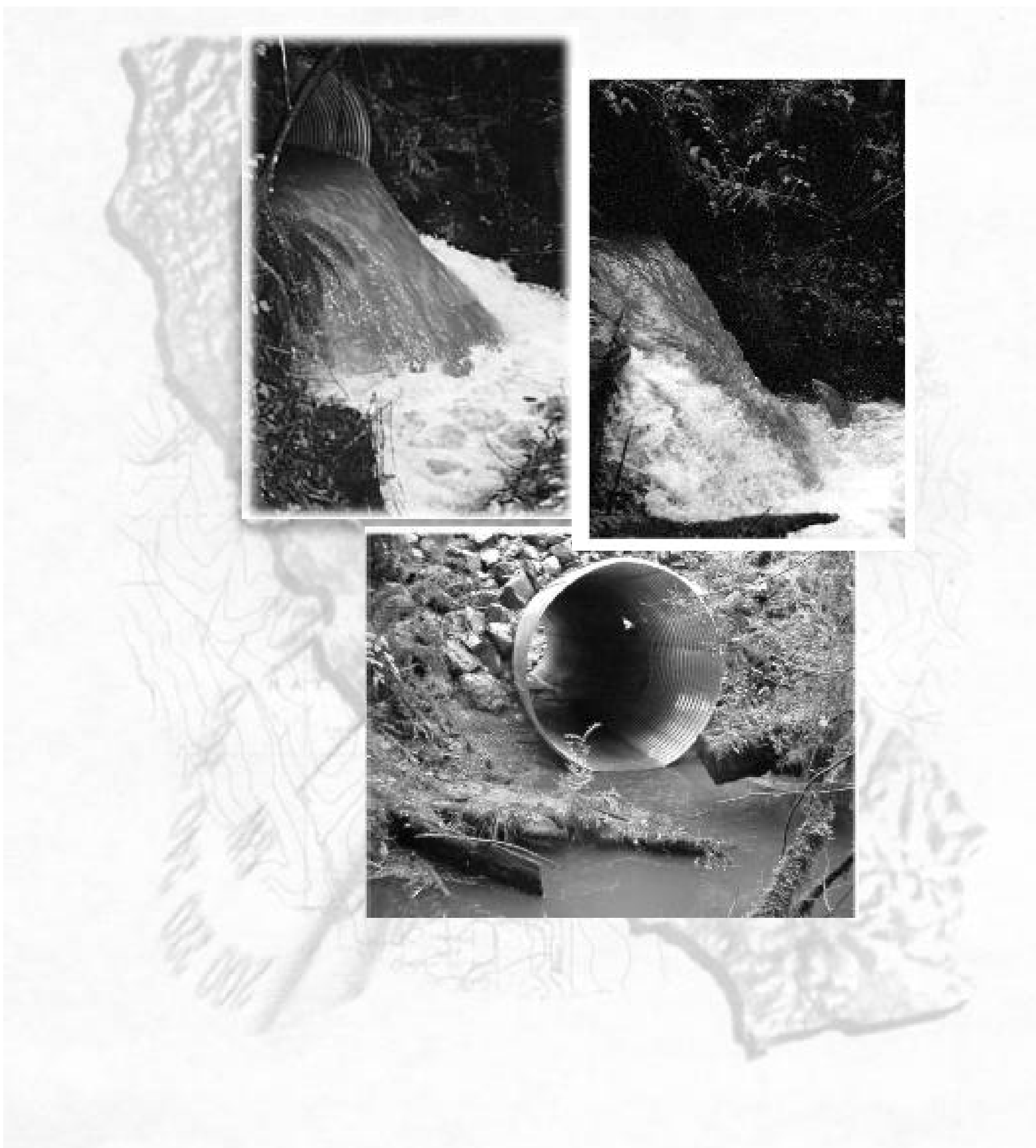
PART IX

FISH PASSAGE EVALUATION AT STREAM CROSSINGS



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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.

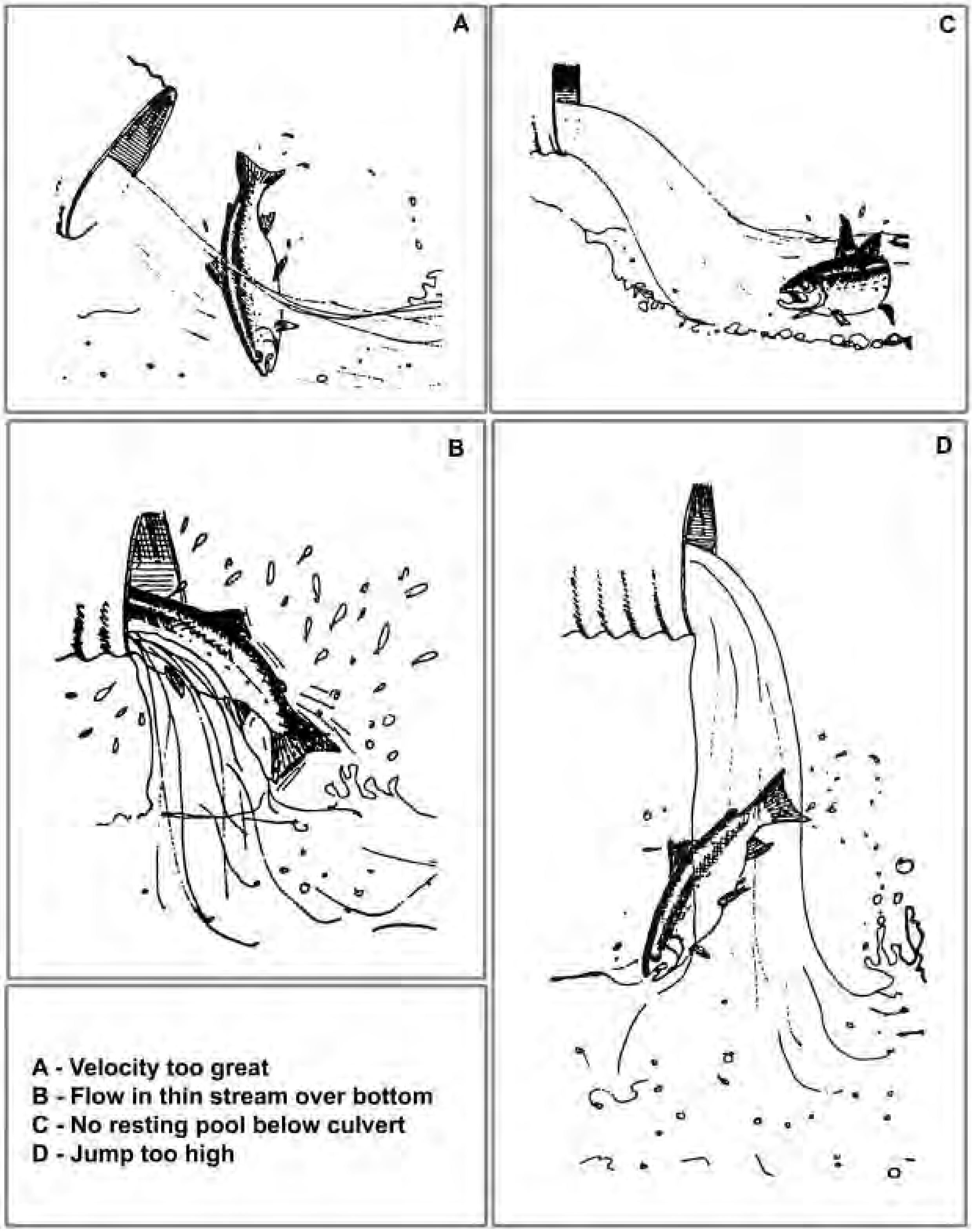


Figure IX-1. Common conditions that block fish passage.

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).

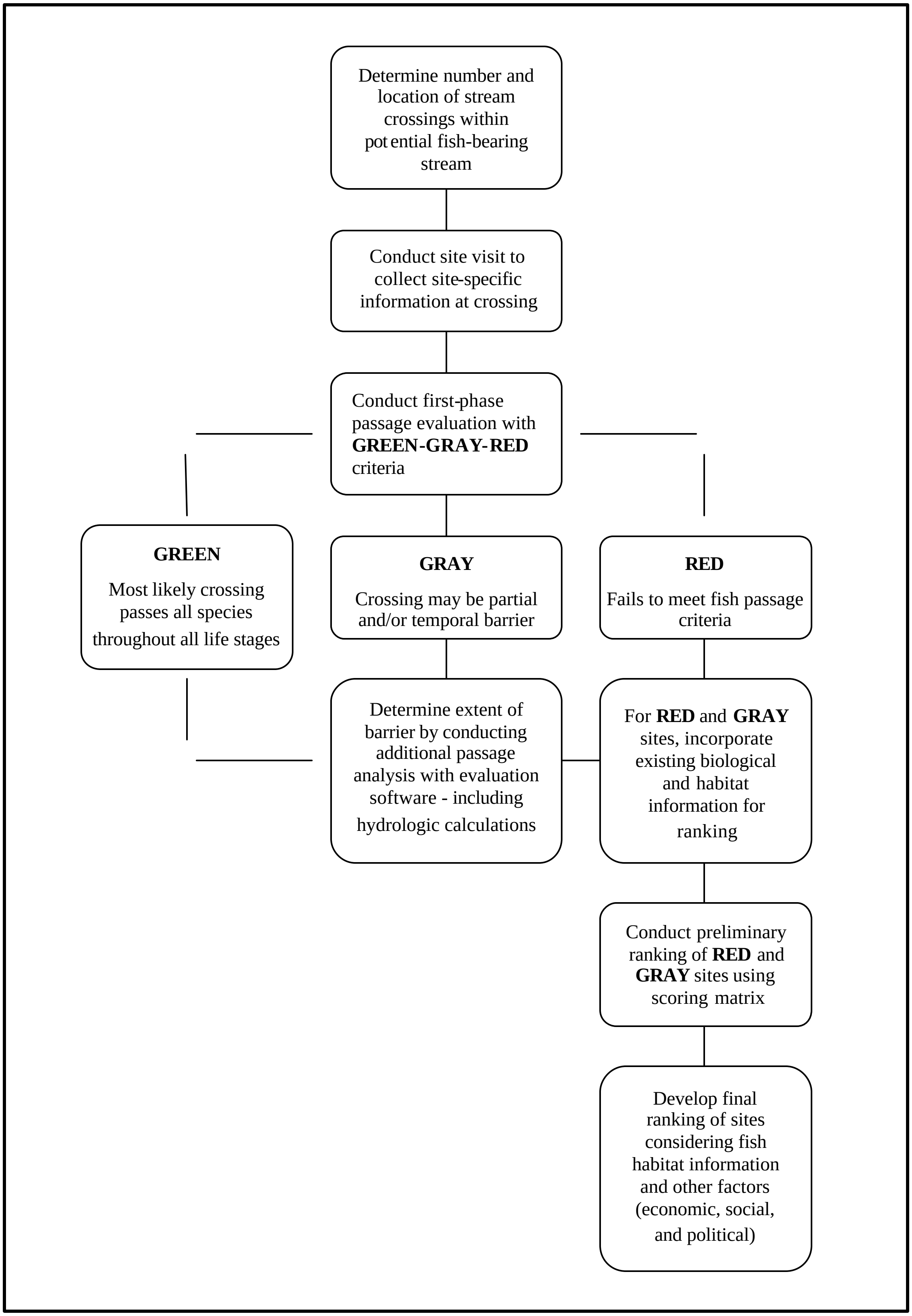


Figure IX-2. Framework for inventory and evaluation of fish passage through stream crossings.

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.

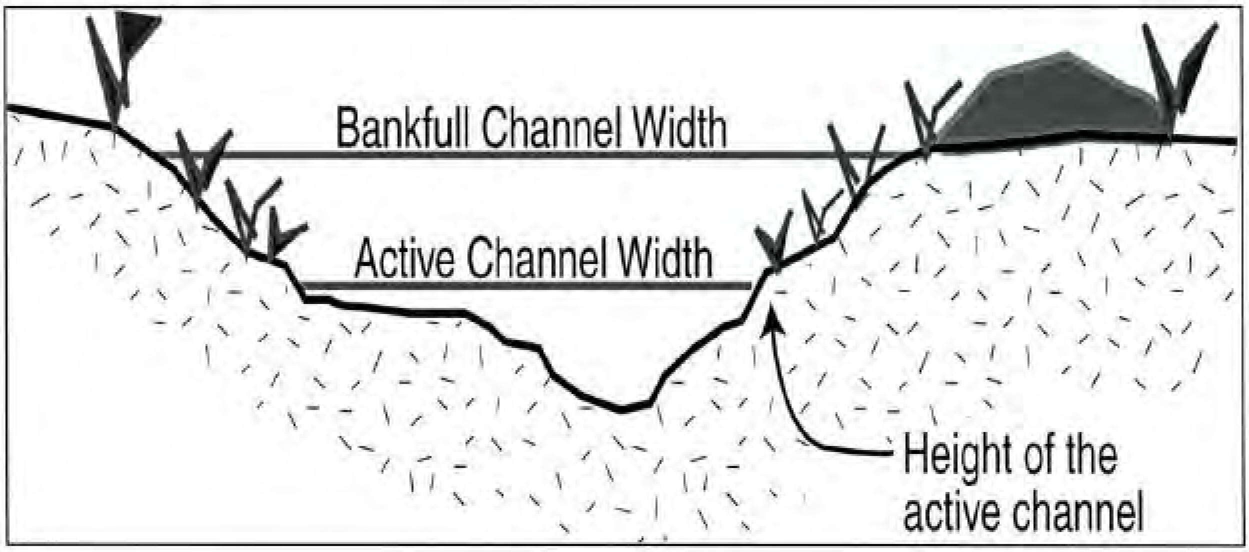


Figure IX-3. Active channel width versus bankfull channel width.

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.

