism. This is material which is directly deliverable to the stream channel if the crossing were to fail. Also determine if there is a potential for water to divert down the road if the crossings capacity is overwhelmed (refer to Part X).
- *Remediation project cost* - The range of treatment options and associated costs must be examined when determining the order in which to proceed. In cases where federal or state listed fish species are present, costs must be weighed against the consequences of not providing unimpeded passage.
- *Opportunity* - Road managers should consider upgrading all migration barriers during road maintenance activities. The ongoing costs of maintaining an undersized or improperly installed culvert may exceed the cost of replacing it with a properly sized and installed crossing. When undersized or older crossings fail during storms, road managers should be prepared to install properly-sized crossings that provide unimpeded passage for all species and life stages of fish.

PREFERRED TREATMENT OPTIONS FOR UNIMPEDED FISH PASSAGE

The following general guidance draws from design standards currently employed in Oregon and Washington, and are consistent with current guidelines for stream crossings in California. However, site-specific characteristics of the stream 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 to occur from removal of a perched culvert. Providing unimpeded passage for the salmonid species of concern will often dictate the design of a culvert upgrade or replacement. Bates et al. (1999) is a reference for stream crossing installation options. Robison et al. (2000) provides a comprehensive review of the advantages and disadvantages of various treatment alternatives based on channel slope and confinement.

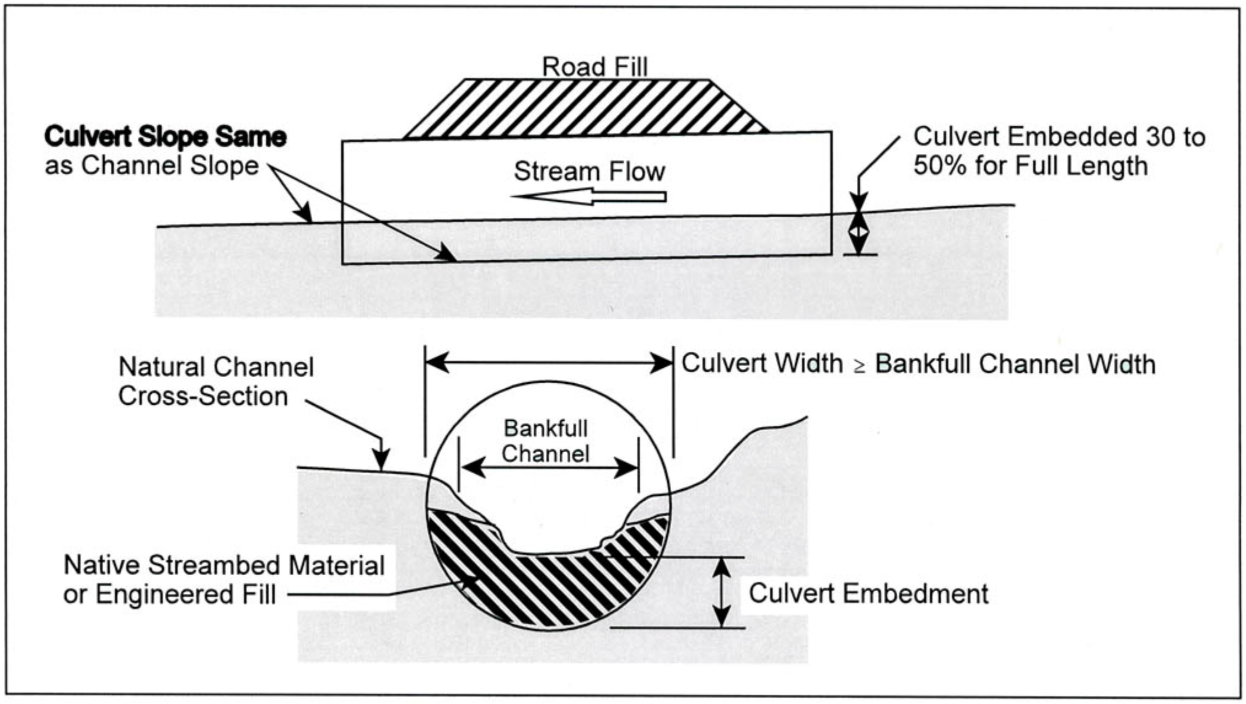


Figure IX-21. Stream simulation strategy option.

NOAA *Guidelines for Salmonid Passage at Stream Crossings* (NOAA 2001) lists the following recommendations for new or replacement crossings, in order of preference. For additional information obtain the NOAA Guidelines at http://swr.nmfs.noaa.gov/hcd/NMFSSCG.PDF.

- Nothing - Road realignment to avoid crossing the stream
- Bridge - Spanning the stream to allow for long term dynamic channel stability
- Streambed simulation strategies - Bottomless arch, embedded culvert design, or ford (Figure IX-21)
- Non-embedded culvert - This is often referred to as hydraulic design, associated with more traditional culvert design approaches and is limited to low slopes for fish passage
- Baffled culvert or structure designed with a fishway for steeper slopes.

STREAM CROSSING REMEDIATION PROJECT CHECKLIST

The following list briefly describes the general phases of a stream crossing remediation project, factors to consider at each site, and permits required:

Project budget - Once a treatment option is selected, develop a detailed project budget, including:

- Engineering design
- Project management
- Permit application preparation and fees
- CEQA compliance - including required botanical, wildlife, fisheries, and archeological surveys
- Construction labor - In-house or subcontracted
- Heavy equipment - In-house, subcontracted, or rented
- Materials and delivery to site
- Traffic bypass
- Water management plan
- Fish relocation from project site
- Construction-phase quality control monitoring
- Revegetation
- Paving and re-striping of roadway
- Post-project monitoring.

Project Design - Designs consistent with current DFG (APPENDIX IX-A) and NOAA (Appendix IX-B) guidelines.

Project Permits - The permit application process should be initiated as soon as possible. Accurately provide all information required on permits, contact appropriate agency for applications and questions regarding permit information. The following are the minimum required agencies' permits and contact information:

- DFG - Lake and Streambed Alteration Agreement (Fish and Game Code § 1600 *et seq.*). Available on DFG website: **www.dfg.ca.gov/1600**
- US Army Corp of Engineers (USACOE) Section 404 Permit - Check USACOE Homepage at: **www.usace.army.mil** or if within San Francisco District check: **www.spn.usace.army.mil/regulatory/**
- NOAA reviews applications submitted to USACOE - For more information on permits, 4(d) rules and species distribution; check: **http://swr.nmfs.noaa.gov**
- California Regional Water Quality Control Board 401 Permit - Check homepage of State Water Resources Control Board to select link to appropriate regional water quality control board: **www.swrcb.ca.gov.**

GUIDANCE TO MINIMIZE IMPACTS DURING STREAM CROSSING CONSTRUCTION

Project planners should incorporate appropriate measures to minimize impacts during stream crossing construction. Listed are some general measures to minimize impacts from instream construction, degradation of water quality, loss or disturbance of riparian vegetation, impacts to aquatic habitat and species during de-watering, and injury and mortality of fish and amphibian species during de-watering. Local conditions and more specific conditions may require additional protective measures be implemented.

Measures to Minimize Disturbance From Instream Construction

- Construction should generally occur during the lowest flow period of the year.
- Construction should occur during the dry period if the channel is seasonally dry.
- Prevent any construction debris from falling into the stream channel. Any material that does fall into a stream during construction should be immediately removed in a manner that has minimal impact to the streambed and water quality.
- Where feasible, the construction should occur from the bank, or on a temporary pad underlain with filter fabric.
- Temporary fill must be removed in its entirety prior to close of work-window.
- Areas for fuel storage, refueling, and servicing of construction equipment must be located in an upland location.
- Prior to use, clean all equipment to remove external oil, grease, dirt, or mud. Wash sites must be located in upland locations so that dirty wash water does not flow into stream channel or wetlands.
- All construction equipment must be in good working condition, showing no signs of fuel or oil leaks.
- Petroleum products, fresh cement, or deleterious materials must not enter the stream channel.
- Operators must have spill clean-up supplies on site and be knowledgeable in their proper use and deployment.
- In the event of a spill, operators must immediately cease work, start clean-up, and notify the appropriate authorities.

Measures to Minimize Degradation of Water Quality

- Isolate the construction area from flowing water until project materials are installed and erosion protection is in place.
- Erosion control measures shall be in place at all times during construction. Do not start construction until all temporary control devices (straw bales, silt fences, etc.) are in place downslope or downstream of project site.

- Maintain a supply of erosion control materials onsite, to facilitate a quick response to unanticipated storm events or emergencies.
- Use erosion controls to protect and stabilize stockpiles and exposed soils to prevent movement of materials. Use devices such as plastic sheeting held down with rocks or sandbags over stockpiles, silt fences, or berms of hay bales to minimize movement of exposed or stockpiled soils.
- Stockpile excavated material in areas where it cannot enter the stream channel. Prior to start of construction, determine if such sites are available at or near the project location. If unavailable, determine location where material will be deposited. If feasible, conserve topsoil for reuse at project location or use in other areas.
- Minimize temporary stockpiling of excavated material.
- When needed, utilize instream grade control structures to control channel scour, sediment routing, and headwall cutting.
- Immediately after project completion and before close of seasonal work-window, stabilize all exposed soil with mulch, seeding, and/or placement of erosion control blankets.