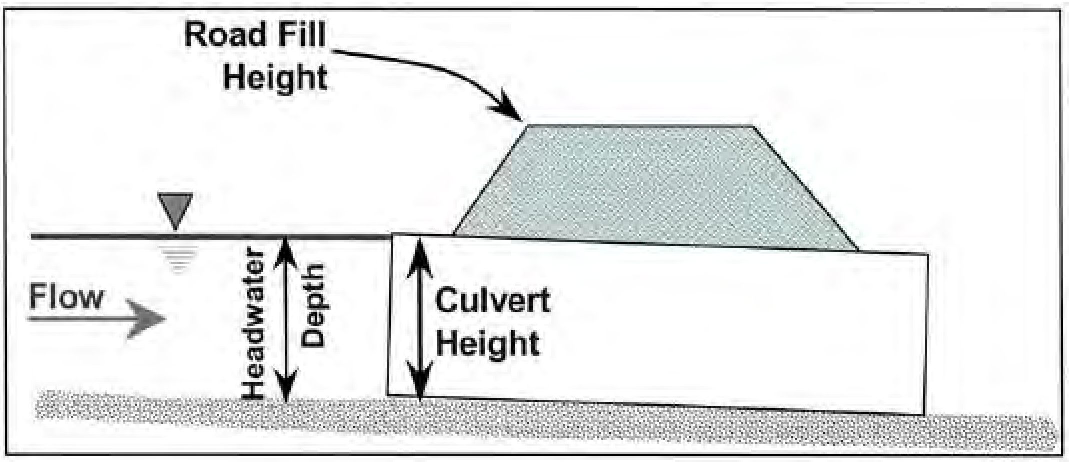


Figure IX-5. Headwater depth and culvert height, HW/D=1.

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.

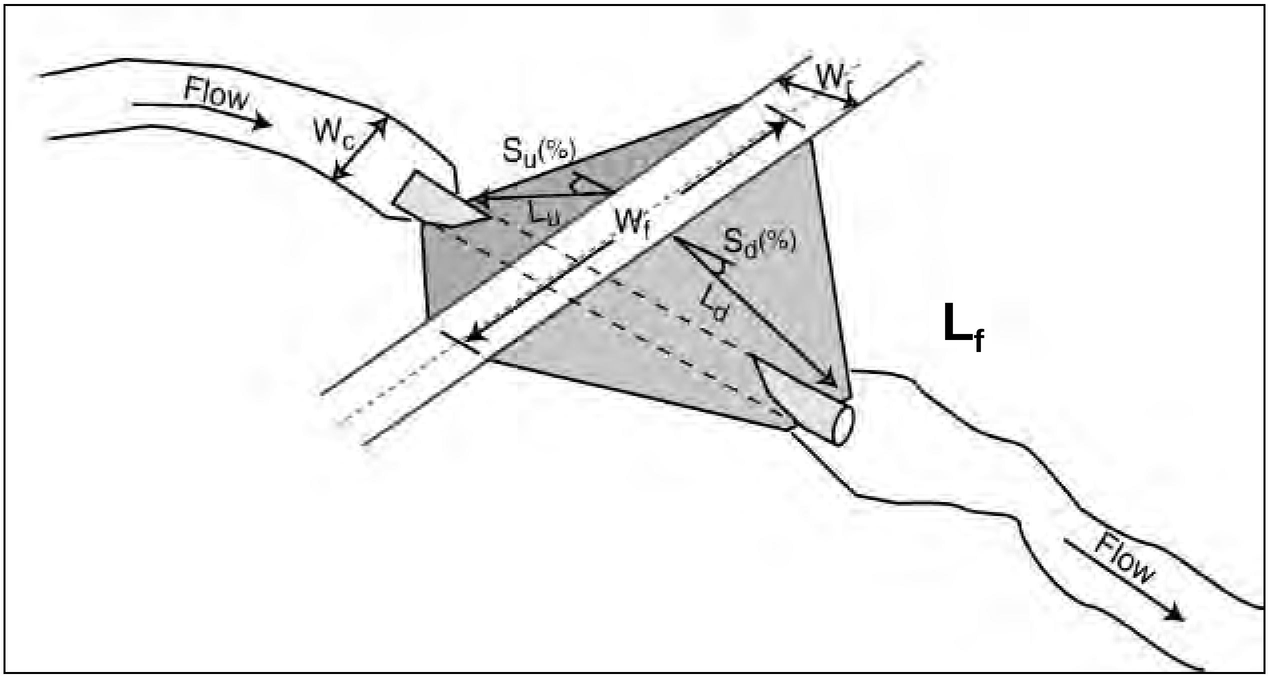


Figure IX-6. Measurements taken to calculate fill volume.

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.

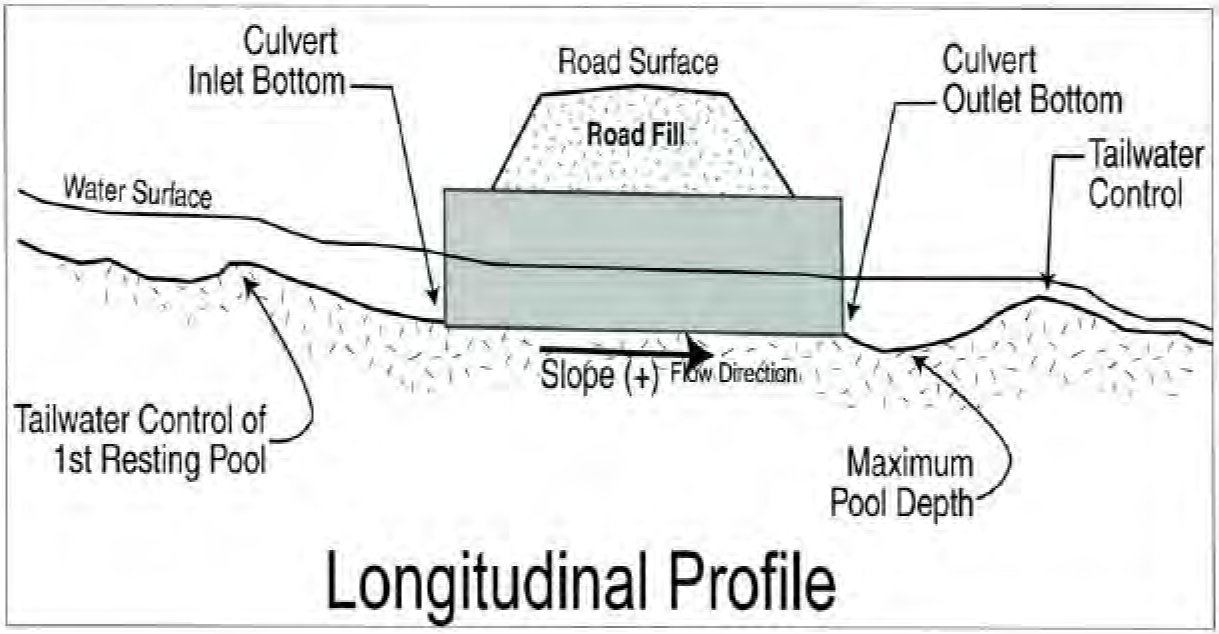


Figure IX-7. Diagram of required survey points for a longitudinal profile through a culvert.

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 0.0′) 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.

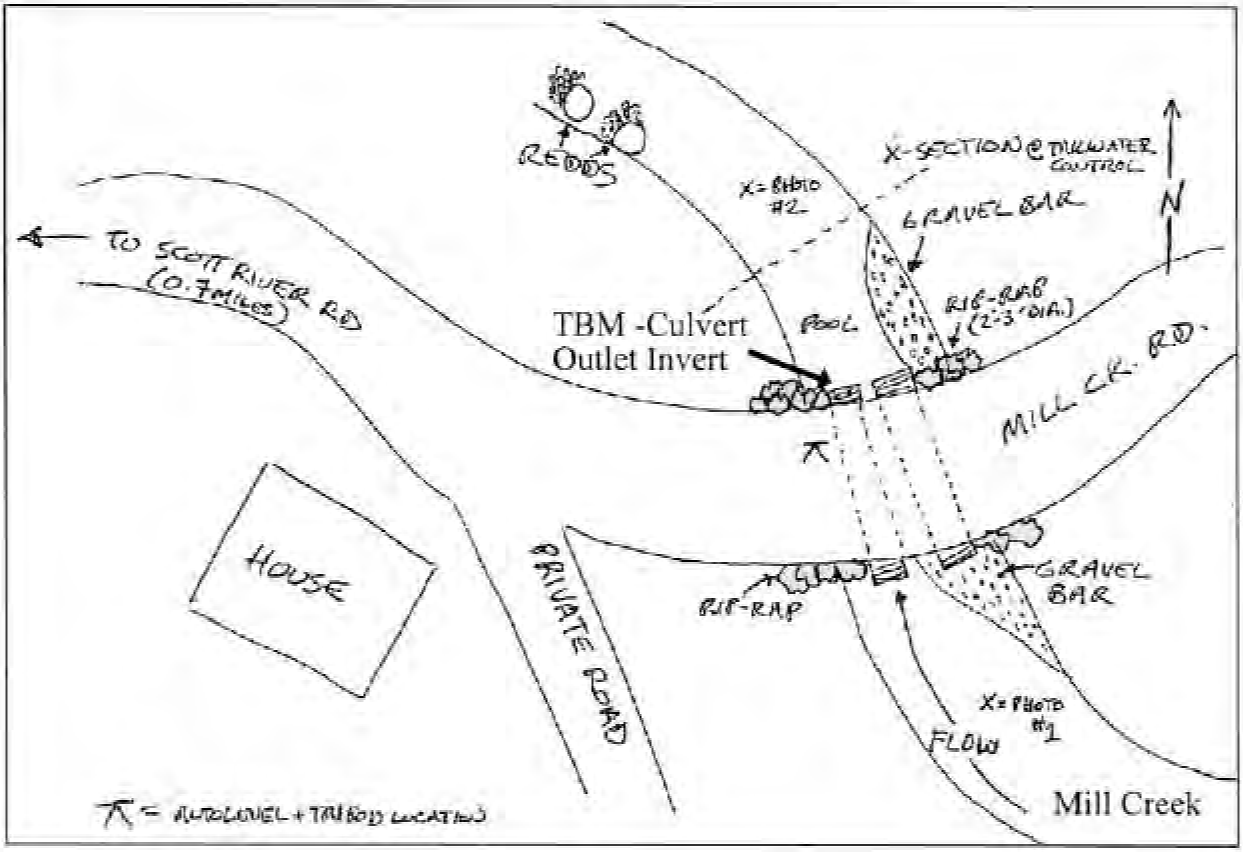


Figure IX-8. Site sketch example.

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.

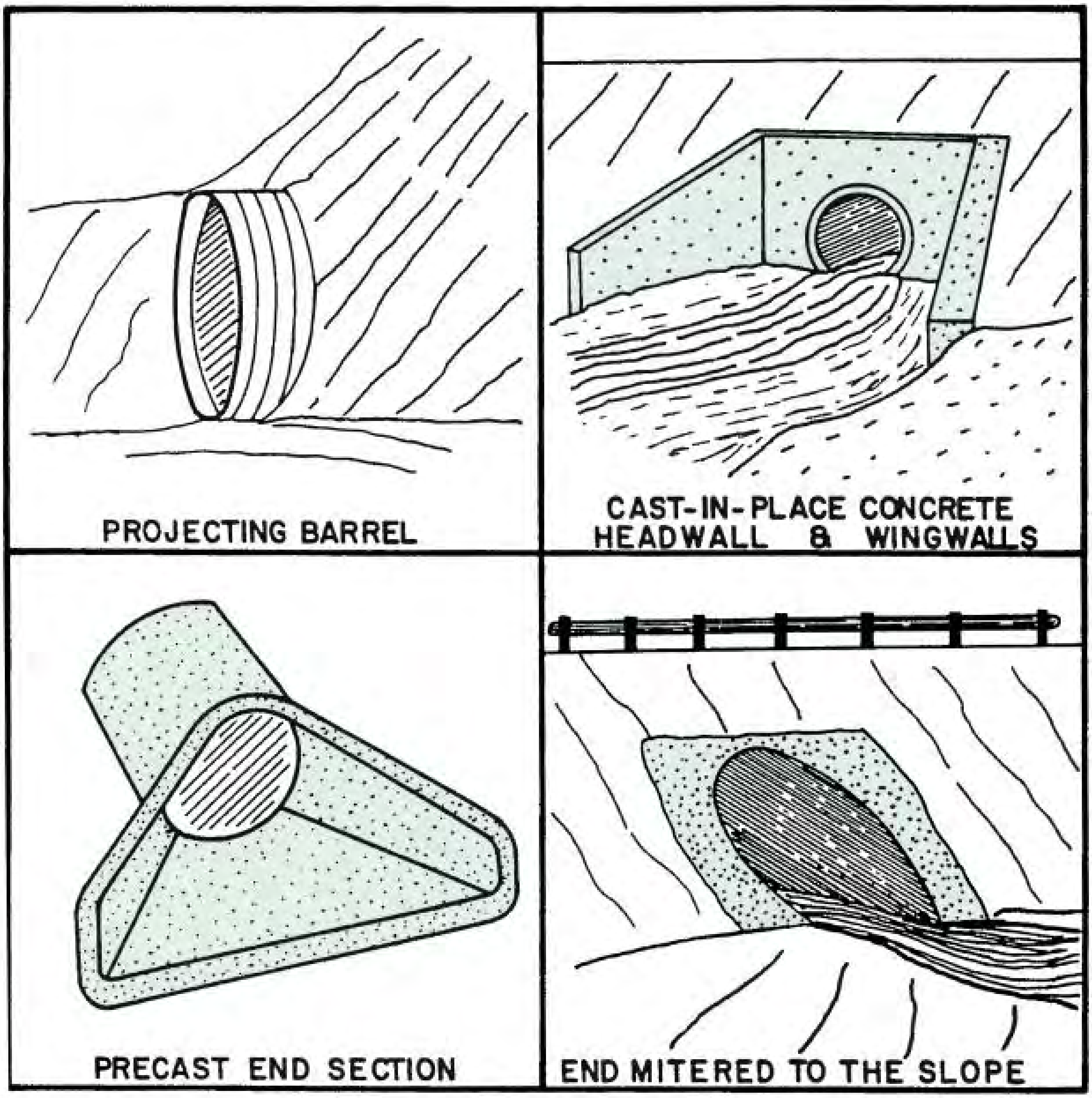


Figure IX-9. Four standard inlet types (Norman et al. 1985).

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 100′ 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.