Measures to Minimize Loss or Disturbance of Riparian Vegetation

- Prior to construction, determine locations and equipment access points that minimize riparian disturbance. Avoid affecting less stable areas.
- Retain as much understory brush and as many trees as feasible, emphasizing shade producing and bank stabilizing vegetation.
- Minimize soil compaction by using equipment with a greater reach or that exerts less pressure per square inch on the ground, resulting in less overall area disturbed or less compaction of disturbed areas.
- If riparian vegetation is to be removed with chainsaws, consider using saws currently available that operate with vegetable-based bar oil.
- Decompact disturbed soils at project completion as the heavy equipment exits the construction area.
- Revegetate disturbed and decompacted areas, with native species specific to the project location that comprise a diverse community of woody and herbaceous species.

Measures to Minimize Impacts to Aquatic Habitat and Species During Dewatering of Project Site

When construction work must occur within a year-round flowing channel, the work site must be dewatered. Dewatering can result in the temporary loss of aquatic habitat, and the stranding, displacement, or crushing of fish and amphibian species. Increased turbidity may occur from disturbance of the channel bed. Following these general guidelines will minimize impacts.

- Prior to dewatering, determine the best means to bypass flow through the work area to minimize disturbance to the channel and avoid direct mortality of fish and other aquatic vertebrates.
- Coordinate project site dewatering with a fisheries biologist qualified to perform fish and amphibian relocation activities.
- Minimize the length of the dewatered stream channel and duration of dewatering.
- Bypass stream flow around work area, but maintain stream flow to channel below construction site.
- The work area must often be periodically pumped dry of seepage. Place pumps in flat areas, well away from the stream channel. Secure pumps by tying off to a tree or stake in place to prevent movement by vibration. Refuel in area well away from stream channel and place fuel absorbent mats under pump while refueling. Pump intakes should be covered with 1/8" mesh to prevent entrainment of fish or amphibians that failed to be removed. Check intake periodically for impingement of fish or amphibians.
- Discharge wastewater from construction area to an upland location where it will not drain sediment-laden water back to stream channel.

Measures to Minimize Injury and Mortality of Fish and Amphibian Species During Dewatering

Prior to dewatering a construction site, fish and amphibian species should be captured and relocated to avoid direct mortality and minimize take. This is especially important if listed species are present within the project site. The following measures are consistent with those defined as *reasonable and prudent* by NOAA for projects concerning several northern California Evolutionary Significant Units for coho salmon, chinook salmon, and steelhead trout.

- Fish relocation activities must be performed only by qualified fisheries biologists, with a current DFG collectors permit, and experience with fish capture and handling. Check with your local DFG biologist for assistance.
- In regions of California with high summer air temperatures, perform relocation activities during morning periods.
- Periodically measure air and water temperatures. Cease activities when water temperatures exceed temperatures allowed by DFG and NOAA.

Exclude fish from re-entering work area by blocking the stream channel above and below the work area with fine-meshed net or screens. Mesh should be no greater than 1/8 inch. It is vital to completely secure bottom edge of net or screen to channel bed to prevent fish from re-entering work area. Exclusion screening should be placed in areas of low water velocity to minimize impingement of fish. Screens should be checked periodically and cleaned of debris to permit free flow of water.

- Prior to capturing fish, determine the most appropriate release location(s). Consider the following when selecting release site(s):
    a. Similar water temperature as capture location

b. Ample habitat for captured fish
c. Low likelihood of fish re-entering work site or becoming impinged on exclusion net or screen.

- Determine the most efficient means for capturing fish. Complex stream habitat generally requires the use of electrofishing equipment, whereas in outlet pools, fish may be concentrated by pumping-down pool and then seining or dip-netting fish.
- Electrofishing should only be conducted by properly trained personnel following DFG and NOAA guidelines.
- Minimize handling of salmonids. However, when handling is necessary, always wet hands or nets prior to touching fish.
- Temporarily hold fish in cool, shaded, aerated water in a container with a lid. Provide aeration with a battery-powered external bubbler. Protect fish from jostling and noise and do not remove fish from this container until time of release.
- Place a thermometer in holding containers and, if necessary, periodically conduct partial water changes to maintain a stable water temperature. If water temperature reaches or exceeds those allowed by DFG and NOAA, fish should be released and rescue operations ceased.
- Avoid overcrowding in containers. Have at least two containers and segregate young-of-year (YOY) fish from larger age-classes to avoid predation. Place larger amphibians, such as Pacific giant salamanders, in container with larger fish.
- If fish are abundant, periodically cease capture, and release fish at pre-determined locations.
- Visually identify species and estimate year-classes of fish at time of release. Count and record the number of fish captured. Avoid anesthetizing or measuring fish.
- Submit reports of fish relocation activities to DFG and NOAA in a timely fashion.
- If feasible, plan on performing initial fish relocation efforts several days prior to the start of construction. This provides the fisheries biologist an opportunity to return to the work area and perform additional electrofishing passes immediately prior to construction. In many instances, additional fish will be captured that eluded the previous days efforts.
- If mortality during relocation exceeds 5 percent, stop efforts and immediately contact the appropriate agencies.

PROJECT MONITORING

The process of integrating watershed hydrology, modeling of hydraulic dynamics through culverts, and passage evaluation for fish migration is still developing. There is a vital need to monitor newly constructed stream crossings to ensure design standards are adequate for both flow conveyance and unimpeded fish passage.

Implementation Monitoring

Many stream crossings are being replaced specifically to permit unimpeded passage of fish. Implementation monitoring is required to ensure that design specifications of projects are being correctly implemented. Engineering firms who design the new stream crossings should have staff on-site during critical phases of construction. Quality control will ensure that design specifications are utilized and accurately measured. Additional monitoring is needed to ensure construction crews follow other project stipulations, such as the water management plan, erosion control plan, traffic bypass plan, emergency spill plan, and riparian revegetation plan.

Project Monitoring

The following monitoring activities may be used to evaluate the effects of a newly constructed stream crossing:

- *Changes in channel longitudinal profile and cross-section* - Conducting channel profiles and cross-sections before and after stream crossing replacement should provide information on reducing or eliminating perched outlets, channel response at sites where upstream channel incision is possible, the formation and stability within embedded crossings, and impacts on downstream channel stability.
- *Spawning surveys during periods of presumed activity* - Pre- and post-project data concerning fish species and redd distribution within the stream reach of interest, both upstream and downsteam of a stream crossing site, will allow an evaluation of changes in spawner distribution.
- *Direct observation of fish migration at site* - Pre- and post-project data could be collected which would allow comparisons of observations of leap attempts in order to demonstrate the successful establishment of unimpeded passage.
- *Measurements of culvert hydraulic characteristics over the range of estimated migration flows* - An effort should be made to determine if the *FishXing* hydraulic modeling for the project design used in the remediation project accurately predicts water depth, velocities, and tailwater conditions. This will help determine if the newly installed stream crossing will perform as expected in providing passage.
- *Photo and/or video documentation of pre-project, construction phases, and post-project* - A variety of established photo points can be used to visually document changes at a particular site.

FISH PASSAGE INVENTORY DATA SHEET

Stream Crossing Type: ☐ **bridge** ☐ **ford** ☐**culvert** ☐ **other**________________ **Date:**____/____/____
Surveyors: Scope:________________________________**Rod:**____
Culvert #_____**of**______**(left bank to right bank)**

Road:	**Mile Post:**	**Crossroad:**
Stream Name:	**Tributary to:**	**Basin:**
Quad:	**T:** **R:** **S:**	**Lat/Long:**

Flow Conditions During Survey: ☐ continuous ☐ isolated pools ☐ dry

Fisheries Information

Fish Presence Observed During Survey: Location: ☐ upstream ☐ downstream ☐ none
Age Classes: ☐ adults ☐ juveniles Species: ____ ☐ unknown
Juvenile Size Classes: ☐ <3" ☐ 3"-6" ☐ >6" Number of Fish Observed:

Stream Crossing Information

Inlet Type: ☐ projecting ☐ headwall ☐ wingwall ☐ mitered ☐ flared
Alignment (deg): ☐ <30° ☐ 30°-45° ☐ >45° **Inlet Apron:** ☐ yes ☐ no
Describe:____
Outlet Configuration: ☐ at stream grade ☐ free-fall into pool ☐ cascade over rip rap
Outlet Apron: ☐ yes ☐ no **Describe:**____
Tailwater Control: ☐ pool tailout ☐ full-spanning log or debris jam ☐ log weir ☐ boulder weir
☐ concrete weir ☐ other______________________☐ no control point (complete a channel cross-section)
Upstream Channel Widths (ft): (1) (2) (3) (4) (5) Average Width:

Culvert Information

Culvert Type: ☐ circular ☐ pipe arch ☐ box ☐ open-bottom arch ☐ other_________________
Diameter (ft):_______ **Height or Rise (ft):**________ **Width or Span (ft):**_______ **Length (ft):**________
Material: ☐ SSP ☐ CSP ☐ aluminum ☐ plastic ☐ concrete ☐ log/wood ☐ other_________
Corrugations (width x depth): ☐ 2 2/3" x ½ ☐ 3" x 1" ☐ 5" x 1" ☐ 6" x 2" ☐ spiral
☐ other__________
Pipe Condition: ☐ good ☐ fair ☐ poor ☐ extremely poor
Describe:____
____

Rustline Height (ft):___________ ☐ NP (new CSP or SSP) ☐ NA (concrete, aluminum, plastic)
Embedded: ☐ yes ☐ no
Depth (ft): inlet_____ outlet_____ Station (ft): start:________ end:_______
Describe Substrate:____
____

Barrel Retrofit (weirs/baffles): ☐ yes ☐ no
Type: ☐ steel ramp baffles ☐ Washington ☐ corner ☐ other:______________________________
Describe (size, number, placement, materials):____
____