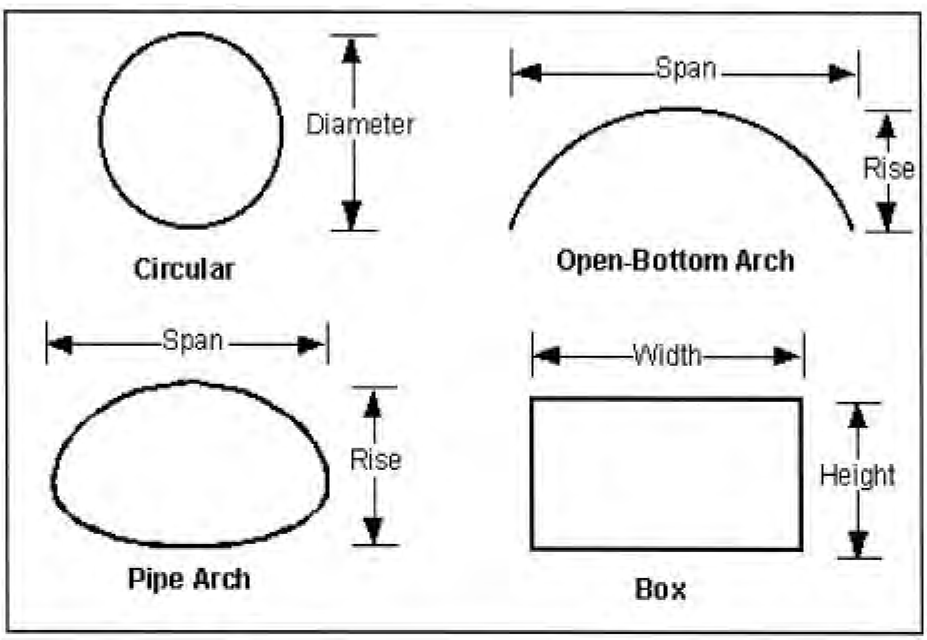


Figure IX-10. Culvert type and dimensions.

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): 2**b**″ x ½″; 3″ x 1″; 5″ x 1″; 6″ x 2″ 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.

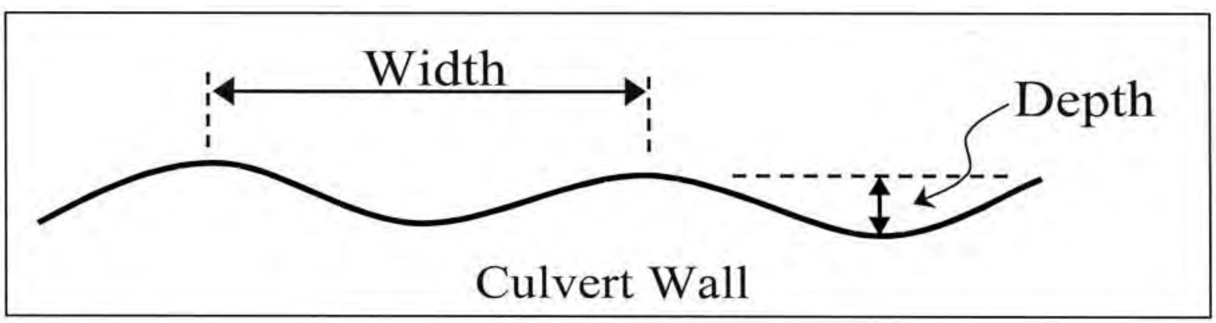


Figure IX-11. Measuring corrugations.

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.

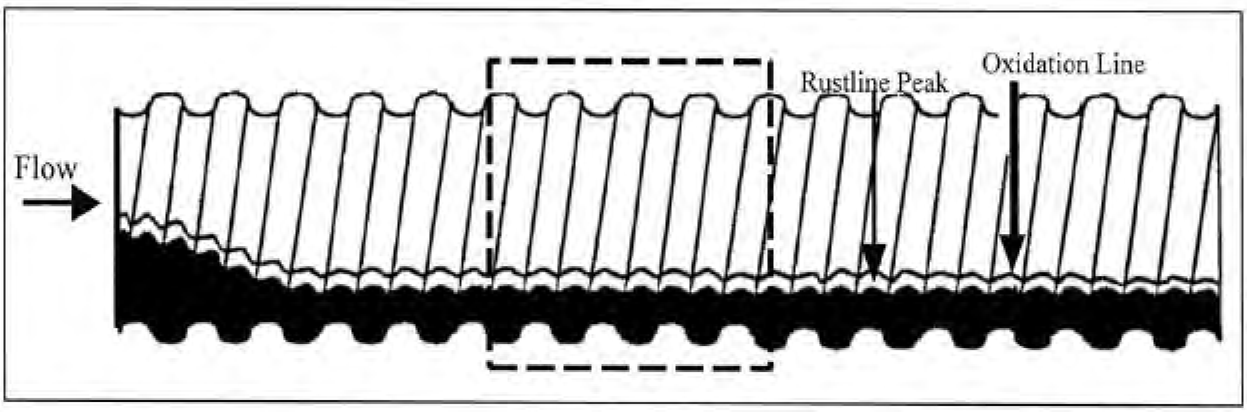
Fair: Noticeable wear or rusting has occurred, but not rusted through the bottom yet.

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 0.1′) 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 0.0′ 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 0.0′ 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).

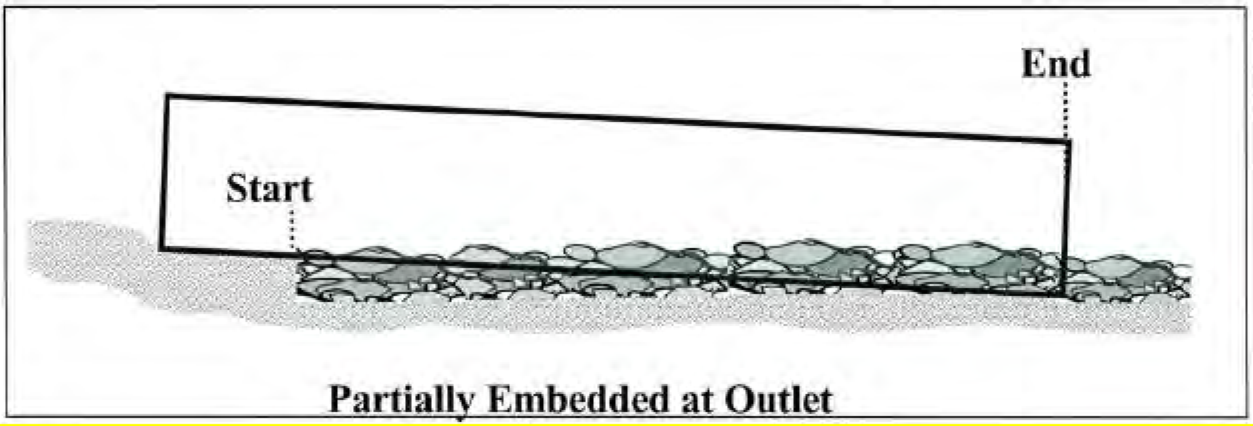


Figure IX-13. Measurements taken at embedded culverts.

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 0.1′ 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 0.1′ 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.

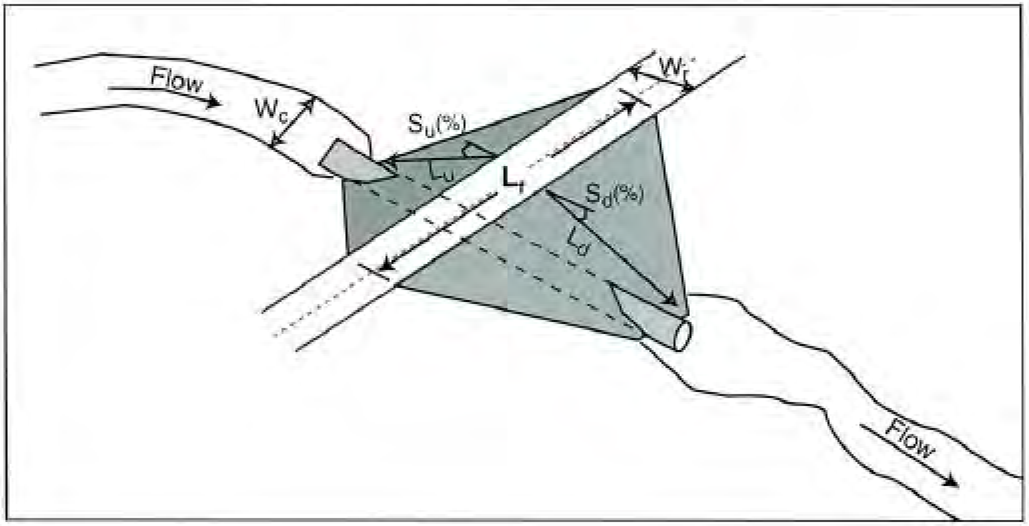


Figure IX-14. Measurements required to generate a rough fill volume estimate.

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*.

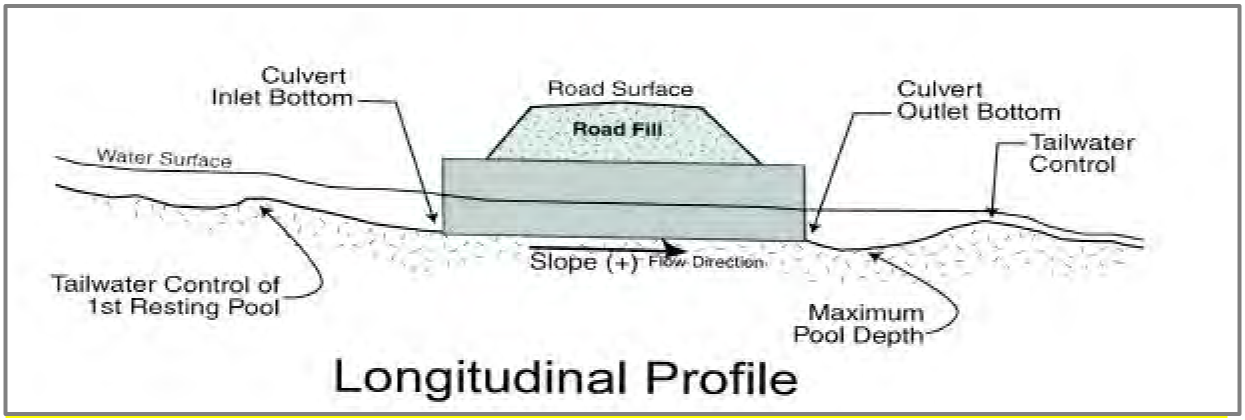


Figure IX-15. Surveyed elevations.

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 0.3′ 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 2.0′ 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

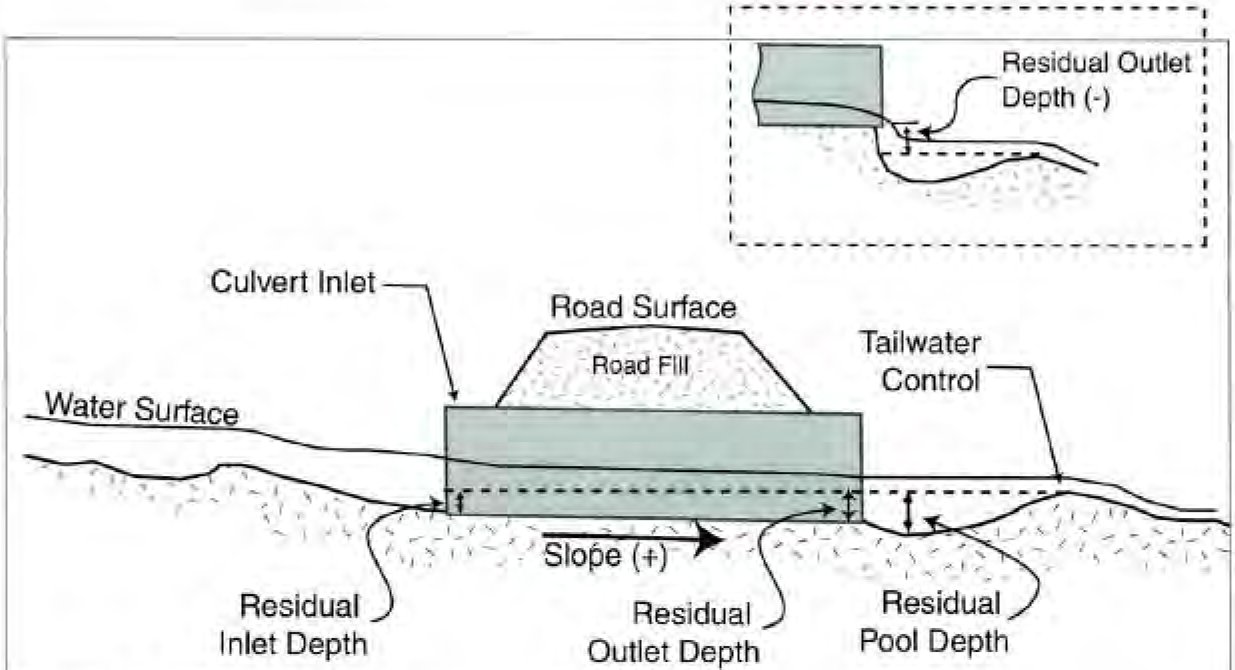
Enter data from the *Fish Passage Inventory Data Sheet* into a database or spreadsheet. From this, various calculations can be completed.

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.