Outlet Beam: ☐ yes ☐ no **Notched:** ☐ yes ☐ no
Breaks-in-Slope: ☐ yes ☐ no Number:
Fill Volume: L_u (ft):_____ S_u (%):_____ W_r (ft): _____ L_d (ft): _____ S_d (%):_____ L_f (ft):_____
W_c (use average channel width) (ft):______

Site Sketch

FISH PASSAGE INVENTORY SURVEYED ELEVATIONS

Longitudinal Surveyed Elevations					Station Description and Water Depth (**Bold** = Required)	Tailwater Cross-section (optional)					
Station (ft)	**BS (+)**	**HI (ft)**	**FS (-)**	**Elevation (ft)**		Station (ft)	BS (+)	HI (ft)	FS (-)	Elevation (ft)	Notes
					TBM:						
					TW Control of 1st resting habitat u/s of inlet						
					Inlet Apron/Riprap						
					Inlet Depth=						
					Outlet Depth=						
					Outlet Apron/Riprap						
					Max. Depth within =						
					Max. Pool Depth						
					TW Control Depth=						
					Active Channel Stage						
					Downstream Channel Slope (%):	**Substrate at X-Section:**					

Additional Surveyed Elevations (including Breaks-in-Slope)						
						Suspected Passage Assessment: Adults: ☐ 100% barrier ☐ partial barrier ☐ no barrier Juveniles: ☐ 100% barrier ☐ partial barrier ☐ no barrier
						Culvert Slope:_______%

Qualitative Habitat Comments:

GLOSSARY

Active Channel Stage: The active channel or ordinary high water level is an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence on the landscape, such as the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial or the bank elevation at which the cleanly scoured substrate of the stream ends and terrestrial vegetation begins (Figure IX-3 and IX-4).

Anadromous Fish: Fish that migrate from the ocean into freshwater to breed. Includes salmon and steelhead trout, as well as several other species of fish.

Apron: A hardened surface (usually concrete or grouted riprap) placed at either the invert of the culvert inlet or outlet to protect structure from scour and storm damage. Aprons often are migration barriers because flow is often shallow with high velocities. Aprons at outlet may also create turbulence and increase stream power that often down cuts the channel, resulting in perched outlets and/or de-stabilized streambanks.

Baffles: Wood, concrete or metal panels mounted in a series on the floor and/or wall of a culvert to increase boundary roughness and thereby reduce the average water velocity in the culvert.

Bankfull Stage: Corresponds to the stage at which channel maintenance is most effective, that is, the discharge at which the stream is moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels. The bankfull stage is most effective or is the dominate channel-forming flow, and has a recurrence interval of 1.5 years (Dunne & Leopold 1978) (Figures IX-3 and IX-4).

Bedload: Sand, silt, and gravel, or soil and rock debris rolled along the bottom of a stream by the moving water. The particles of this material have a density or grain size which prevents movement far above or for a long distance out of contact with the streambed under natural flow conditions.

Bottomless-arch: A type of culvert with rounded sides and top attached to concrete or steel footings set below stream grade. The natural stream channel and substrate run through the length of the culvert, providing streambed conditions similar to the actual stream channel.

Breaks-in-slope: Steeper sections within a culvert. As culverts age they often sag when road fills slump. *FishXing* is able to model changes in velocity created by varying slopes within several culvert sections.

CFS: Cubic feet per second.

Corrugations: Refers to the undulations present in CSP and SSP culvert material. Corrugations provide surface roughness which increases over the width and depth of standard dimensions.

CSP: Corrugated steel pipe. Pipe diameter is comprised of a single sheet of material.

Culvert: A specific type of stream crossing, used generally to convey water flow through the road prism base. Typically constructed of either steel, aluminum, plastic, or concrete. Shapes include circular, oval, squashed-pipe (flat floor), bottomless-arch, square, or rectangular (Figure IX-10).

Culvert Entrance: The downstream end of a culvert through which fish enter to pass upstream.

Culvert Exit: The upstream end of a culvert through which a fish exit to pass upstream.

Culvert Inlet: The upsteam end of a culvert through which stream flow enters.

Culvert Outlet: The downstream end of a culvert through which stream flow discharges.

Embedment: The depth to which a culvert bottom is buried into the streambed. It is usually expressed as a percentage of the culvert height or diameter.

Exceedance Flow: n percent exceedance flow is the flow that is equaled or exceeded n percent of the time.

Fish Passage: The ability of both adult and juvenile fish to move both up and down stream.

Fishway: A structure for passing fish over vertical impediments. It may include special attraction devices, entrances, collection and transportation channels, a fish ladder, and exit.

FishXing: A computer software program developed by the Six Rivers National Forest Watershed Interactions Team. *FishXing* models culvert hydraulics (including open-bottom structures) and compares the predicted values with data regarding swimming and leaping abilities and minimum water depth requirements for numerous fish species.

Flood Frequency: The frequency with which a flood of a given discharge has the probability of recurring. For example, a "100-year" frequency flood refers to a flood discharge of a magnitude likely to occur on the average of once every 100 years or, more properly, has a one-percent chance of being exceeded in any year. Although calculation of possible recurrence is often based on historical records, there is no guarantee that a "100-year" flood will occur at all within the 100-year period or that it will not recur several times.

Floodplain: The area adjacent to the stream constructed by the river in the present climate and inundated during periods of high flow.

Flood Prone Zone: Spatially, this area generally corresponds to the modern floodplain, but can also include river terraces subject to significant bank erosion. For delineation, see definition for floodplain.

Flow Duration (or Annual Exceedance Flow): A flow duration curve describes the natural flow characteristics of a stream by showing the percentage of time that a flow is equal to or greater than a given value during a specified period (annual, month, or migration period). Flow exceedance values are important for describing the flow conditions under which fish passage is required.

Gradient Control Weirs: Stabilizing weirs constructed in the streambed to prevent lowering of the channel bottom.

Hydraulic Capacity: The maximum amount of flow (in cfs) that a stream crossing can convey at 100 percent of inlet height.

Hydraulic Controls: Weirs constructed primarily of rocks or logs, in the channel below a culvert for the purpose of controlling water depth and water velocity within the crossing.

Hydraulic Jump: An abrupt transition in streamflow from shallow and fast (supercritical flow) to deep and slow (subcritical flow).

Inlet: Upstream entrance to a culvert.

Inlet Invert: Location at inlet, on the culvert floor where an elevation is measured to calculate culvert slope.

Invert: Lowest point of the crossing.

Maximum Average Water Velocity in Culvert: The highest average water velocity for any cross-section along the length of the culvert, excluding the effects of water surface drawdown at the culvert outlet.

Outlet: Downstream opening of a culvert.

Outlet Invert: Location at outlet, on the culvert floor, where an elevation is measured to calculate culvert slope.

Ordinary High Water Mark: The mark along the bank or shore up to which the presence and action of the water are common and usual, and so long continued in all ordinary years, as to leave a natural line impressed on the bank or shore and indicated by erosion, shelving, changes in soil characteristics, destruction of terrestrial vegetation, or other distinctive physical characteristics.

Passage Flow: Migration flows.

Peak Flow: One-hundred year flow event.

Perched Outlet: A condition in which a culvert outlet is suspended over the immediate downstream pool, requiring a migrating fish to leap into culvert.

Pipe-arch: A type of culvert with a flat floor and rounded sides and top, usually created by shaping or squashing a circular CSP or SSP pipe.

Q_{hp}: Stream discharge (in cfs) at high passage flow. For adult salmonids, in California defined as the 1 percent exceedance flow (the flow equaled or exceeded 1 percent of the time) during the period of expected migration.

Q_{lp}: Stream discharge (in cfs) at low passage flow. For adult salmonids, in California defined as the 90 percent exceedance flow for the migration period.

Recurrence Interval: Also referred to as flood frequency, or return period. It is the average time interval between actual occurances of a hydrological event of a given or greater magnitude. A flood event with a two-year recurrence interval has a 50 percent chance of occurring in any given year.

Roads: For purposes of these guidelines, roads include all sites of intentional surface disturbance for the purpose of vehicular or rail traffic and equipment use, including all surfaced and unsurfaced roads, temporary roads, closed and inoperable roads, legacy roads, skid trails, tractor roads, layouts, landings, turnouts, seasonal roads, fire lines, and staging areas.

Riffle Crest: See "tailwater control".

Salmonids: A taxonomic group of fish that includes salmon and steelhead trout, among others.

Section 10 and 404 Regulatory Programs: The principal federal regulatory programs, carried out by the US Army Corps of Engineers, affecting structures and other work below mean high water. The Corps, under Section 10 of the River and Harbor Act of 1899, regulates structures in, or affecting, navigable waters of the US as well as excavation or deposition of materials (e.g., dredging or filling) in navigable waters. Under Section 404 of the Federal Water Pollution Control Act Amendments (Clean Water Act of 1977), the Corps is also responsible for evaluating application for Department of the Army permits for any activities that involve the placement of dredged or fill material into waters of the United States, including adjacent wetlands.

SSP: Structural steel plate. Pipe diameter is comprised of multiple sheets of material which are usually bolted together.

Stream Crossing: Any human-made structure generally used for transportation purposes that crosses over or through a stream channel including a paved road, unpaved road, railroad track, biking or hiking trail, golf-cart path, or low-water ford. A stream crossing encompasses the structure employed to pass stream flow as well as associated fill material within the crossing prism.

Supercritical Flow: Fast and shallow flowing water that is usually associated with a hydraulically steep, smooth surface.

Tailwater Control: The channel feature which influences the water surface elevation immediately downstream of the culvert outlet. The location controlling the tailwater elevation is often located at the riffle crest immediately below the outlet pool. Tailwater control is also the channel elevation that determines residual pool depth.

Thalweg: The line connecting the lowest or deepest points along a streambed.

Waters of the United States: Currently defined by regulation to include all navigable and interstate waters, their tributaries and adjacent wetlands, as well as isolated wetlands and lakes and intermittent streams.

Weir: a) A notch or depression in a levee, dam, embankment, or other barrier across or bordering a stream, through which the flow of water is measured or regulated; b) A barrier constructed across a stream to divert fish into a trap; c) A dam (usually small) in a stream to raise the water level or divert its flow.

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APPENDIX IX-A

STATE OF CALIFORNIA RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

CULVERT CRITERIA FOR FISH PASSAGE

For habitat protection, ecological connectivity should be a goal of stream-road crossing designs. The narrowest scope of crossing design is to pass floods. The next level is requiring fish passage. The next level includes sizing the crossing for sediment and debris passage. For ecosystem health, "ecological connectivity" is necessary Ecological connectivity includes fish, sediment, debris, other organisms and channel/floodplain processes.

Ken Bates – WDFW

INTRODUCTION

The following criteria have been adopted by the California Department of Fish and Game (DFG) to provide for upstream fish passage at culverts. This is not a culvert design manual, rather it is supplemental criteria to be used by qualified professionals for the design of culverts that meet both hydraulic and fish passage objectives while minimizing impacts to the adjacent aquatic and riparian resources. The objective of these criteria is to provide unimpaired fish passage with a goal of providing ecological connectivity.

Previous versions of the DFG Culvert Criteria were based on hydraulic design of culverts to match the swimming performance of adult anadromous salmonids. This revision of the criteria has been expanded to include considerations for juvenile anadromous salmonids, non-anadromous salmonids, native non-salmonids, and non-native fish. While criteria are still included for the hydraulic design option, criteria have been added for two additional design options that are based on the principles of ecological connectivity. The two additional design methods are:

- Active Channel Option
- Stream Simulation Option

The criteria contained in this document are based on the works of several organizations including state and federal agencies, universities, private organizations and consulting professionals. These criteria are intended to be consistent with the National Oceanic and Atmospheric Administration Fisheries, Southwest Region (NOAA-SWR) *Guidelines for Salmonid Passage at Stream Crossings*, as well as being in general agreement with Oregon and Washington Departments of Fish and Wildlife culvert criteria for fish passage. This document is considered a "Work in Progress" and will be revised as new information warrants.

The Caltrans Highway Design Manual defines a culvert as "A closed conduit which allows water to pass under a highway," and in general, has a single span of less than 6.1 meters (20 feet) or multiple spans totaling less than 6.1 meters. For the purpose of fish passage, the distinction between bridge, culvert or low water crossing is not as important as the effect the structure has on the form and function of the stream. To this end, these criteria conceptually apply to bridges and low water crossings, as well as culverts.

The primary factors that determine the extent to which fish passage will be impacted by the construction of a crossing are:

- The degree of constriction the crossing has on the stream channel
- The degree to which the streambed is allowed to adjust to vertically
- The length of stream channel impacted by the crossing
- The degree to which the stream velocity has been increased by the crossing.

For unimpaired fish passage, it is desirable to have a crossing that is a large percentage of the channel bankfull width, allows for a natural variation in bed elevation, and provides bed and bank roughness similar to the upstream and downstream channel.

In general, bridges are preferred over culverts because they typically do not constrict a stream channel to as great a degree as culverts and usually allow for vertical movement of the streambed. Bottomless culverts may provide a good alternative for fish passage where foundation conditions allow their construction and width criteria can be met. In all cases, the vertical and lateral stability of the stream channel should be taken into consideration when designing a crossing.

APPLICATION OF CRITERIA

These criteria are intended to apply to new and replacement culverts where fish passage is legally mandated or is otherwise important to the life histories of the fish and wildlife that utilize the stream and riparian corridor. Not all stream crossings may be required to provide upstream fish passage, and of those that do, some may only require passage for specific species and age classes of fish.

Where existing culverts are being modified or retrofitted to improve fish passage, the Hydraulic Design Option criteria should be the design objective for the improvements. However, it is acknowledged that the conditions that cause an existing culvert to impair fish passage may also limit the remedies for fish passage improvement. Therefore, short of culvert replacement, the Hydraulic Design Option criteria should be the goal for improvement and not the required design threshold.

To determine the biological considerations and applicable criteria for a particular culvert site, the project sponsors should contact the Department of Fish and Game, the National Oceanic and Atmospheric Administration Fisheries (for projects in marine and anadromous waters) and the US Fish and Wildlife Service (for projects in anadromous and fresh waters) for guidance.

It is the responsibility of the project sponsor to obtain the most current version of the culvert criteria for fish passage. Copies of the current criteria are available from the Department of Fish and Game through the appropriate Regional office, which should be the first point of contact for any stream crossing project. Addresses and phone numbers for the California Department of Fish and Game Regional Offices are shown in Table IX A-1.

California Dept. of Fish and Game Regional Offices		
Region	**Address**	**Phone Number**
Northern California -North Coast Region	601 Locust Street Redding, CA 96001	(530) 225-2300
Sacramento Valley -Central Sierra Region	1701 Nimbus Drive Rancho Cordova, CA 95670	(916) 358-2900
Central Coast Region	7329 Silverado Trail P.O. Box 47 Yountville, CA 94599	(707) 944-5500
San Joaquin Valley - Southern Sierra Region	1234 E. Shaw Avenue Fresno, CA 93710	(559) 243-4005 x151
South Coast Region	4649 Viewridge Avenue San Diego, CA 92123	(858) 467-4200
Eastern Sierra - Inland Deserts Region	4775 Bird Farm Road Chino Hills, CA 9709	(909) 597-9823

Table IX-A- 1. California Department of Fish and Game regional offices.

DESIGN OPTIONS

All culverts should be designed to meet appropriate hydraulic capacity and structural integrity criteria. In addition, where fish passage is required, the culvert shall be designed to meet the criteria of the Active Channel Design Option, Stream Simulation Design Option or the Hydraulic Design Option for Upstream Fish Passage. The suitability of each design option is shown in Table IX-A-2.

Allowable Design Options			
Fish Passage Requirement	**Active Channel Design Option or Stream Simulation Design Option**	**Hydraulic Design Option For Upstream Fish Passage**	**Hydraulic Capacity & Structural Integrity**
Adult Anadromous Salmonids	X	X	
Adult Non-Anadromous Salmonids	X	X	
Juvenile Salmonids	X	X	
Native Non-Salmonids	X	Conditional based on species swimming data	
Non-Native Species	X		
Fish Passage Not Required	X		X

Table IX-A- 2. Suitability design options.

Active Channel Design Option

The Active Channel Design Option (Figure IX-A-1) 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 bedload 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 less than 3 percent
- Short culvert length (less than 100 feet)
- Passage required for all fish.

Culvert Setting & 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 percent slope).

Embedment - The bottom of the culvert shall be buried into the streambed not less than 20 percent of the culvert height at the outlet and not more than 40 percent of the culvert height at the inlet.

Embedment does not apply to bottomless culverts.

See section on Considerations, Conditions, and Restrictions for all design options.

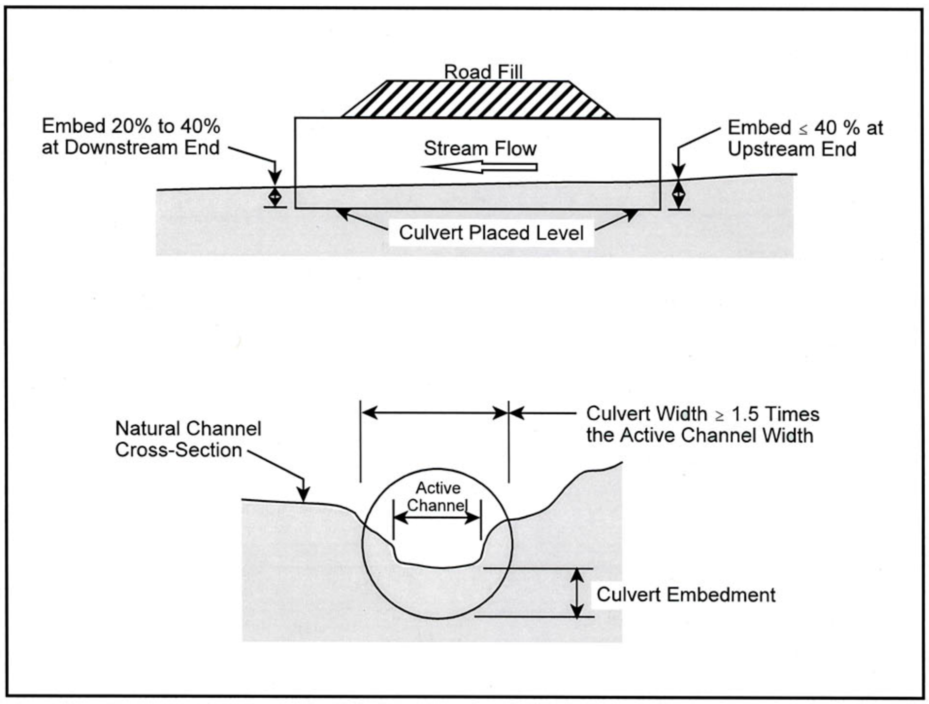

Figure IX-A-1. Active channel design option.