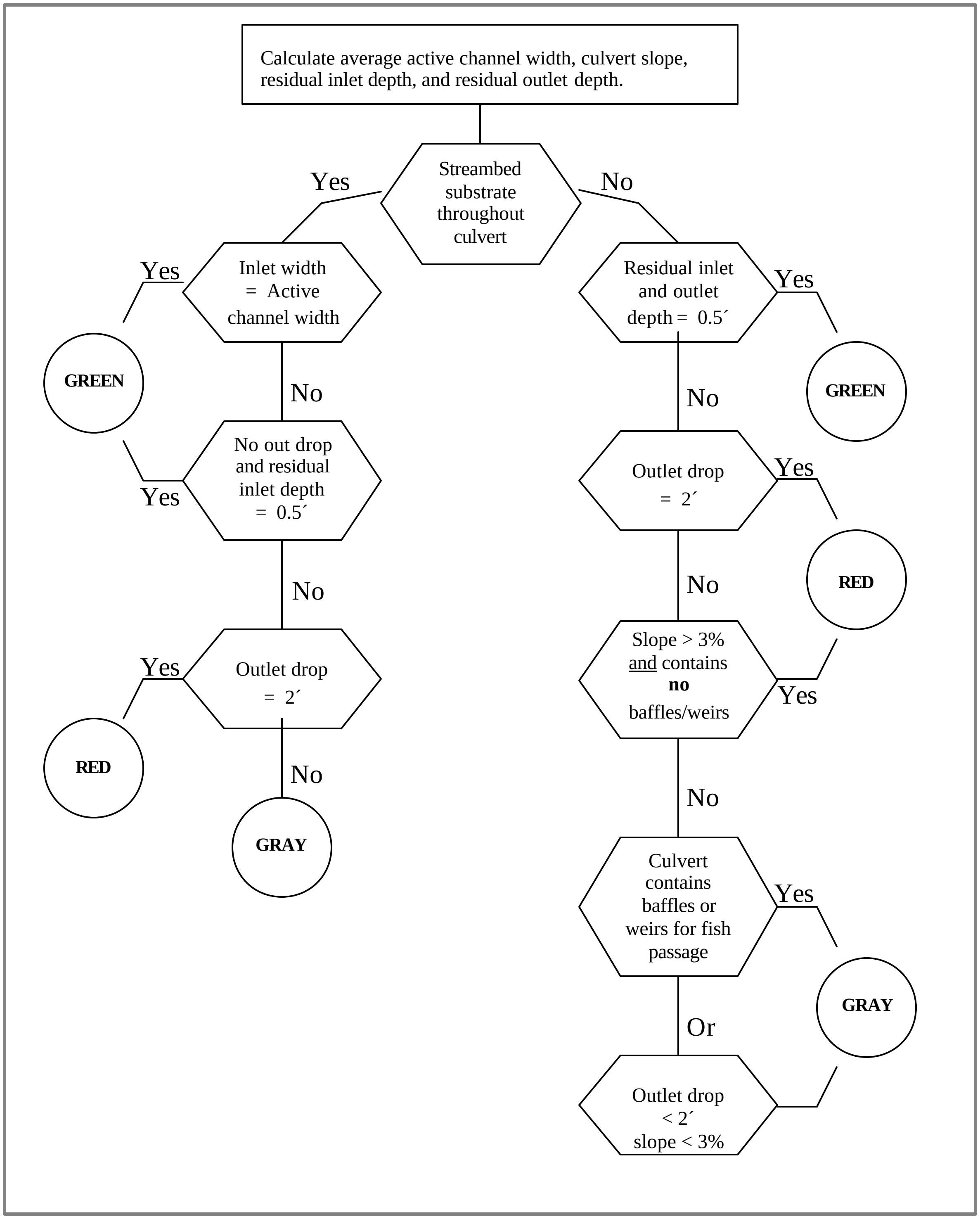


Figure IX-17. GREEN-GRAY-RED first-phase passage evaluation filter.

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:

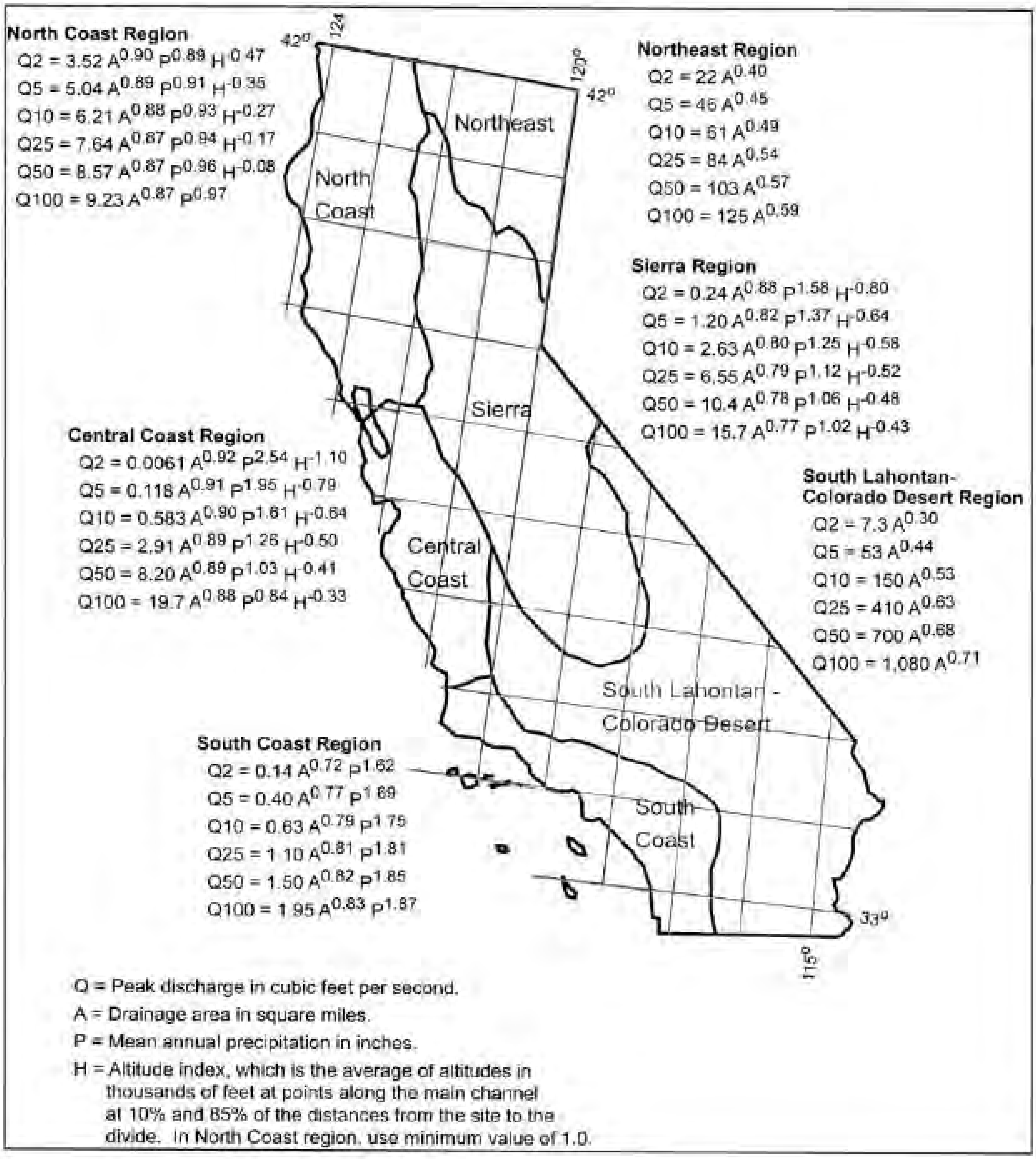
- Regional flood estimation equations for various recurrence intervals
- The rational method
- Estimates using local stream gaging data.

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).

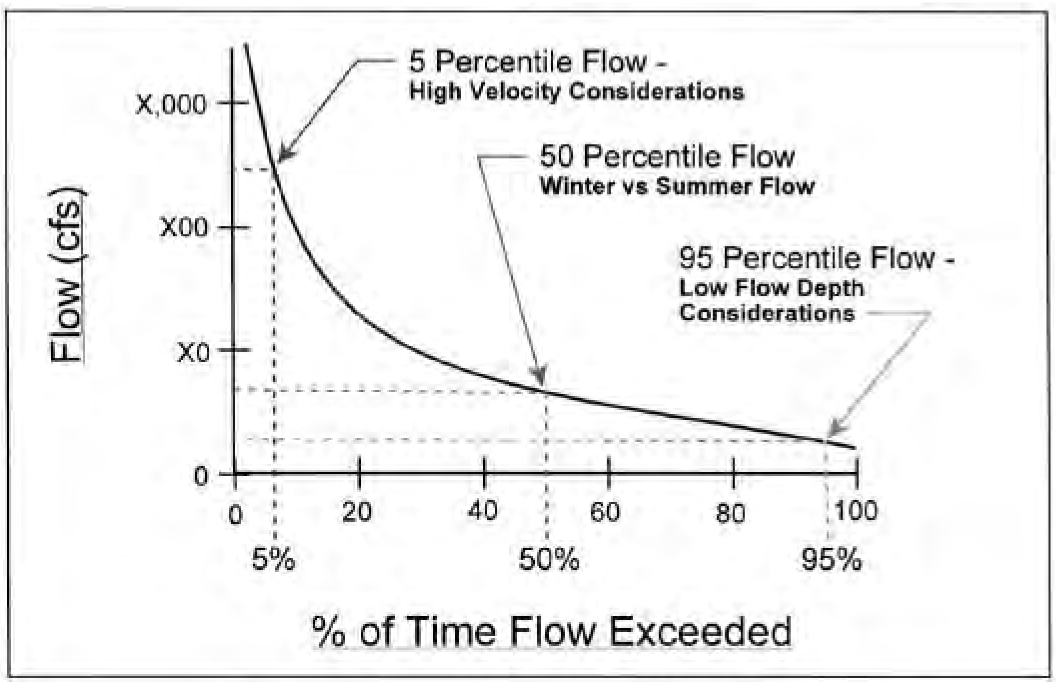


Figure IX-19. Example of a flow duration curve.

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/se	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).

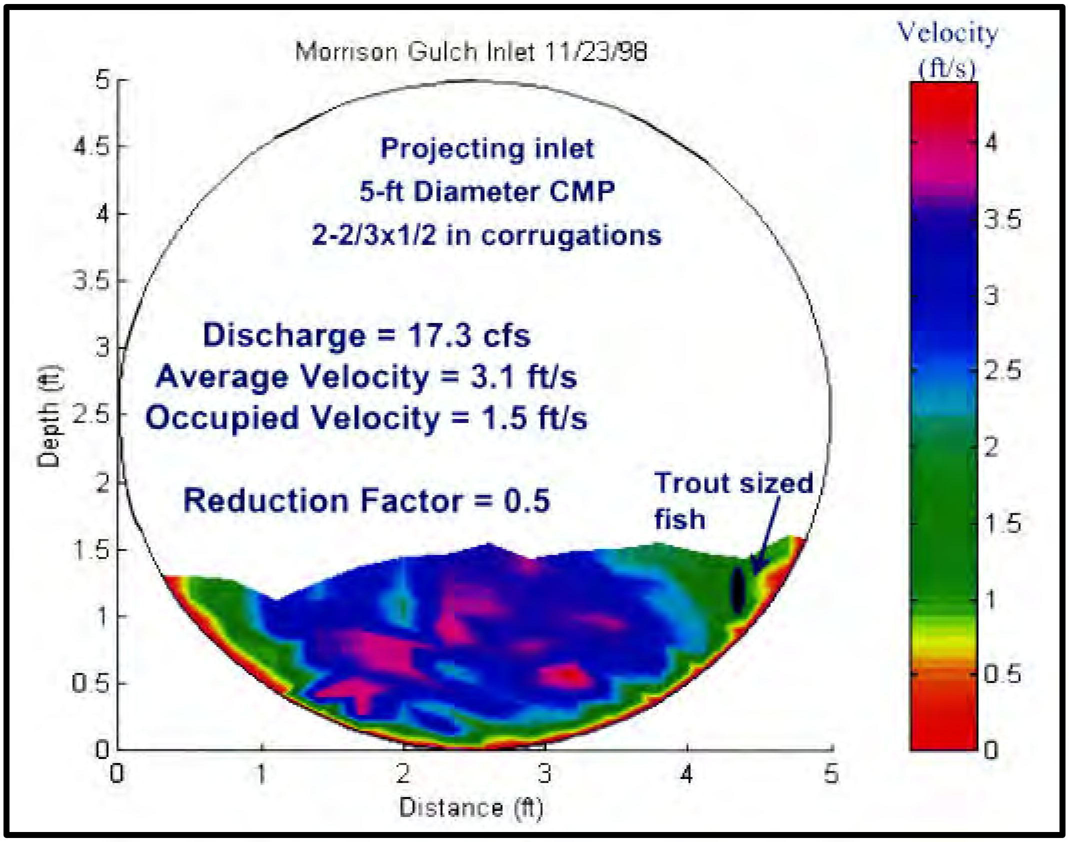
Table IX-6. Minimum water depth requirements and swimming and leaping ability inputs for *FishXing*.

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 minimu m 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 <500′; 1 point for 1,000′; 2 points for 2,000′; and 5.5 points for 5,500′). 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.

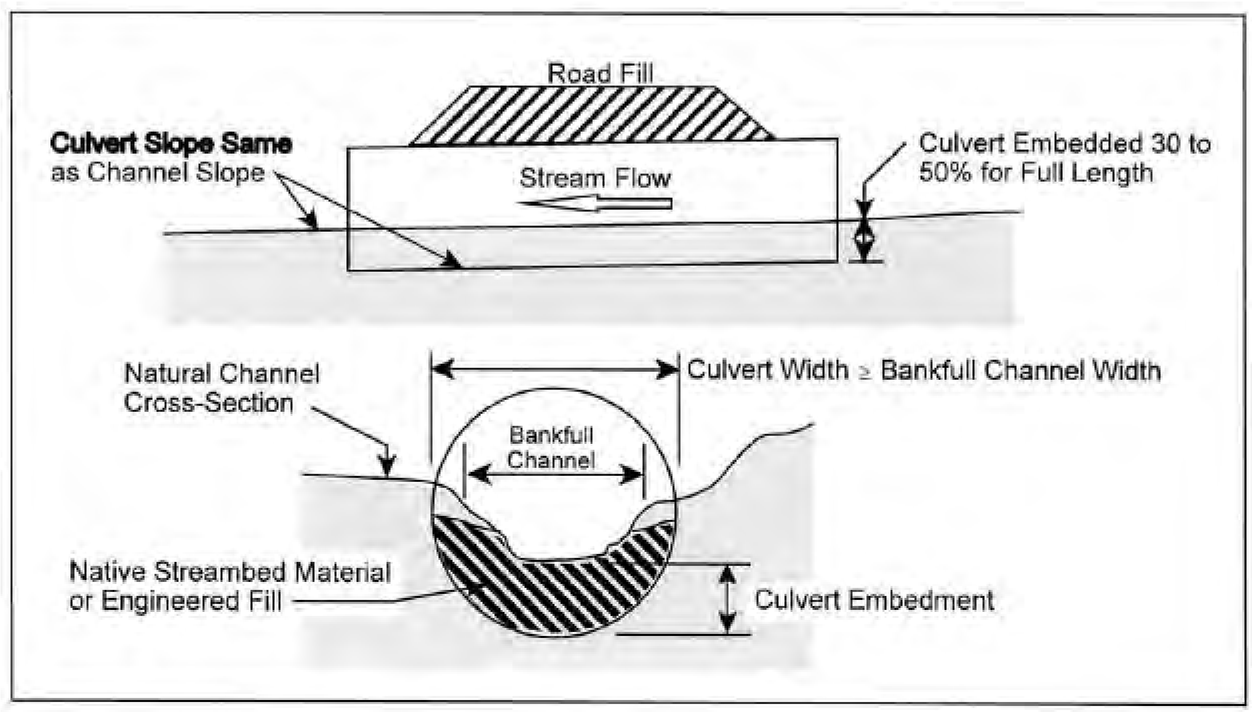


Figure IX-21. Stream simulation strategy option.

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.

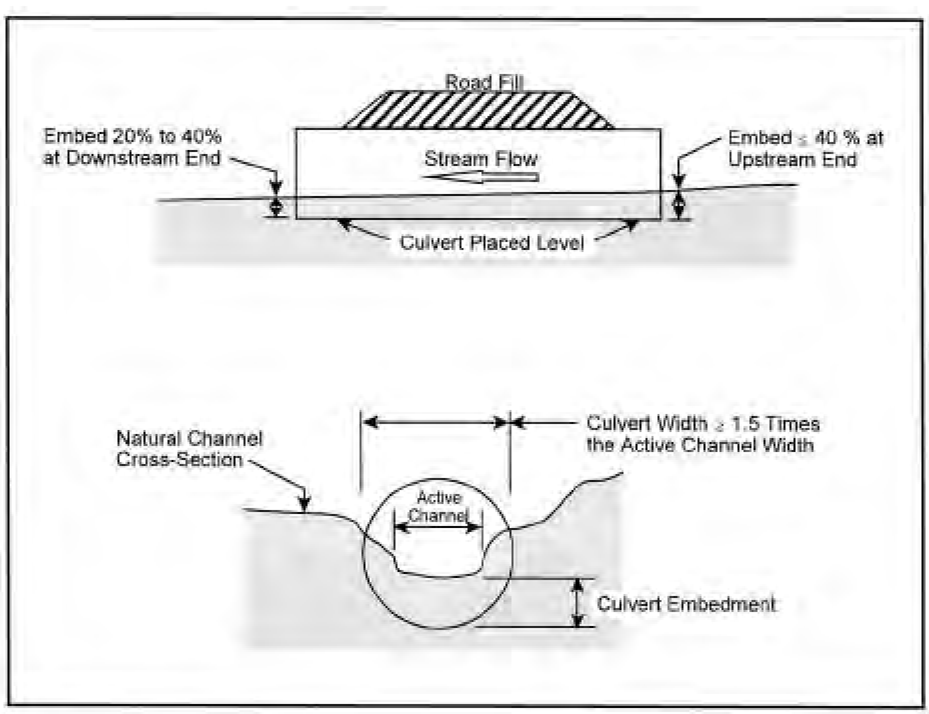

Figure IX-A-1. Active channel design option.

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.

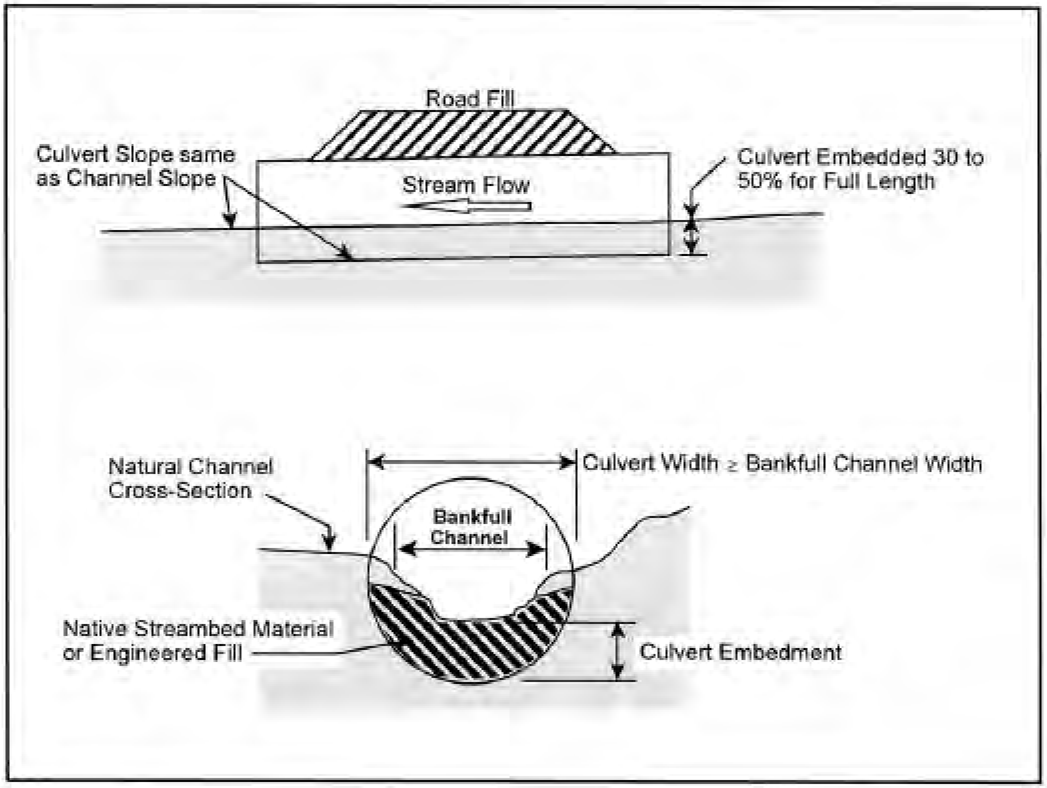

Figure IX-A- 2 Stream simulation design option.

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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Behlke, C.E., D.L. Kane, R.F. McLean, and M.D. Travis. 1991. *Fundamentals of Culvert Design for Passage of Weak-Swimming Fish, Final Report.* Alaska DOT&PF and USDT, Federal Highway Administration, FHWA-AK-RD-90-10.

California Department of Fish and Game: www.dfg.ca.gov

California Department of Fish and Game. 1998. *California Salmonid Stream Habitat Restoration Manual, 3rd Edition*. Habitat Conservation Division.

National Oceanic and Atmospheric Administration Fisheries, Southwest Region. *Stream Crossing Guidelines* http://swr.nmfs.noaa.gov/habitat.htm

FishXing software and learning systems for the analysis of fish passage through culverts. USDA. Forest Service. 1999. *Fish Xing. Version 2.2.* Six Rivers National Forest Watershed Interactions Team, Eureka, CA. www.stream.fs.fed.us/fishxing/

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Washington Department of Fish and Wildlife, 1999. *Fish Passage Design at Road Culverts*. www.wa.gov/wdfw/hab/engineer/cm/toc.htm

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

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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.

PART X

UPSLOPE EROSION INVENTORY AND SEDIMENT CONTROL GUIDANCE

This manual describes methods and techniques used with varying degrees of success by watershed 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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INTRODUCTION

Watersheds and streams have a natural background rate of erosion. Delivery of eroded sediment to stream systems occurs through various transport processes that operate in all watersheds. Natural erosion and sediment delivery varies from relatively low amounts in stable watersheds underlain by resistant rock types, to comparatively high amounts in watersheds that have soft rock types that erode more easily. During large storm events, mass wasting or landsliding, large-scale gully erosion, and stream bank erosion are more likely to occur. Between large disturbance events, erosion rates are generally lower and overall sediment delivery is low, although sediment may still enter the stream from various erosion processes. This can increase due to human influences. Native anadromous salmonids have evolved and successfully adapted through eons to stream habitat conditions produced by these natural processes within this dynamic environment. Excessive sediment delivery to streams can have a deleterious effect on anadromous salmonids by filling in pool habitat and burying spawning substrate.

Purpose

Part X, *Upslope Erosion Inventory and Sediment Control Guidance*, describes the California Department of Fish and Game (DFG) methodology for the identification of upslope and stream bank erosion, and techniques for the implementation of cost-effective erosion control treatments in salmonid watersheds. These treatments focus on erosion prevention and control on managed lands. The goal is to reduce the human influences and restore erosion to a level more consistent with the natural background rate. *Part X* discusses several components of watershed restoration:

- Sediment production and delivery;
- Upslope erosion assessment;
- Analysis and reporting of assessment data;
- Implementing sediment control work;
- Quality control, documentation of projects, and project monitoring.

The erosion assessment protocols included in *Part X* are for the identification and quantification of existing and potential sediment sources in upslope and stream bank locations. The inventory data forms include problem identification, quantification of existing and potential sediment sources, and the selection of proper treatment options. To conduct a successful assessment, the survey team must understand basic upslope erosion processes and be familiar with basic erosion control and erosion prevention techniques applicable to a particular setting. They must also be familiar with the heavy equipment used, its application for the various restoration techniques, and have the ability to estimate production rates. The general erosion control techniques presented must be adapted to site-specific conditions. Additional topic-specific publications and manuals for erosion prevention and control are included in the list of references.

Scope and Limitations

Part X has been prepared to provide the reader with an overview of basic information on watershed erosion processes (especially road-related erosion). This includes: how to identify and conduct a basic or simplified inventory of the erosion features associated with these processes; and some of the most common, less technical methods by which these processes and their impacts can be prevented or controlled. Only the most straightforward and most common of erosion control and erosion prevention treatments have been described. Because this is not a comprehensive technical guidance manual, and because of the highly varied site specific conditions that are likely to be encountered in the field, not all the information needed to identify, evaluate and treat complex erosion processes or mass wasting features has been included.

Steps for identifying potential and existing landslides are outlined. After following these steps, the restoration practitioner should be able to recognize whether a landslide problem exists within a specified area, and then to seek the expertise of a geotechnical specialist for further analysis of the problem, assessment of risk, and recommendations for control and correction. Consultation with licensed and experienced professionals may also be required in situations that require a more detailed evaluation of field conditions, prescription options and treatment methods to address complex geomorphic processes or in situations that require highly technical analyses or employ complex treatment methods. This is especially true for situations involving all but the smallest mass wasting features (e.g., cutbank failures, minor embankment failures) and treatment areas located in steep and potentially unstable hillslope areas. Identification and prescriptive treatment of all but the most simple of earth failures is outside the scope of this document.

Audience

This guide has been written in non-scientific terms and is intended for persons conducting field inventories to identify areas that may be contributing excessive sediment to streams. Among others, this may include contractors, equipment operators, watershed planners, field technicians, and landowners. This guide is not intended to supplant, nor is it capable of supplanting, trained, experienced, and skilled watershed scientists and workers. It is intended as supplemental guidance on inventory and erosion control methods for the specialist. It is also intended to provide a basic knowledge of erosion control and prevention, and road and culvert removal planning and implementation techniques for persons without specialized training but an interest or need to participate in watershed protection activities.

LEGAL REQUIREMENTS

Upland erosion control and erosion prevention work typically involves earth moving and other work in around stream channels and on lands that often have other environmental limitations and restrictions. Permits for such activities are a normal component of restoration work. When working on Fisheries Restoration Grant Program (FRGP) projects, the Department of Fish and Game generally takes the lead role in securing the necessary California Environmental Quality Act (CEQA) permits.

For all projects that modify the bed or banks of a stream channel or divert the flow of a watercourse, no matter how small, a Streambed Alteration Agreement will be required from DFG. The Agreement spells out the permitted activities, the allowed timing of project work and the on-the-ground mitigations and protections that must be applied. Typical activities covered by the Streambed Alteration Agreement process include installation of stream crossing culverts, armored fill and bridge installations, installations of rock armor on a stream bank, and excavations of stream crossing fill.

Other CEQA clearances typically handled by DFG may include field surveys by trained experts in several disciplines and include archaeological surveys, listed plant surveys and surveys for threatened or endangered animal species. These surveys may identify listed species or areas of particular sensitivity that result in operating restrictions or exclusions of operations in certain portions of the project area. All of the biological surveys must be conducted at key times of the year (e.g., plant surveys are conducted during blooming periods), so pre-project planning is critical.

On the field level, federal and state water quality and pollution regulations are administered and enforced by Regional Water Quality Control Boards. Depending on the type of project being considered, consultation with a Regional Board may be required. The DFG Streambed Alteration Agreement contains requirements for controlling sediment and other pollution from a project site, but the Regional Boards enforce water quality violations through Stop-Work Orders, Clean Up and Abatement Orders, and Waste Discharge Requirements. Regional Board staff can provide technical information on how to control project-related pollution.

If trees will be cut during restoration activities and the logs and wood sold as byproducts of the restoration work, the project will also be subject to the California Forest Practices Act. A licensed forester can assist with preparation of the required permits needed for commercial forestry operations. If, on the other hand, the wood will not be sold but used in the project (e.g., to place in the stream channel or to use as bank protection), a timber harvest plan may not be necessary. In either case, consultation with a local office of the Department of Forestry and Fire Protection is recommended.

Finally, if the preliminary survey of an erosion area suggests that a failure area of unknown type and depth may be present, characterization of the problem and any treatment prescriptions must be developed in consultation with a licensed geotechnical specialist. All but the smallest landslides can be very complex features and the development of effective treatment options more often than not will require consultation with a licensed geotechnical specialist. The Board for Geologists and Geophysicists (BGG) examines and licenses Professional Geologists, Certified Engineering Geologists and Certified Hydrogeologists in California. The Board and licensed professionals in the field can provide information on circumstances that require professional advice.

SEDIMENT PRODUCTION AND DELIVERY

Land use activity can accelerate the natural background rate of erosion. It may also result in chronic delivery of sediment to stream channels. Three geomorphic processes are responsible for most sediment delivery from upland areas (Figure X-1). These are:

- Chronic surface erosion from bare soil areas;
- Fluvial erosion, including gully and stream channel erosion;
- Mass wasting or landsliding.