Stream Simulation Design Option

The Stream Simulation Design Option (Figure IX-A-2) 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 design flows, water velocity, and water depth is not required for this options since the stream hydraulic characteristics within the culvert are designed to mimic the stream conditions upstream and downstream of the crossing.

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 percent
- Moderate to long culvert length (greater than 100 feet)
- Passage required for all fish
- Ecological connectivity required.

Culvert Setting & 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 6 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 percent.

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

Substrate Configuration and Stability

- Culverts with slopes greater than 3 percent shall have the bed inside the culvert arranged into a series of step-pools with the drop at each step not exceeding the limits shown in Table IX-A-7.
- Smooth walled culverts with slopes greater than 3 percent 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.

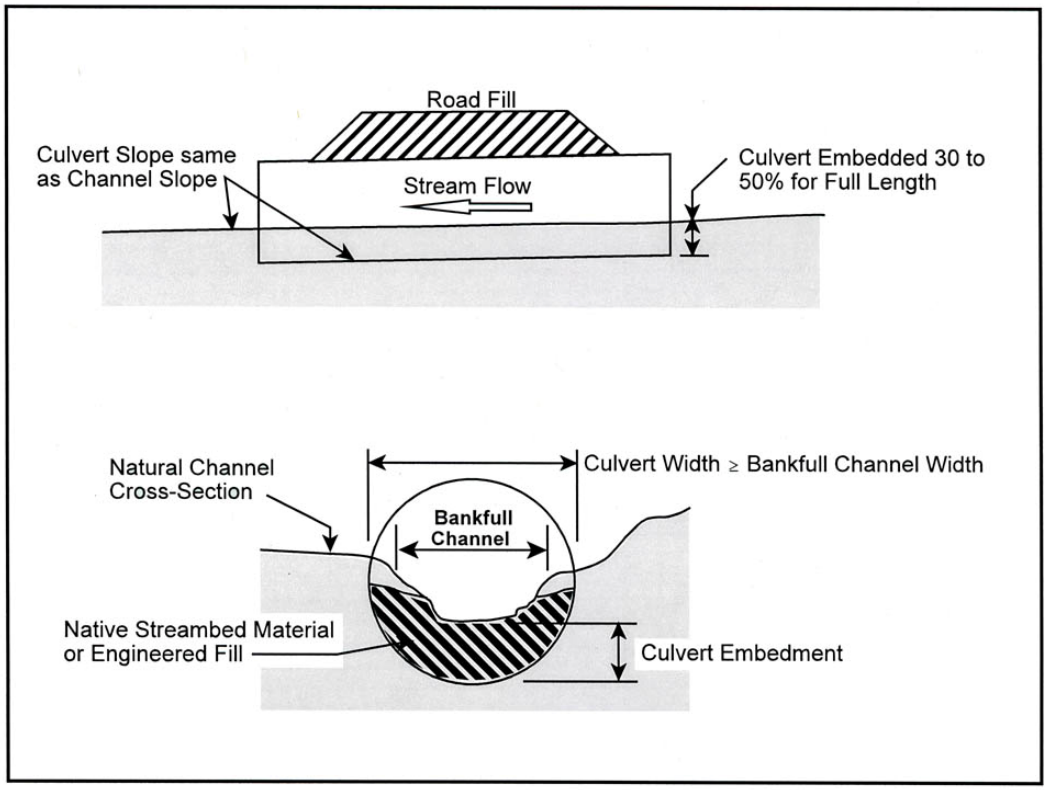

Figure IX-A- 2 Stream simulation design option.

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. This method targets distinct species of fish, therefore it 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 percent)
- Active Channel Design or Stream Simulation Options is not physically feasible
- Swimming ability and behavior of target species of fish is known
- Ecological connectivity not required
- Evaluation of proposed improvements to existing culverts.

HYDROLOGY

High Design Flow for Fish Passage

The high design flow for fish passage is used to determine the maximum water velocity within the culvert. Where flow duration data is available or can be synthesized, use the values for Percent Annual Exceedance Flow shown in Table IX-A-3. If flow duration data is not available the values shown for Percentage of 2-year Recurrence Interval Flow may be used as an alternative.

High Design Flow for Fish Passage		
Species/Life Stage	**Percent Annual Exceedance Flow**	**Percentage of 2-year Recurrence Interval Flow**
Adult Anadromous Salmonids	1%	50%
Adult Non-Anadromous Salmonids	5%	30%
Juvenile Salmonids	10%	10%
Native Non-Salmonids	5%	30%
Non-Native Species	10%	10%

Table IX-A- 3. High design flow for fish passage.

Low Design Flow for Fish Passage

The low design flow for fish passage is used to determine the minimum depth of water within a culvert. Where flow duration data is available or can be synthesized, use the values for Percent Annual Exceedance Flow shown in Table IX-A-4. If the Percent Annual Exceedance Flow is determined to be less than the Alternate Minimum Flow, use the Alternate Minimum Flow. If flow duration data is not available, the values shown for Alternate Minimum Flow may be used.

Low Design Flow for Fish Passage		
Species/Lifestage	**Percent Annual Exceedance Flow**	**Alternate Minimum Flow (cfs)**
Adult Anadromous Salmonids	50%	3
Adult Non-Anadromous Salmonids	90%	2
Juvenile Salmonids	95%	1
Native Non-Salmonids	90%	1
Non-Native Species	90%	1

Table IX-A- 4. Low design flow for fish passage.

Hydraulics

Maximum Average Water Velocity in Culvert (At high design flow) - Where fish passage is required, the maximum average water velocity within the culvert shall not exceed the values shown in Tables IX-A-5 and IX-A-6.

Minimum Water Depth in Culvert (At low design flow) - Where fish passage is required, the minimum water depth within the culvert shall not be less than the values shown in Table IX-A-5.

Species/Lifestage	Maximum Average Water Velocity (fps)	Minimum Flow Depth (ft)
Adult Anadromous Salmonids	See Table 6	1.0
Adult Non-Anadromous Salmonids	See Table 6	0.67
Juvenile Salmonids	1	0.5
Native Non-Salmonids	Species specific swimming performance data is required for the use of the hydraulic design option for non-salmonids. Hydraulic design is not allowed for these species without this data.	
Non-Native Species		

Table IX-A- 5. Maximum average water velocity and minimum depth of flow.

Culvert Length (ft)	Adult Non-Anadromous Salmonids (fps)	Adult Anadromous Salmonids (fps)
<60	4	6
60-100	4	5
100-200	3	4
200-300	2	3
>300	2	2

Table IX-A- 6. Culvert length vs. maximum average water velocity for adult salmonids.

Maximum Outlet Drop - Hydraulic drops between the water surface in the culvert to the pool below the culvert should be avoided for all cases. Where fish passage is required and a hydraulic drop is unavoidable, its magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown in Table IX-A-7. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Lifestage	Maximum Drop (ft)
Adult Anadromous Salmonids	1
Adult Non-Anadromous Salmonids	1
Juvenile Salmonids	0.5
Native Non-Salmonids	Where fish passage is required for native non-salmonids, no hydraulic drop shall be allowed at the culvert outlet unless data is presented which will establish the leaping ability and leaping behavior of the target species of fish.
Non-Native Species	

Table IX-A- 7. Maximum drop at culvert outlet.

Hydraulic Controls - Hydraulic controls in the channel upstream and/or downstream of a crossing can be used to provide a continuous low flow path through the crossing and stream reach. They can be used to facilitate fish passage by establishing the following desirable conditions:

- Control depth and water velocity within the crossing
- Concentrate low flows
- Provide resting pools upstream and downstream of the crossing
- Control erosion of the streambed and banks.

Baffles - Baffles shall not be used in the design of new or replacement culverts in order to meet the hydraulic design criteria.

Adverse Hydraulic Conditions - The following hydraulic conditions are generally considered to be detrimental to efficient fish passage and should be avoided. The degree to which they impede fish passage depends upon the magnitude of the condition. Crossings designed by the Hydraulic Design Option should be evaluated for the following conditions at high design flow for fish passage:

- Super critical flow
- Hydraulic jumps
- Highly turbulence conditions
- Abrupt changes in water surface elevation at inlet and outlet.

Culvert Setting & Dimensions

Culvert Width - The minimum culvert width shall be 3 feet.

Culvert Slope - The culvert slope shall not exceed the slope of the stream through the reach in which the crossing is being placed. If embedment of the culvert is not possible, the maximum slope shall not exceed 0.5 percent.

Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20 percent of the height of the culvert below the elevation of the tailwater control point downstream of the culvert. The minimum embedment should be at least 1 foot. Where physical conditions preclude embedment, the hydraulic drop at the outlet of a culvert shall not exceed the limits specified above.

CONSIDERATIONS, CONDITIONS, AND RESTRICTIONS FOR ALL DESIGN OPTIONS

Anadromous Salmonid Spawning Areas

The hydraulic design method shall not be used for new or replacement culverts in anadromous salmonid spawning areas.

High Design Flow for Structural Integrity

All culvert stream crossings, regardless of the design option used, shall be designed to withstand the 100-year peak flood flow without structural damage to the crossing. The analysis of the structural integrity of the crossing shall take into consideration the debris loading likely to be encountered during flooding.

Headwater Depth

The upstream water surface elevation shall not exceed the top of the culvert inlet for the 10-year peak flood and shall not be greater than 50 percent of the culvert height or diameter above the top of the culvert inlet for the 100-year peak flood.

Oversizing for Debris

In some cases, it may be necessary to increase the size of a culvert beyond that calculated for flood flows or fish passage in order to pass flood-borne debris. Where there is significant risk of inlet plugging by flood borne debris, culverts should be designed to pass the 100-year peak flood without exceeding the top of the culvert inlet. Oversizing for flood-borne debris may not be necessary if a culvert maintenance agreement has been effected and the culvert inlet can be safely accessed for debris removal under flood flow conditions.

Inlet Transitions

A smooth hydraulic transition should be made between the upstream channel and the culvert inlet to facilitate passage of flood borne debris.

Interior Illumination

Natural or artificial supplemental lighting shall be provided in new and replacement culverts that are over 150 feet in length. Where supplemental lighting is required, the spacing between light sources shall not exceed 75 feet.

Adverse Conditions to be Avoided

- Excessive skew with stream alignment
- Changes in alignment within culvert
- Trash racks and livestock fences
- Realignment of the natural stream channel.

Multiple Culverts

Multiple culverts are discouraged where the design criteria can be met with a single culvert. If multiple culverts are necessary, a multi-barreled box culvert is preferred over multiple individual culverts. Site-specific criteria may apply to multiple culvert installations.

Bottomless Culverts

Bottomless culverts are generally considered to be a good solution where fish passage is required, so long as culvert width criteria are met and the culvert footings are deep enough to avoid scour exposure. Site-specific criteria may apply to bottomless culverts installations.

CULVERT RETROFITS FOR FISH PASSAGE

Culverts that have fish passage problems were generally designed with out regard for fish passage. While these culverts may convey stream flow, they are often undersized for the watershed hydrology, stream fluvial processes, have been placed at a slope that is too steep for fish passage, or have had the outlet raised above the channel bed in order to control the water velocity in the culvert. Most of these problems arise from the culvert being undersized. For undersized culverts it is difficult, if not impossible, to meet the objective of unimpaired fish passage without replacing the culvert. However, in many cases, fish passage can be significantly improved for some species and their life stages without fully meeting the hydraulic criteria for new culverts. In some cases a modest improvement in hydraulic conditions can result in a significant improvement in fish passage.

Where existing culverts are being modified or retrofitted to improve fish passage, the Hydraulic Design Option criteria should be the design objective for improvements. However, it is acknowledged that the conditions that cause an existing culvert to impair fish passage may also limit the remedies for fish passage improvement. Therefore, short of culvert replacement, the Hydraulic Design Option criteria should be the goal for improvement and not the required design threshold.

A protocol for fish passage evaluation at existing culverts is included in the Department of Fish and Game's *California Salmonid Stream Habitat Restoration Manual*. This manual also includes information methods for improving fish passage at road crossings.

Fish passage through existing non-embedded culverts may be improved through the use of gradient control weirs upstream or downstream of the culvert, interior baffles or weirs, or in some cases, fish ladders. However, these measures are not a substitute for good fish passage design for new or replacement culverts.

Gradient Control Weirs

- Downstream Channel - Control weirs can be used in downstream channel to backwater through culvert or reduce an excessive hydraulic drop at a culvert outlet. The maximum drop at the culvert outlet shall not exceed the values in Table IX-A-7.
- Upstream Channel - Control weirs can be used in the channel upstream of the culvert inlet to re-grade the bed slope and improve exit conditions.
- Hydraulic Drop - The individual hydraulic drop across a single control weir shall not exceed the values in Table IX-A-7, except that boulder weirs may drop 1 foot per weir for all salmonids, including juveniles.

Baffles

Baffles may provide incremental fish passage improvement in culverts with excess hydraulic capacity that cannot be made passable by other means. Baffles may increase clogging and debris accumulation within the culvert and require special design considerations specific to the baffle type.

Fishways

Fishways are generally not recommended, but may be useful for some situations where excessive drops occur at the culvert outlet. Fishways require specialized site-specific design for each installation.

SELECT REFERENCES AND INTERNET WEB SITES

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APPENDIX IX-B

National Oceanic and Atmospheric Administration Fisheries
Southwest Region

GUIDELINES FOR SALMONID PASSAGE AT STREAM CROSSINGS

INTRODUCTION

This document provides guidelines for design of stream crossings to aid upstream and downstream passage of migrating salmonids. It is intended to facilitate the design of a new generation of stream crossings, and assist the recovery of threatened and endangered salmon species. These guidelines are offered by the National Oceanic and Atmospheric Administration Fisheries, Southwest Region (NOAA-SWR), as a result of its responsibility to prescribe fishways under the Endangered Species Act, the Magnuson-Stevens Act, the Federal Power Act, and the Fish and Wildlife Coordination Act. The guidelines apply to all public and private roads, trails, and railroads within the range of anadromous salmonids in California.

Stream crossing design specifications are based on the previous works of other resource agencies along the US West Coast. They embody the best information on this subject at the time of distribution. Meanwhile, there is mounting evidence that impassable road crossings are taking a more significant toll on endangered and threatened fish than previously thought. New studies are revealing evidence of the pervasive nature of the problem, as well as potential solutions. Therefore, this document is appropriate for use until revised, based on additional scientific information, as it becomes available.

The guidelines are general in nature. There may be cases where site constraints or unusual circumstances dictate a modification or waiver of one or more of these design elements. Conversely, where there is an opportunity to protect salmonids, additional site-specific criteria may be appropriate. Variances will be considered by the NOAA on a project-by-project basis. When variances from the technical guidelines are proposed, the applicant must state the specific nature of the proposed variance, along with sufficient biological and/or hydrologic rationale to support appropriate alternatives. Understanding the spatial significance of a stream crossing in relation to salmonid habitat within a watershed will be an important consideration in variance decisions.

Protocols for fish-barrier assessment and site prioritization are under development by the California Department of Fish and Game (DFG). These will be available in updated versions of the *California Salmonid Stream Habitat Restoration Manual*. Most streams in California also support important populations of non-salmonid fishes, amphibians, reptiles, macroinvertebrates, insects, and other organisms important to the aquatic food web. Some of these may also be threatened or endangered species and require "ecological connectivity" that dictate other design criteria not covered in this document. Therefore, the project applicant should check with the local Fish and Game office, the US Fish and Wildlife Service (USFWS), and/or tribal biologists to ensure other species are fully considered.

The California Department of Transportation Highway Design Manual defines a culvert as "A closed conduit which allows water to pass under a highway," and in general, has a single span of less than 20 feet or multiple spans totaling less than 20 feet. For the purpose of fish passage, the distinction between bridge, culvert or low water crossing is not as important as the effect the structure has on the form and function of the stream. To this end, these criteria conceptually apply to bridges and low water crossings, as well as culverts.

PREFERRED ALTERNATIVES AND CROSSINGS

The following alternatives and structure types should be considered in order of preference:

- Nothing - Road realignment to avoid crossing the stream
- Bridge - spanning the stream to allow for long term dynamic channel stability
- Streambed simulation strategies - bottomless arch, embedded culvert design, or ford
- Non-embedded culvert - this is often referred to as a hydraulic design, associated with more traditional culvert design approaches limited to low slopes for fish passage
- Baffled culvert, or structure designed with a fishway - for steeper slopes.

If a segment of stream channel where a crossing is proposed is in an active salmonid spawning area then only full span bridges or streambed simulations are acceptable.

DESIGNING NEW AND REPLACEMENT CULVERTS

The guidelines below are adapted from culvert design criteria published by many federal and state organizations including the California Department of Fish and Game (DFG 2002). It is intended to apply to new and replacement culverts where fish passage is legally mandated or important.

Active Channel Design Method

The Active Channel Design method is a simplified design that is intended to size a culvert sufficiently large and embedded deep enough into the channel to allow the natural movement of bedload 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 method since the stream hydraulic characteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. This design method is usually not suitable for stream channels that are greater than 3 percent in natural slope or for culvert lengths greater than 100 feet. Structures for this design method are typically round, oval, or squashed pipes made of metal or reinforced concrete.

- 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 percent slope).
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 20 percent of the culvert height at the outlet and not more than 40 percent of the culvert height at the inlet.

Stream Simulation Design Method

The Stream Simulation Design method 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 culvert are intended to function as they would in a natural channel. 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 designed to mimic the stream conditions upstream and downstream of the crossing. The structures for this design method are typically open bottomed arches or boxes but could have buried floors in some cases. These culverts contain a streambed mixture that is similar to the adjacent stream channel. Stream simulation culverts require a greater level of information on hydrology and geomorphology (topography of the stream channel) and a higher level of engineering expertise than the Active Channel Design method.

- 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 6 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 percent.
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 30 percent and not more than 50 percent of the culvert height. For bottomless culverts the footings or foundation should be designed for the largest anticipated scour depth.

Hydraulic Design Method

The Hydraulic Design method 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. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species. There are significant errors associated with estimation of hydrology and fish swimming speeds that are resolved 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 method 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 method can be applied to the design of new and replacement culverts and can be used to evaluate the effectiveness of retrofits of existing culverts.

- Culvert Width - The minimum culvert width shall be 3 feet.
- Culvert Slope - The culvert slope shall not exceed the slope of the stream through the reach in which it is being placed. If embedment of the culvert is not possible, the maximum slope shall not exceed 0.5 percent.
- Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20 percent of the height of the culvert below the elevation of the tailwater control point downstream of the culvert. The minimum embedment should be at least 1 foot. Where physical conditions

preclude embedment, the hydraulic drop at the outlet of a culvert shall not exceed the limits specified above.