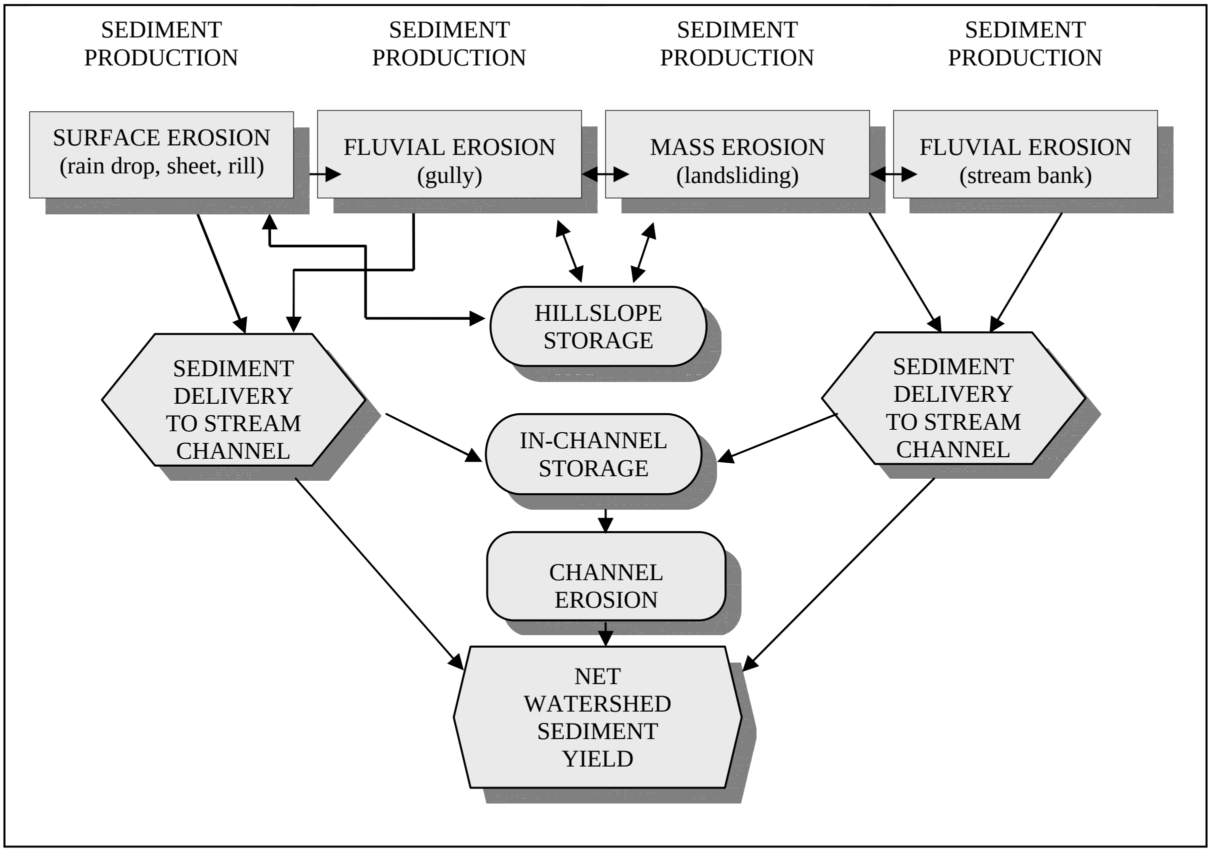


Figure X-1. Flow chart of erosion and sediment delivery to stream channels.

Understanding these processes is necessary for conducting successful upslope assessment and restoration (Table X-1). Most of these processes, once initiated, result in erosion of sediment, which transports to hillslopes or stream channels. Whether the sediment remains in storage, either on the hillslope or within the channel, depends on the sediment types; and the timing, magnitude and frequency of storm events within a watershed. Once sediment suspends in water, or is mobile within the streambed, it becomes part of the net watershed sediment yield.

Watershed erosion processes are neither simple nor easily controlled by human intervention. Some conditions are not restorable, reversible, or correctable. Successful treatments for erosion prevention and erosion control should be designed to address the erosion process (surface erosion, fluvial erosion, or mass wasting), not the land use. Thus, gully control practices are generally the same whether they are applied on agricultural areas, grazed land or for road-related erosion sites.

Finally, it is generally not possible, nor necessarily desirable, to stop all erosion. The preferred approach is one that reduces the risk of erosion or reduces the volume of eroded sediment delivered to a stream by the most effective and cost-effective method.

Process	Typical upslope sediment source locations	Sediment source characteristics and restoration opportunity					
		Nature of erosion processes	Aggregate sediment delivery	Sediment type	Preventable erosion?	Controllable erosion?	Preventable sediment delivery?
Surface erosion	Surface erosion from bare soil areas (road surfaces, construction sites, burned areas, etc.)	Chronic	Moderate	Fine Grained	Sometimes	Rarely	Usually
Mass wasting	Road fillslope failures	Mostly episodic, triggered by large storm events	Low to Moderate	Fine to Medium Grained	Usually	Rarely	Usually
	Landing failures		Low to Moderate	Fine to Medium Grained	Usually	Rarely	Usually
	Road cutbank failures		Low	Fine to Medium Grained	Rarely	Sometimes	Usually
	Stream bank landslides		Low to Moderate	All Grain Sizes	Sometimes	Rarely	Rarely
	Non-road (hillslope) debris landslides		Low to High	All Grain Sizes	Sometimes	Rarely	Rarely
	Earthflows and large, slow moving landslides		Low to Moderate	All Grain Sizes	Rarely	Rarely	Rarely
Fluvial erosion	Stream crossing washouts (gullies)		Low to Moderate	Fine to Medium Grained	Usually	Usually	Rarely
	Stream diversions (gullies)		Low to Moderate	Fine to Medium Grained	Usually	Usually	Rarely
	Other road-related gullying		Low	Fine to Medium Grained	Usually	Usually	Usually
	Non-road gullying		Low	Fine to Medium Grained	Sometimes	Sometimes	Rarely
	Stream bank erosion		Low to Moderate	All Grain Sizes	Sometimes	Sometimes	Rarely

Table X-1. Sources, magnitude and restoration potential of sediment production and delivery mechanisms in upland watersheds.

To accurately identify upslope sediment sites and recommend effective and cost-effective treatments, restoration practitioners must have a clear understanding of the following:

- How erosion processes operate and lead to sediment delivery to streams;
- How land use affects erosion processes in predictable ways;
- Which erosion processes are preventable and controllable, and which are not;
- How the recommended erosion treatment will result in reduced sediment delivery to a stream.

Surface Erosion

Surface erosion results from raindrop impact and un-channeled water flowing over bare soil during and after rainstorms. Exposed soil is a direct consequence of almost all land use activities. Anywhere there is bare soil there will be potential for surface erosion. Runoff and surface erosion from bare soil areas depends on rainfall intensity and duration, the frequency of disturbance, the length of time exposed, soil type and grain size. Often, surface erosion from bare soil areas diminishes after the first rain event, except on unsurfaced roads and other bare soil areas where disturbance and resultant surface erosion can become a chronic problem.

Rates of surface erosion vary from watershed to watershed. In some watersheds where mass wasting is relatively uncommon, but soil easily erodes, surface erosion can be the predominant sediment delivery process. Surface erosion turns into sediment delivery when the runoff discharges into a stream channel, often through rills or small gullies. The development of rills, defined as channels smaller than 1' x 1' in cross section, is included with surface erosion processes.

Characteristics of Surface Erosion

- Surface erosion is greatest in fine granular soils such as silt and sand. Areas of decomposed granitic bedrock are particularly susceptible. It is typically lowest in rocky or clay-rich soils.
- Surface erosion is greatest in the first year after exposure and usually diminishes greatly thereafter unless the area is chronically disturbed as on unsurfaced roads.
- Surface erosion moves and delivers mostly fine sediment such as clay, silt or fine sand.
- Eroded sediment does not move long distances unless transported by rills, gullies or other concentrated flow channels such as road ditches or ruts.
- Sediment delivery to a stream requires direct connection of bare soil areas with stream flow channels such as rills, gullies, and ditches.
- Site-by-site, surface erosion volumes are often comparatively small, but cumulatively, over time, or over large watershed areas, volumes can be very large.

Restoration and Protection Principles for Surface Erosion

- Keep bare soil to an absolute minimum when conducting land use activities. This is the single most effective method for preventing land use related surface erosion.

- Mulch or revegetate bare soil adjacent to stream channels, or other flow transport paths, to the break-in-slope near those areas. Mulching is the single most effective and cost-effective method for controlling surface erosion.
- Keep runoff from bare soil areas well dispersed. Dispersing runoff keeps sediment on-site and prevents sediment delivery to streams.
- Direct any concentrated runoff from bare soil areas into natural buffers of vegetation or to gentler sloping areas where sediment can settle out.
- Prevent rills by breaking large or long bare areas up into smaller patches that can be effectively drained before rills can develop.
- Disconnect and disperse flow paths, including roadside ditches, which might otherwise deliver fine sediment to stream channels. This prevents most sediment delivery.

Fluvial Erosion

Fluvial erosion includes gully erosion and stream bank erosion. It occurs when concentrated flowing water scours and erodes soil along its path, whether it is within a natural stream channel, or on a previously un-channeled slope. The amount of erosion that occurs is a combined function of the energy of the flowing water and resistance of the flow path to scour. Thus, the greater the flow volume or flow velocity, the greater is the erosive power. Similarly, the more erodible the soil type, the more soil loss will occur. Fine grain granular soils like silt and sand are most likely to erode; and rocky soils and bedrock are the least likely to erode.

Fluvial erosion can also be a chronic source of sediment, where gullies gradually increase in size or stream banks continue to erode, with routine runoff events. However, most erosion and sediment delivery from fluvial processes occurs during episodic storm events. The largest storm events usually trigger greatly increased fluvial erosion, as new gullies form and existing gullies enlarge. Periods between episodic storm events are usually times of lower fluvial erosion rates.

Fluvial erosion is usually a very efficient sediment delivery mechanism. The larger a gully system, the more likely the eroded sediment will be delivered directly to a stream channel. Fluvial erosion rates can vary greatly between watersheds, depending on soil types, land use and land management practices.

Fluvial erosion may be accelerated by land use activities that result in increased runoff, or allow runoff to concentrate and discharge onto hillslopes prone to erosion. Fluvial erosion commonly occurs at gullies developed on hillslopes at culvert outlets, diverted streams, washed-out stream crossings, inboard ditches, and stream channels exposed to increased runoff.

Stream crossings are common sites of gully erosion along road systems. They commonly fail in the following ways:

- Overtopping, which may occur when a culvert plugs, or its capacity is exceeded and water flows over the road;
- Stream diverts when a culvert plugs or its capacity is exceeded, and the stream flow is diverted down the road, instead of over-topping the stream crossing fill;

- The crossing collapses when the stream flow tunnels through the fill, as occurs with Humboldt log crossings, and rusted out culverts;
- Stream crossing fills without culverts on abandoned roads gradually erode and wash out.

Characteristics of Fluvial Erosion

Although minor scour may occur and banks may locally collapse and erode between storms, a gully formed by a large runoff or flow event may not grow significantly, until an equal or larger event occurs. The following are characteristics of fluvial erosion:

- Sediment delivery from fluvial erosion can be both chronic and episodic. Fluvial erosion produces, transports, and delivers both fine and coarse sediment to stream channels.
- Stable gullies can serve as conduits for fine sediment delivered from other sources, such as roads. Any sediment delivered to a gully system from another sediment source such as road surface runoff, is likely to deliver to a stream channel somewhere down slope.
- Gullies are channels that have a cross sectional area over one square foot (1' x 1'). Gullies are like conveyor belts; they are very efficient sediment delivery mechanisms that can transport eroded sediment long distances over varied terrains and slopes.
- Gullies in rocky soils tend to eventually armor themselves and become increasingly resistant to continued down cutting and enlargement.
- Individual fluvial erosion sites may be small (less than 10 yd^3) but huge gullies (greater than 1,000 yd^3) can also develop on unstable hillslopes. Concentrated runoff and diverted streams can create large gullies, and may trigger the formation of landslides on otherwise stable hillslopes.

Restoration and Protection Principles for Fluvial Erosion

- Prevent gullies by dispersing runoff from roads, ditches and construction sites, by correctly designing, installing and maintaining drainage structures (e.g., road shape, rolling dips and culverts) and by keeping streams in their natural channels. No single point of discharge from a road or other disturbed area should carry sufficient flow to create gullies. If gullies continue to develop, further disperse the runoff.
- Direct any concentrated runoff from bare soil areas, such as road surfaces, into natural buffers of vegetation, or to areas where sediment can settle out of the runoff.
- Dewater active gullies to prevent their enlargement and to reduce their capacity for sediment transport.
- When dewatering is not possible, options include channel armoring and grade control structures. These specialized erosion control techniques are more costly and less effective than prevention and dewatering, and do not stop sediment transport. They typically require an engineered design, proper installation, and a commitment to maintenance (*Part VII*).

Mass Wasting

In many watersheds in north coastal California, mass wasting is the most common geologic process of sediment production. Common types of landslides in the natural environment range from large rotational and translational landslides and earthflows, to large and small debris slides, to small slumps. Landslides typical in steep forested terrain of coastal California have been described (CGS 1999) and mapped (CGS 1982-95) in many coastal watersheds of northern California. CGS Note 50, *Factors Affecting Landslides in Forested Terrain*, provides descriptions and illustrations of the various types of landslides that have been identified on the north coast. The California Geological Survey (CGS) landslide inventory maps (CGS Note 40) can be used to locate basic landslide features that have been identified and mapped in many salmonid watersheds of Del Norte, Humboldt, and Mendocino counties, as well as selected other watersheds of the State (CGS 1982-95). These maps can help restorationists identify unstable and potential unstable terrain within watersheds that are targeted for erosion inventories and development of erosion control plans.

Landsliding is a gravitational process. Soil slides down slope when the gravitational forces exceed the forces that hold it in place (friction). Factors affecting landslide sediment delivery include proximity to a stream, slope steepness, slope shape, moisture content, and soil composition. Landsliding occurs in the natural environment, but land management activities that cause increased driving forces or decreased slope resistance can accelerate it. Road construction and its associated spoil disposal is an example of a land management activity that may trigger landsliding. Land management activities that cause or increase landsliding include:

- Slopes undercut and destabilized during road or other construction activities;
- Un-compacted and unstable spoil materials disposed of onto steep slopes;
- The diversion and collection of water on otherwise stable slopes.

There are a number of indicators of unstable or potentially unstable slopes. In the field, potentially unstable ground often, but not always, displays direct evidence of instability such as cracks, scarps, and leaning or pistol-butted trees. Previous failures in similar locations in nearby areas may also suggest the potential for addition slope instability. Slopes may also exhibit indirect evidence or a suite of contributing factors that can lead to slope instability. These factors include but are not limited to steep or oversteepened slopes, convergent topography, colluvial soils on impermeable shallow bedrock, emergent groundwater, hydrophillic (water loving) vegetation and mottled soils indicative of elevated ground water, known unstable soils and geologic formations, and proximity to faults and shear zones.