Hydrology for Fish Passage under the Hydraulic Design Method

High Flow Design For Fish Passage - The high flow design for adult fish passage is used to determine the maximum water velocity within the culvert. Where flow duration data is available or can be synthesized the high fish passage design flow for adult salmonids should be the 1 percent annual exceedance. If flow duration data or methods necessary to compute them are not available then 50 percent of the 2 year flood recurrence interval flow may be used as an alternative. Another alternative is to use the discharge occupied by the cross-sectional area of the active stream channel. This requires detailed cross-section information for the stream reach and hydraulic modeling. For upstream juvenile salmonid passage the high design flow should be the 10 percent annual exceedance flow.

Low Flow Design For Fish Passage - The low flow design for fish passage is used to determine the minimum depth of water within a culvert. Where flow duration data is available or can be synthesized the 50 percent annual exceedance flow or 3 cfs, whichever is greater, should be used for adults and the 95 percent annual exceedance flow or 1 cfs, whichever is greater, should be used for juveniles.

Maximum Average Water Velocities in the Culvert at the High Fish Passage Design Flow

Average velocity refers to the calculated average of velocity within the barrel of the culvert. Juveniles require 1 fps or less for upstream passage for any length culvert at their High Fish Passage Design Flow. For adult salmonids use the following table to determine the maximum velocity allowed.

Culvert Length (ft)	Velocity (fps) - Adult Salmonids
<60	6
60-100	5
100-200	4
200-300	3
>300	2

Table IX-B- 1. Water velocity for culvert length.

Minimum Water Depth at the Low Fish Passage Design Flow

For non-embedded culverts, minimum water depth shall be twelve inches for adult steelhead trout and salmon, and six inches for juvenile salmon.

Juvenile Upstream Passage

Hydraulic design for juvenile upstream passage should be based on representative flows in which juveniles typically migrate. Recent research (NOAA 2001, in progress) indicates that providing for juvenile salmon up to the 10 percent annual exceedance flow will cover the majority of flows in which juveniles have been observed moving upstream. The maximum average water velocity at this flow should not exceed 1 fps. In some cases, over short distances, 2 fps may be allowed.

Maximum Hydraulic Drop

Hydraulic drops between the water surface in the culvert and the water surface in the adjacent channel should be avoided for all cases. This includes the culvert inlet and outlet. Where a hydraulic drop is unavoidable, its magnitude should be evaluated for both high design flow and low design flow and shall not exceed 1 foot for adults or 6 inches for juveniles. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth should be provided.

Structural Design and Flood Capacity

All culvert stream crossings, regardless of the design option used, shall be designed to withstand the 100-year peak flood flow without structural damage to the crossing. The analysis of the structural integrity of the crossing shall take into consideration the debris loading likely to be encountered during flooding. Stream crossings or culverts located in areas where there is significant risk of inlet plugging by flood borne debris should be designed to pass the 100-year peak flood without exceeding the top of the culvert inlet (Headwater-to-Diameter Ratio less than one). This is to ensure a low risk of channel degradation, stream diversion, and failure over the life span of the crossing. Hydraulic capacity must be compensated for expected deposition in the culvert bottom.

Other Hydraulic Considerations

Besides the upper and lower flow limit, other hydraulic effects need to be considered, particularly when installing a culvert:

- Water surface elevations in the stream reach must exhibit gradual flow transitions, both upstream and downstream.
- Abrupt changes in water surface and velocities must be avoided, with no hydraulic jumps, turbulence, or drawdown at the entrance.
- A continuous low flow channel must be maintained throughout the entire stream reach.

In addition, especially in retrofits, hydraulic controls may be necessary to provide resting pools, concentrate low flows, prevent erosion of streambed or banks, and allow passage of bedload material.

Culverts and other structures should be aligned with the stream, with no abrupt changes in flow direction upstream or downstream of the crossing. This can often be accommodated by changes in road alignment or slight elongation of the culvert. Where elongation would be excessive, this must be weighed against better crossing alignment and/or modified transition sections upstream and downstream of the crossing. In crossings that are unusually long compared to streambed width, natural sinuosity of the stream will be lost and sediment transport problems may occur even if the slopes remain constant. Such problems should be anticipated and mitigated in the project design.

RETROFITTING CULVERTS

For future planning and budgeting at the state and local government levels, redesign and replacement of substandard stream crossings will contribute substantially to the recovery of salmon stocks throughout the state. Unfortunately, current practices do little to address the problem: road crossing corrections are usually made by some modest level of incremental, low cost “improvement” rather than re-design and replacement. These usually involve bank or structure stabilization work, but frequently fail to address fish passage. Furthermore, bank stabilization using hard point techniques frequently denigrates the habitat quality and natural features of a stream. Nevertheless, many existing stream crossings can be made better for fish passage by cost-effective means. The extent of the needed fish passage improvement work depends on the severity of fisheries impacts, the remaining life of the structure, and the status of salmonid stocks in a particular stream or watershed.

For work at any stream crossing, site constraints need to be taken into consideration when selecting options. Some typical site constraints are ease of structure maintenance, construction windows, site access, equipment, and material needs and availability. The decision to replace or improve a crossing should fully consider actions that will result in the greatest net benefit for fish passage. If a particular stream crossing causes substantial fish passage problems which hinder the conservation and recovery of salmon in a watershed, complete redesign and replacement is warranted. *Consolidation and/or decommissioning of roads can sometimes be the most cost-effective option*. Consultations with NOAA or DFG biologists can help in selecting priorities and alternatives.

Where existing culverts are being modified or retrofitted to improve fish passage, the Hydraulic Design method criteria should be the design objective for the improvements. However, it is acknowledged that the conditions that cause an existing culvert to impair fish passage may also limit the remedies for fish passage improvement. Therefore, short of culvert replacement, the Hydraulic Design method criteria should be the goal for improvement but not necessarily the required design threshold.

Fish passage through existing non-embedded culverts may be improved through the use of gradient control weirs upstream or downstream of the culvert, interior baffles or weirs, or in some cases, fish ladders. However, these measures are not a substitute for good fish passage design for new or replacement culverts. The following guidelines should be used:

- Hydraulic Controls - Hydraulic controls in the channel upstream and/or downstream of a culvert can be used to provide a continuous low flow path through culvert and stream reach. They can be used to facilitate fish passage by establishing the following desirable conditions: Control depth and water velocity within culvert, concentrate low flows, provide resting pools upstream and downstream of culvert and prevent erosion of bed and banks. A change in water surface elevation of up to one foot is acceptable for adult passage conditions, provided water depth and velocity in the culvert meet other hydraulic guidelines. A jump pool must be provided that is *at least* 1.5 times the jump height, or a minimum of two feet deep, whichever is deeper.
- Baffles - Baffles may provide incremental fish passage improvement in culverts with excess hydraulic capacity that cannot be made passable by other means. Baffles may increase clogging and debris accumulation within the culvert and require special design considerations specific to the baffle type. Culverts that are too long or too high in gradient require resting pools, or other forms of velocity refuge spaced at increments along the culvert length.
- Fishways - Fishways are generally not recommended, but may be useful for some situations where excessive drops occur at the culvert outlet. Fishways require specialized site-specific design for each installation. A NOAA or DFG fish passage specialist should be consulted.

- Multiple Culverts - Retrofitting multiple barrel culverts with baffles in one of the barrels may be sufficient as long as low flow channel continuity is maintained and the culvert is reachable by fish at low stream flow.

OTHER GENERAL RECOMMENDATIONS

Trash racks and livestock fences should not be used near the culvert inlet. Accumulated debris may lead to severely restricted fish passage, and potential injuries to fish. Where fencing cannot be avoided, it should be removed during adult salmon upstream migration periods. Otherwise, a minimum of 9 inches clear spacing should be provided between pickets, up to the high flow water surface. Timely clearing of debris is also important, even if flow is getting around the fencing. Cattle fences that rise with increasing flow are highly recommended.

Natural or artificial supplemental lighting should be provided in new and replacement culverts that are over 150 feet in length. Where supplemental lighting is required, the spacing between lightsources shall not exceed 75 feet.

The NOAA and the DFG set instream work windows in each watershed. Work in the active stream channel should be avoided during the times of year salmonids are present. Temporary crossings, placed in salmonid streams for water diversion during construction activities, should meet all of the guidelines in this document. However, if it can be shown that the location of a temporary crossing in the stream network is not a fish passage concern at the time of the project, then the construction activity only needs to minimize erosion, sediment delivery, and impact to surrounding riparian vegetation.

Culverts shall only be installed in a de-watered site, with a sediment control and flow routing plan acceptable to NOAA or DFG. The work area shall be fully restored upon completion of construction with a mix of native, locally adapted, riparian vegetation. Use of species that grow extensive root networks quickly should be emphasized. Sterile, non-native hybrids may be used for erosion control in the short term if planted in conjunction with native species.

Construction disturbance to the area should be minimized and the activity should not adversely impact fish migration or spawning. If salmon are likely to be present, fish clearing or salvage operations should be conducted by qualified personnel prior to construction. If these fish are listed as threatened or endangered under the federal or state Endangered Species Act, consult directly with NOAA and DFG biologists to gain authorization for these activities. Care should be taken to ensure fish are not chased up under banks or logs that will be removed or dislocated by construction. Return any stranded fish to a suitable location in a nearby live stream by a method that does not require handling of the fish.

If pumps are used to temporarily divert a stream to facilitate construction, an acceptable fish screen must be used to prevent entrainment or impingement of small fish. Contact NOAA or DFG hydraulic engineering staff for appropriate fish screen specifications. Unacceptable wastewater associated with project activities shall be disposed of off-site in a location that will not drain directly into any stream channel.

POST-CONSTRUCTION EVALUATION AND LONG TERM MAINTENANCE AND ASSESSMENT

Post-construction evaluation is important to assure the intended results are accomplished, and that mistakes are not repeated elsewhere. There are three parts to this evaluation:

- Verify the culvert is installed in accordance with proper design and construction procedures
- Measure hydraulic conditions to assure that the stream meets these guidelines
- Perform biological assessment to confirm the hydraulic conditions are resulting in successful passage.

NOAA and/or DFG technical staff may assist in developing an evaluation plan to fit site-specific conditions and species. The goal is to generate feedback about which techniques are working well, and which require modification in the future. These evaluations are not intended to cause extensive retrofits of any given project unless the as-built installation does not reasonably conform to the design guidelines, or an obvious fish passage problem continues to exist. Over time, the NOAA anticipates that the second and third elements of these evaluations will be abbreviated as clear trends in the data emerge.

Any physical structure will continue to serve its intended use only if it is properly maintained. During the storm season, timely inspection and removal of debris is necessary for culverts to continue to move water, fish, sediment, and debris. In addition, all culverts should be inspected at least once annually to assure proper functioning. Summary reports should be completed annually for each crossing evaluated. An annual report should be compiled for all stream crossings and submitted to the resource agencies. A less frequent reporting schedule may be agreed upon for proven stream crossings. Any stream crossing failures or deficiencies discovered should be reported in the annual cycle and corrected promptly.

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INTERNET RESOURCES

California Department of Fish and Game

http://www.dfg.ca.gov

National Oceanic and Atmospheric Administration Fisheries Southwest Region

http://swr.nmfs.noaa.gov

Washington Department of Fish and Wildlife Fish Passage Technical Assistance

http://www.wa.gov/wdfw/hab/engineer/habeng.htm

Oregon Road/Stream Crossing Restoration Guide, Spring 1999 (with ODFW criteria)

http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/orfishps.htm

FishXing software and learning systems for the analysis of fish migration through culverts

http://www.stream.fs.fed.us/fishIXing/

USDA Forest Service Water-Road Interaction Technology Series Documents

http://www.stream.fs.fed.us/water-road/indeIX.html

British Columbia Forest Practices Code Stream Crossing Guidebook for Fish Streams

http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/stream/str-toc.htm

Please direct questions regarding this material to:
National Oceanic and Atmospheric Administration Fisheries Phone: (707) 575-6050
Hydraulic Engineering Staff Fax: (707) 578-3425
777 Sonoma Avenue, Suite 325
Santa Rosa, CA 95404
Email: nmfs.swr.fishpassage@noaa.gov

APPENDIX IX-C

EXAMPLE FISH PASSAGE FLOWS CALCULATION

This is a step by step illustration of calculating fish passage flows for analyzing a stream crossing using *FishXing*. The calculations are for a fictitious culvert in a coastal drainage in the Santa Cruz area. The culvert has a drainage area of 3.56 mi^2. The calculated fish passage flows in this example are for adult steelhead trout. Passage flows for other species or lifestages would be derived using a similar methodology.

This example uses data from the USGS website for gage 11161800. The identical data can be obtained at:
http://water.usgs.gov/nwis/discharge?site_no=11161800&agency_cd=USGS&format=rdb&begin_date=&end_date=&period=

Step 1:

Obtain gage data.

This example project has stream flow characteristics similar to that of San Vicente Creek, a small watershed where there was a USGS gage with a long flow history. In some cases data might need to be combined from several nearby gages.

Print the data in tabular form to the browser then copy and paste the entire file into a spreadsheet.

 # US Geological Survey
 # National Water Information System
 # Retrieved: 2002-01-11 10:34:24 EST
This file contains published daily mean streamflow data.
This information includes the following fields:

agency_cd Agency Code
site_no USGS station number
dv_dt date of daily mean streamflow
dv_va daily mean streamflow value, in cubic-feet per-second
dv_cd daily mean streamflow value qualification code

Sites in this file include:

USGS 11161800 SAN VICENTE C NR DAVENPORT CA

agency_cd	site_no	dv_dt	dv_va	dv_cd
5s	15s	10d	12n	3s
USGS	11161800	1969-10-01	1.7	
USGS	11161800	1969-10-02	1.7	
USGS	11161800	1969-10-03	1.7	
USGS	11161800	1969-10-04	1.7	
USGS	11161800	1969-10-05	1.8	
USGS	11161800	1969-10-06	1.8	
USGS	11161800	1969-10-07	1.8	
USGS	11161800	1969-10-08	1.8	
USGS	11161800	1969-10-09	1.9	
USGS	11161800	1969-10-10	2.0	

USGS	11161800	1969-10-11	2.1
USGS	11161800	1969-10-12	2.1
USGS	11161800	1969-10-13	2.3
USGS	11161800	1969-10-14	2.4
USGS	11161800	1969-10-15	8.9
USGS	11161800	1969-10-16	11
USGS	11161800	1969-10-17	3.3
USGS	11161800	1969-10-18	2.7
USGS	11161800	1969-10-19	2.5
USGS	11161800	1969-10-20	2.4
USGS	11161800	1969-10-21	2.4
USGS	11161800	1969-10-22	2.4
USGS	11161800	1969-10-23	2.4
USGS	11161800	1969-10-24	2.4

Continued for approximately 5,800 records to:

USGS	11161800	1985-09-27	1.5
USGS	11161800	1985-09-28	1.5
USGS	11161800	1985-09-29	1.4
USGS	11161800	1985-09-30	1.5

Step 2:

Remove the verbiage in the header to get a uniform set of data columns.

USGS	11161800	1969-10-01	1.7
USGS	11161800	1969-10-02	1.7
USGS	11161800	1969-10-03	1.7
USGS	11161800	1969-10-04	1.7
USGS	11161800	1969-10-05	1.8
USGS	11161800	1969-10-06	1.8
USGS	11161800	1969-10-07	1.8
USGS	11161800	1969-10-08	1.8
USGS	11161800	1969-10-09	1.9
USGS	11161800	1969-10-10	2.0
USGS	11161800	1969-10-11	2.1
USGS	11161800	1969-10-12	2.1
USGS	11161800	1969-10-13	2.3
USGS	11161800	1969-10-14	2.4
USGS	11161800	1969-10-15	8.9
USGS	11161800	1969-10-16	11
USGS	11161800	1969-10-17	3.3
USGS	11161800	1969-10-18	2.7
USGS	11161800	1969-10-19	2.5
USGS	11161800	1969-10-20	2.4
USGS	11161800	1969-10-21	2.4
USGS	11161800	1969-10-22	2.4
USGS	11161800	1969-10-23	2.4

USGS	11161800	1969-10-24	2.4
USGS	11161800	1969-10-25	2.4
USGS	11161800	1969-10-26	2.4
USGS	11161800	1969-10-27	2.4
USGS	11161800	1969-10-28	2.3
USGS	11161800	1969-10-29	2.3
USGS	11161800	1969-10-30	2.3
USGS	11161800	1969-10-31	2.1
USGS	11161800	1969-11-01	2.1
USGS	11161800	1969-11-02	2.1
USGS	11161800	1969-11-03	2.1
USGS	11161800	1969-11-04	2.0
USGS	11161800	1969-11-05	4.0
USGS	11161800	1969-11-06	3.3
USGS	11161800	1969-11-07	2.9
USGS	11161800	1969-11-08	2.7
USGS	11161800	1969-11-09	2.6
USGS	11161800	1969-11-10	2.5
USGS	11161800	1969-11-11	2.5
USGS	11161800	1969-11-12	2.4
USGS	11161800	1969-11-13	2.4
Continued for approximately 5,800 records to:			
USGS	11161800	1985-09-27	1.5
USGS	11161800	1985-09-28	1.5
USGS	11161800	1985-09-29	1.4
USGS	11161800	1985-09-30	1.5

Step 3:

Use the “Text to Columns” feature under the “Data” menu to sort the data into four columns in preparation for ranking. Select the flow column and use the sort function to sort and rank the flows from highest to lowest.

1	854
2	560
3	430
4	295
5	240
6	229
7	212
8	202
9	201
10	194
11	190
Continued for approximately 5, 800 records:	
5,841	0.42
5,842	0.42

5,843	0.42
5,844	0.42
2917	0.42

Step 4:

Identify the rank of the 50 percent and 1 percent exceedance flows for the lower and upper fish passage flows for adult steelhead trout, as defined by the criteria. (For analyzing other species or life stages, use the appropriate exceedance percentage found in Table IX-5). Find what flow rate corresponds to the desired ranking.

For the 5,844 records selected, Q50% rank is computed as: 0.50 X 5,844 = 2,922

A rank of 2,922 corresponds to a flow of 3.3 cfs

Q1% rank is computed as: 0.01 X 5,844 = 58.44

Rounding to the nearest whole number rank of 58 corresponds to a flow of 86 cfs

Step 5:

Multipy these fish passage flows by the ratio of the watershed area above our culvert (3.56 square miles) to the area of the gaged watershed (6.07 square miles). Note: several modern mapping programs make it easy to outline and determine the watershed area above any given point.

Lower Adult Fish Passage Flow

Q50% at the stream crossings: 3.3 cfs X (3.56 mi^2 / 6.07 mi^2) = 1.9 cfs

Upper Adult Fish Passage Flow

Q1% at the stream crossings: 86 cfs X (3.56 mi^2 / 6.07 mi^2) = 50.4 cfs

If a gaged stream is nearby but has a different aspect or annual precipitation, ratios can be used to correct for this as well. Use these two numbers as the lower and upper fish passage flows in *FishXing* analysis.