Water in and on hillslopes is usually a key contributing factor to the occurrence of landslides. Landslides often occur in close geographic proximity to springs, seeps and other forms of emergent groundwater. Roads intercept subsurface flow paths, with water either emerging from the cutbank (contributing to cutbank failures) or being blocked by overburden and uncompacted earthen materials disposed of downslope of the road (sidecast materials). Subsurface damming of groundwater contributes to fillslope failures and to larger debris slides where topographic swales and colluvial hollows fail by the build up of water pressures in the subsurface.

In general, the smaller the landslide, the more easily it can be prevented or controlled. In contrast, larger management-related landslides may be preventable, but they are rarely controllable once they begin sliding (TRB 1978; GSA 1987). Landsliding rates can vary greatly between watersheds, depending on natural slope stability, land use and management practices. Landsliding becomes sediment delivery when material slides or flows into a stream channel. Some types of landslides are efficient at delivering sediment to streams while others rarely result in sediment delivery. Both timing and location in the watershed determine this. For example, streamside debris slides are infrequent but may result in substantial direct delivery of sediment, whereas cutbank landslides along roads are notoriously frequent, but typically lack major amounts of sediment delivery. Very few landslides deliver all their material to a stream; some sediment is generally stored on the hillslope.

Characteristics of Mass Wasting

- Sediment delivery to stream channels from landsliding occurs primarily as episodic inputs as the result of direct landsliding. Some slide surfaces, such as those on large landslides along roads or stream channels may remain largely un-vegetated for years, but surface erosion and gulling of the slide surface usually produces far less sediment delivery than the landslide event itself.
- Landsliding is predominantly an episodic process that occurs during or in response to rainfall and runoff events. Large storm events typically cause more and bigger landslides.
- Steep hillslopes, weak rock types and certain soils are more prone to landsliding than other soil types. In general, steeper hillslopes have a higher potential for landslides. Diverted runoff or slopes undercut by migrating streams can cause landslides to form on previously stable hillslopes.
- Sediment delivery is largely controlled by slope steepness, slope shape (i.e., concave, convex or planar), landslide volume, water content (fluidity), and proximity to the stream. Not all landslides deliver sediment to a stream channel. This depends on the failure mechanism, the distance between the failure area and the stream channel, and the overall mass of the slide.
- Some landslides that start out as small volumes can quickly increase in volume as they move down slope. Other landslides may quickly lose material as they move down slope. Water content, hillslope steepness and shape, landslide mass and the type, size and amount of vegetation in the landslide’s path largely control the distance sediment moves.
- Landslides that do result in direct delivery, deliver any trees and other organic material present in the area of failure along with all sediment grain sizes that are present on the hillslope and in the underlying soil and bedrock material.

Restoration and Protection Principles for Mass Wasting

- Prevent accelerated landsliding by identifying, avoiding and protecting potentially unstable slopes through appropriate land management.
- Only treat landslides that have the potential to deliver sediment to a stream channel.
- Divert surface and subsurface drainage to stable areas away from steep, unstable slopes.
- Revegetation is a valid long-term restoration technique for unstable and potentially unstable slopes, but revegetation is sometimes very difficult and the benefits will take decades to develop.
- Small landslides, especially those that occur in sidecast materials, are often most effectively prevented or controlled by direct excavation of all or most of the potentially unstable material. This is often the most effective and cost-effective technique for preventing road-related landsliding.

- In some instances, sediment delivery from some medium and large size landslides can be controlled by excavating and removing material at the head of the slide. Removal of mass from the top of a slide may unload the slide sufficiently to stabilize the remaining mass. Projects to stabilize landslides must consider the size and volume of the slide, the volume of sediment to excavate, and the predicted volume of sediment prevented from delivery to a stream. The amount of unloading required is a technical assessment that requires professional analysis. The California Business and Professions Code requires that such a determination be made by a registered Professional Geologist, a Certified Engineering Geologist, or geotechnical Professional Engineer working within their area of expertise.
- The most cost-effective restoration treatment for large, uncontrollable landslides is often direct excavation and removal of slide material poised for delivery to a stream. This technique reduces sediment delivery but does not attempt to prevent or control landslide movement. Corrective actions and control measures for medium and large landslides are outside the scope of this document and require the assistance of appropriately trained and experienced Professional Geologists, Engineering Geologists and Geotechnical Engineers.
- Large landslide scars can be slow to revegetate, and although highly visible for many years after the initial failure, the scars may be an artifact of past landsliding and not an indication of future landslide potential. In many cases, most future sediment delivery from bare landslide scars will come from surface erosion and gullying. These processes are often not cost-effective to control due to the difficulty of access, extremely steep slopes, and harsh site conditions.
- Vertical head scarps and tension cracks around the top of old landslides are usually signs of stress relief that developed during or immediately after the original landslide failure. They are usually not sites of future sediment delivery because the potential sediment volumes are comparatively small and any material that does fail is usually redeposited immediately down slope on the original slide mass. Head scarp areas of old landslide scars should only be considered for treatment if there is the potential for future sediment delivery, and then only in consultation with licensed and experienced geotechnical professionals.

UPSLOPE EROSION ASSESSMENT

Determining which watersheds have the greatest potential for salmonid restoration is critical in identifying candidate watersheds for erosion assessment. Impacted watersheds with restorable salmonid populations are obvious targets for erosion assessment. Recovery of ecosystem function will be most successful where there is both restoration and prevention efforts. There is no easy, quick, or cheap way to restore most watersheds.

Healthy watersheds with strong salmon and steelhead populations are also in need of erosion assessment, for they will be the seat of future stock recovery for nearby degraded watersheds (Bradbury et al 1995). Although healthy watersheds may serve as refugia for salmonid populations, consider the potential for future sediment-related degradation. This dictates the inventory of healthy watersheds, and inclusion of sediment reduction measures in future land use activities.

Assessment Scales and Priority Criteria

Watershed problems and restoration treatments vary across the landscape. It is important to set priorities for both upslope assessment and for resultant protection and restoration actions. In the context of this manual, salmonid conservation biology drives the need for upslope assessment and restoration. For this reason, it is important to develop a biologically based strategy for setting watershed assessment, protection and restoration priorities (Bradbury et al 1995).

Watershed Categorization

Divide watersheds into logical assessment and restoration units. Prioritize both upslope assessment and actual restoration treatments on these land units (Figure X-2). From large to small, these assessment land units include:

- River basins - large land units with an integrated drainage system often exceeding 300 square miles in area and containing many named subbasins and watersheds and many miles of fish bearing (or Class I) stream channels (e.g., Mattole River, 396 mi^2);
- Subbasins - intermediate to large size land units, consisting of integrated drainage systems with an area generally ranging from 50 to 300 square miles or more and generally including many named watersheds and Class I stream channels and tributaries (e.g. Western Mattole Planning Subbasin, 89 mi^2);
- Watersheds - intermediate sized land units, consisting of integrated drainage systems with an area generally ranging from 10 to 50 square miles with a number of named tributaries and few to many sub-watersheds and Class I stream channels (e.g., Honeydew Creek, 17.2 mi^2);
- Sub-watersheds - smaller watershed units generally ranging from 1 to 10 square miles with few or no Class I stream channels (e.g., Bear Trap Creek, 1.7 mi^2);
- Hillslope units - logical topographic or management units within a watershed or sub-watershed that may be defined by natural boundaries (such as ridges and streams) or by management features (such as roads);
- Sites - individual treatment sites of on-going or future sediment delivery ranging in size from 100 ft^2 (or less) to 100 acres. This includes individual stream crossings, gullies, stream banks, road reaches, landslides and other erosion sources.

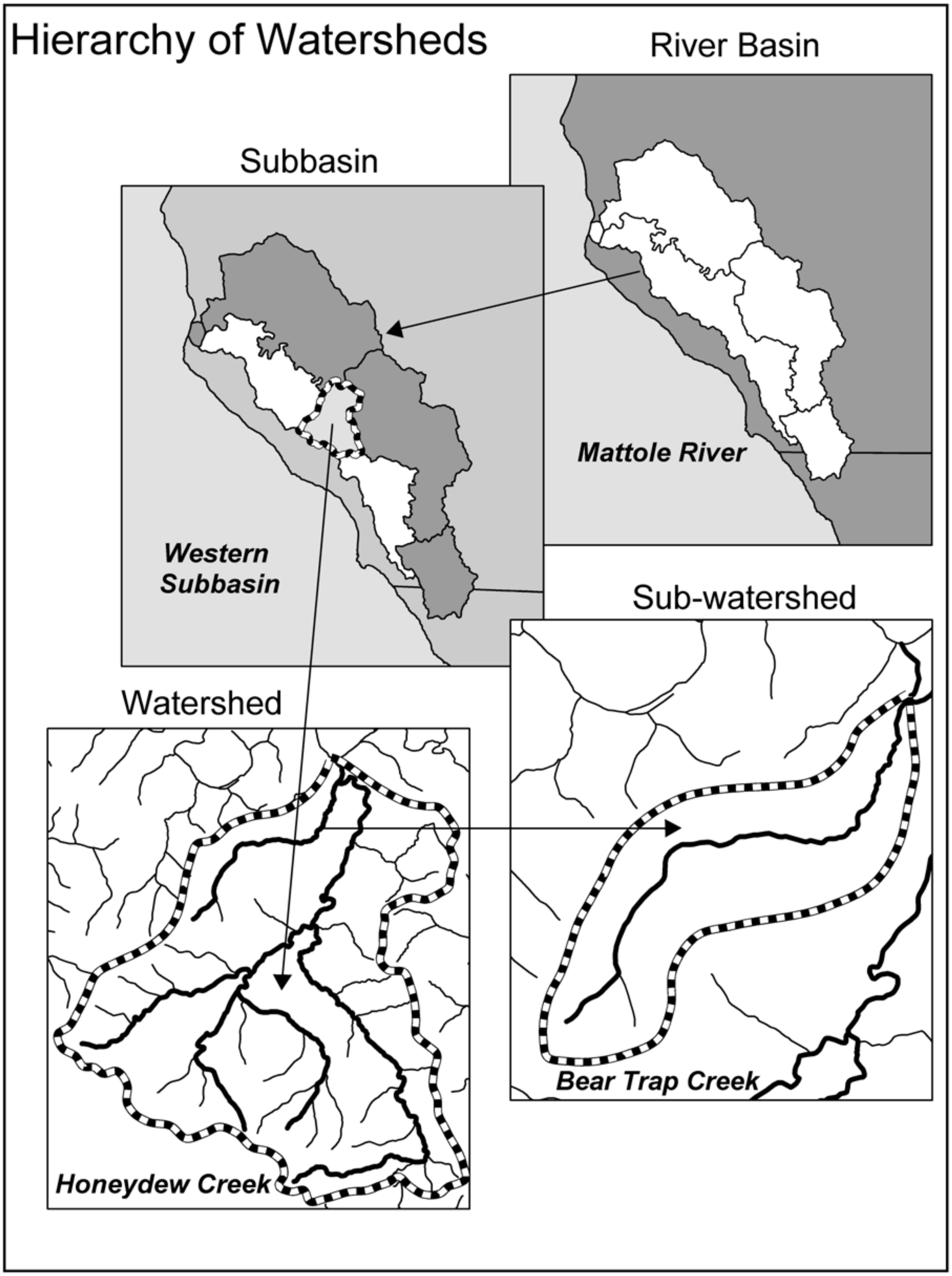


Figure X-2. Watershed hierarchy.

Priority Criteria

Prior to conducting an upslope assessment, research the relative health of the salmonid populations and habitat conditions in the assessment area of interest. Base the assessment on known or suspected limiting factors for salmonids, as well as on potential resources at risk where the aquatic system is not severely impaired but where watershed threats may be imminent. This dual focus will direct assessments to watersheds where the best benefit to the resources are achievable. Information that would support this conclusion, and the decision to proceed with an upslope assessment, is often available from DFG or other professionals who are most familiar with watershed conditions, historic and present use by salmonids, limiting factors, threats and the overall health of the aquatic system. A restoration and protection strategy can then be employed which makes logical and biological sense.

1st Priority - Habitat Protection

Aim initial efforts at protecting the best remaining refuge watersheds; that is, those areas with the best habitat, and healthiest and most diverse populations of fish and other forms of aquatic life. This may also include areas where special at-risk populations are present. The success of the protection effort is dependent on the effective use of protective land use practices and preventative land management.

2nd Priority - Habitat Restoration

This includes impacted watersheds that still have the potential for recovery. In these watersheds, use restoration as a tool to enhance or recover fish populations and aquatic ecosystem function over the intermediate term. These watersheds include streams that have had historic fish runs but do not currently support viable fish populations. Because of relatively few limiting factors, restoration activities should focus on the causes, not symptoms, to improve watershed and habitat conditions and processes. These sites, when improved, will become logical areas for fish to re-colonize most rapidly. Even though protective land use practices are undertaken, full recovery of these watersheds could take decades.

3rd Priority - Water Quality Restoration

This includes those sub-watersheds and headwater areas where access for anadromous fish is naturally limited due to increased stream gradient or natural barriers. These areas nonetheless perform vital ecological function for the entire aquatic ecosystem, by providing cool, clean water, large woody debris, and food (nutrient) products for aquatic species. Example treatments include upslope and riparian restoration to reduce sediment inputs and to lower summer water temperatures to larger connecting streams utilized by anadromous fish.

4th Priority – Mainstem River Restoration

Estuary enhancement, adult and juvenile salmonid migration improvements and riparian restoration are projects done directly to improve the main channel of most large river basins to improve fish and aquatic habitat. These areas are critical for anadromous fish.

5th Priority or Last Priority Watersheds

It may be best to consider watersheds with multiple limiting factors non-restorable. These watersheds could absorb most of the money that is available for watershed restoration, with little or no chance for noticeable recovery within the time span of several human generations (Frissell

1993). Identify non-restorable watersheds early in the planning process. Consider work in these areas after protection and completion of erosion prevention in the more productive watersheds is accomplished.

Site Specific Assessment Strategies

When not all of a watershed or sub-watershed can be completely inventoried with the available funding and resources, there are other strategies that can be employed to help direct assessment efforts. Certain sub-watershed areas and management conditions are more likely to contain problems than others; these are usually the best places to focus on when inventory resources are limited. Two recommended areas to focus on are:

- Sensitive landscape areas**:** Lower hillslope areas; steep hillslopes; riparian zones; fish bearing stream channels; areas with a high density of stream channels; and areas of highly erodible or unstable soil. These areas are sensitive because of their susceptibility to erosion and/or mass wasting, or because they are so close to stream channels that any significant erosion would deliver sediment to streams and adversely affect fish habitat.
- Common sediment producing areas in managed landscapes: This considers roads of all types, including railroad grades, jeep trails, and logging skid trails; quarries and rock pits; cultivated agricultural areas on hillslopes; all terrain vehicle (ATV) and livestock trails; development and construction sites; and recently burned or cleared areas.

Assessment Scales

When possible, assess a watershed in its entirety. If social and economic factors necessitate a partial assessment, then assess the most biologically important sub-watersheds first, with completed inventories developed into prioritized restoration plans for the inventoried sub-watersheds as the assessment progresses. Alternately, if funds are limited, assessment of low risk areas (e.g., ridge tops) in these same sub-watersheds can be deferred while those portions of the landscape that are most likely to contain significant, treatable sediment sources (e.g., lower and middle hillslope areas with high road densities and/or abandoned roads and numerous stream crossings) can be inventoried first. Sometimes, landowner access will partially dictate which watershed areas can be inventoried.

The following list outlines some examples of high and low priority assessment areas or features used to stratify a watershed or sub-watershed for partial assessment.

Higher priority assessment areas in watersheds typically include such features as:

- Roads in sensitive hillslope locations (steep, unstable slopes);
- Roads built in highly erodible terrain (decomposed granite and erodible grassland soils);
- Roads with numerous and/or volumetrically large stream crossings;
- Old roads and abandoned roads with stream crossings;
- High use, unsurfaced or rock surfaced roads;
- Hillslopes exhibiting diverted streams and skid trails;
- Class I stream channels;
- Recent construction areas, rock pits and borrow sites.

Lower priority assessment areas typically include such features as:

- Ridge tops and ridge top roads;
- Upper hillslope roads with gentle or moderate slope gradients (<35%);
- Hillslopes with roads but few or no streams;
- Roads built on moderate or gentle hillslope areas anywhere in a watershed;
- Harvested hillslopes that have been cable yarded or helicopter logged;
- Hillslope areas with little or no recent land management.

If portions of a watershed or sub-watershed are selected for assessment, as opposed to the entire area, have the plan reviewed by an experienced restoration specialist or DFG biologist before proceeding. Partial assessments run the risk of improperly ignoring or excluding portions of a watershed that may be affecting or threatening salmonid spawning and rearing habitat.

Landowners have found sediment source inventories to be very useful for conserving both natural resources, and time and money. For example, the landowner can query the resultant database to determine how many sites exist and how much future erosion could occur along each particular road. If erosion at a number of sites is uncontrollable, then the landowner may choose to decommission the road and access that portion of the property through a new, more stable route. Through this analysis, the landowner may decide some roads may be worth upgrading while targeting others for permanent or temporary decommissioning.

Upslope Sediment Source Assessment Elements

Watersheds where salmonid resources are impaired or threatened by sediment derived from land use impacts are important candidates for upslope assessment and treatment. Conduct upslope assessments only after securing written permission from landowners or land managers. Two important watershed conditions to identify and consider include:

- Watersheds where degraded instream or riparian habitat limits salmonid populations and the problems have been caused by excessive sediment from the watershed to the streams;
- Watersheds where the instream habitat and riparian zone is not presently impaired, but stream resources are at potential risk because impacts may be imminent due to upslope instability and/or disturbance.

This dual focus will direct upslope assessment to watersheds where assessments will most likely lead to treatments that benefit salmonids and the overall health of the aquatic system. This methodology for upslope assessment promotes proactive watershed restoration for salmonids. It identifies significant sources of ongoing or future erosion that will lead to sediment delivery to streams in the watershed and that are amenable to treatment. This is termed a “forward looking assessment of sediment delivery”. Not all potential sediment sites may be treated, but their identification is an important first step to developing a cost-effective restoration plan.

Base a forward-looking upslope assessment upon field assessments that use logical, standardized, science-based observations, measurements, and deductive reasoning. The goal of this uniform data collection and resultant inventory is to deliver a watershed restoration plan that:

- Identifies the nature and magnitude of the erosion problems in the watershed;

- Provides quantified risk assessment data;
- Estimates the volume of sediment potentially prevented from delivery to streams;
- Develops a prioritized list of site-specific treatment prescriptions and associated cost estimates.

Assessment of past erosion and sediment delivery can provide an estimate of the relative magnitude and causes of various past sources of sediment delivery. This will provide some understanding of the importance of human-caused sediment sources over which there could be some control. Such an analysis may also provide insight about which land use practices contribute to increased sediment delivery, and might still be a factor in accelerated erosion.

Transportation Planning

The process of identifying a long-term strategy for road and erosion management is termed a transportation plan. Such a plan is developed by working closely with the landowner, and includes and integrates an estimate of the capital expenditures needed to upgrade and/or decommission elements of the present road network as well as the expected reduced long-term maintenance costs once all erosion prevention work has been undertaken.

In developing and implementing a transportation plan, consider all existing roads for either decommissioning or upgrading, depending upon their utility to the landowner and their risk to the aquatic ecosystem. Not all roads are high-risk roads and those that pose a low risk of affecting aquatic habitat may not need immediate attention. It is therefore important to rank and prioritize roads in each sub-watershed based on their potential to impact downstream resources, as well as their importance to the overall transportation system and management needs of the landowner.

Quality Assurance and Quality Control in Upslope Assessment

Quality assurance is an important component of both the assessment and the implementation phase of watershed restoration. Sediment source assessments, and the subsequent erosion prevention activities, are expensive. In the assessment process, the use of quality assurance measures minimizes the likelihood that incorrect interpretations will lead to unnecessary or overly expensive implementation. Quality assurance during a sediment source assessment ensures that the assessment is as thorough and accurate as possible. To achieve quality assurance it is required that:

- Inventory personnel are properly trained;
- Crew size is a minimum of two persons for efficiency and safety;
- Data are collected in a systematic and standardized format;
- Established protocols are followed;
- Significant sediment sources are not overlooked or ignored;
- Sediment savings volume estimates are accurate;
- Treatment cost-estimates are accurate and reasonable.

Quality control during implementation treatments represents another critically important component of effective and cost-effective upslope restoration and sediment control. Quality control measures utilized during the on-the-ground erosion prevention and control work helps ensure that the most effective and efficient techniques are applied, and that the completed project meets the design standards established during the inventory process.

Technical Oversight of Inventory Crews
The work of inventory crews should receive regular technical review by qualified erosion control or watershed assessment specialists to verify the thoroughness, accuracy and consistency of problem identification, field interpretations, volume calculations, delivery estimates and treatment prescriptions.

Review of Field Assessments and Treatment Prescriptions
Once the field component of the inventory is completed, conduct a review of the preliminary assessment data. Include in the review the crew supervisor, affected landowners, and the erosion control or watershed assessment specialist(s). The review should consist of field site inspections and review of the products of the assessment including:

- Adherence to established assessment protocols;
- Accuracy in problem site identification;
- Accuracy in problem site quantifications (e.g., volume measurements and delivery estimates);
- Correctness in proposed restoration treatment prescriptions;
- Precision of heavy equipment and labor prescriptions, and associated cost estimates.

On large watershed assessments, or in cases where there are significant revisions identified during the review, more than one field visit may be warranted. The crew supervisor should write a brief report describing the revisions and attached it to the *Upslope Inventory Data Form*.

Review of Prioritized Restoration Plan and Cost Analyses
Review the draft restoration plan before it is finalized, to assure the cost analysis is accurate and correct, and that the prioritized restoration plan for the watershed is supported by the inventory results. Reviews conducted by qualified and experienced agency personnel or qualified specialists should include a brief narrative or checklist confirming the content, accuracy, and thoroughness of the inventory and the restoration plan, as well as the appropriateness, effectiveness and cost-effectiveness of the proposed restoration treatments.

Assessment Preparation

Prior to conducting field inventory work, several preliminary tasks will make the subsequent fieldwork easier and more meaningful.

Review Available Information

Contact DFG fisheries staff to see if there is a watershed assessment report or stream inventory report for the assessment area. Contact other public resource agencies, private landowners, watershed groups and any other potential data sources to gather all relevant information on land use, erosion, stream conditions and aquatic resources for the area. Review existing maps, data and reports that might be useful in conducting the assessment and preparing the plan.

Obtain Supplies and Equipment

Prior to beginning the sediment source assessment, assemble the necessary office and field supplies and equipment (Table X-2).

Complete Contractor and Field Crew Trainings

Project personnel should complete DFG-approved basic field training in sediment source assessment. The trainers are qualified and experienced erosion control and watershed assessment specialists. The training includes erosion site identification, site description methods and classification, problem quantification, prescription development, cost-effectiveness analysis, air photo analysis, map making, field sketching, monitoring techniques and database analysis procedures. The training also includes discussion about and typical examples of complex erosion problems and mass wasting features likely to require consultation with a licensed, experienced geologist, engineering geologist, geotechnical engineer, hydrologist or qualified erosion control specialist.

Conduct Analysis of Stereo Aerial Photos

Prior to going into the field, conduct an air photo analysis of the assessment area to help identify the location of sensitive roads and other high priority areas for field mapping, analysis and potential treatment. Potential sources for air photos include:

- California Department of Forestry (CDF);
- Department of Conservation/California Geological Survey (CGS);
- Department of Fish and Game (DFG);
- Regional Water Quality Control Boards (RWQCB);
- County Assessor or Planning departments;
- United States Geological Survey (USGS);
- National Resource Conservation Service (NRCS);
- Bureau of Land Management (BLM);
- Environmental Protection Agency (EPA);
- US Forest Service (USFS);
- Private industrial landowners;
- Commercial air photo vendors.

Public resource agencies are likely to know the best sources of available photography for a particular watershed. Select historic aerial photographic coverage from a number of years (perhaps one flight per decade) to bracket major storms. Photos are available beginning in the 1940's or 1950's for most watersheds.

Air photo analysis is useful to develop a general basin background and land use history, including a road construction history. It is important to identify maintained and abandoned roads, and landings that are potential or on-going sediment sources. Air photos can also be used to develop an optional landslide history for the watershed, as well as an historical assessment of stream channel conditions, although in most streams only major areas of bank erosion or channel aggradation will be visible.

<u>Necessary or desirable items:</u>

- Aerial photos (1:12,000 or larger scale; laminated if using in the field)
- Mylar (3 mil, frosted on one side cut to 9" x 9"; for mapping sites on photos)
- Data form, on waterproof paper
- Computer with database software (e.g., MS Access)
- Clipboards
- Mechanical pencils (several per person)
- Scientific calculators, with trigonometric functions (solar powered preferable)
- Permanent markers, fine point (for marking information on flagging at sites)
- 150 foot tape with marks in 10ths of feet (one per crew)
- Pocket rulers (with 10ths and 50ths scale; one per person)
- Clinometers (marked in degrees and percent; one per person)
- Flagging - color(s) to be identified by crew (several boxes)
- Vests (one per person)
- Good field boots (treated waterproof)
- Drafting tape
- First aid kits, first aid supplies and survival supplies (e.g., matches, knife)
- Day packs
- Pocket stereoscopes (one per crew is probably sufficient)
- Map wheel (for measuring distances on maps and photos)
- Planimeter or dot grid (for measuring areas on maps and photos)

<u>Optional items:</u>

- 4x4 field vehicle(s)
- Distance measuring computer(s) for vehicles
- Geographic Positioning System (GPS) unit (portable, for mapping site locations)
- Electronic range finder (laser hand-held distance measuring device)
- Small chain saw, axe, brush hook or equivalent
- Rope (for going down steep slopes)
- Tow rope, cable or chain (for moving downed trees)
- Increment borer (for dating trees on landslides)
- Laptop computer (for field data entry, database and data analysis)
- Software for calculating stream crossing volumes
- Geographic Information System (GIS) mapping software
- Pocket rods marked in 10ths of feet (one per person)
- Compass
- Colored pencil set
- Rain gear and rubber boots
- Table stereoscope
- Monopod
- Digital camera and batteries, or 35mm camera and film, with 28mm zoom lens (wide angle required)
- Radio (CB, mobile phone or other for emergencies and communication)

Table X-2. Field equipment and material needed for upslope watershed assessments.

Results of the air photo analysis should be represented on a large format hard copy map (scale 1" = 1000', or larger), or in electronic GIS format so that future field inventoried sediment sites can be accurately plotted. The map will show roads by type, time of construction and past use, and status. Once fieldwork is completed, this base map will show all inventoried sites and it will form an important component of the watershed restoration plan.

Collect Field Data

Use the *Upslope Inventory Data Form* and the *Stream Bank Inventory Data Form* to record information in the field. Collect data on paper data forms or electronically in hand held or laptop computers. Paper data forms provide the security of a hard copy of the original data and the flexibility of allowing for developing field sketches and collecting other non-database information. Collecting data on waterproof paper forms is generally the preferred method.

Data Format

Collect field data in both qualitative and quantitative formats, depending on the question. Enter the data in a relational database with all data fields in unique, pre-established formats. Exceptions are where a descriptive response is necessary, or where other types of information are recorded that cannot be entered in the database, such as a sketch map of the site (Figure X-3). Collect data measurements in predefined units (feet, inches, meters, cubic yards, etc.).

Site Definition Criteria

Most watersheds have many locations of existing and potential erosion. It would not make sense to inventory them all, because some are very small and some will not deliver sediment to a stream channel.

- Inventory only sites of future sediment delivery. When working for DFG, do not inventory an erosion site if it is unlikely to deliver sediment to a stream in the event of future erosion or hillslope failure.
- Prior to the start of a sediment source inventory, establish a minimum sediment delivery volume to qualify a site as a measurable site. Typically, the minimum volume will be between 10 and 50 yds^3 of sediment delivery. Smaller sites should be located on a map or photo, but not described on a site data form. Use the *Upslope Inventory Data Form* to record sites that meet or surpass the established minimum volume criteria.
- For chronic road-related sediment sources, there is no minimum site volume. Inventory all sites of chronic sediment delivery.

Some sites of past erosion remain as eyesores. Often, large bare soil areas are mistaken to be more important than they really are. Define sites not by appearance, but by an analytical evaluation of the potential for future sediment delivery by erosion processes.

Upslope inventories often focus on road-related erosion because of its comparative importance, accessibility, and the relatively high cost-effectiveness of erosion prevention and erosion control treatments at road sites. In road-related inventories, include all stream crossing sites. Stream crossing sites normally have extremely high potential for direct sediment delivery to streams in the event of a culvert failure or stream diversion.

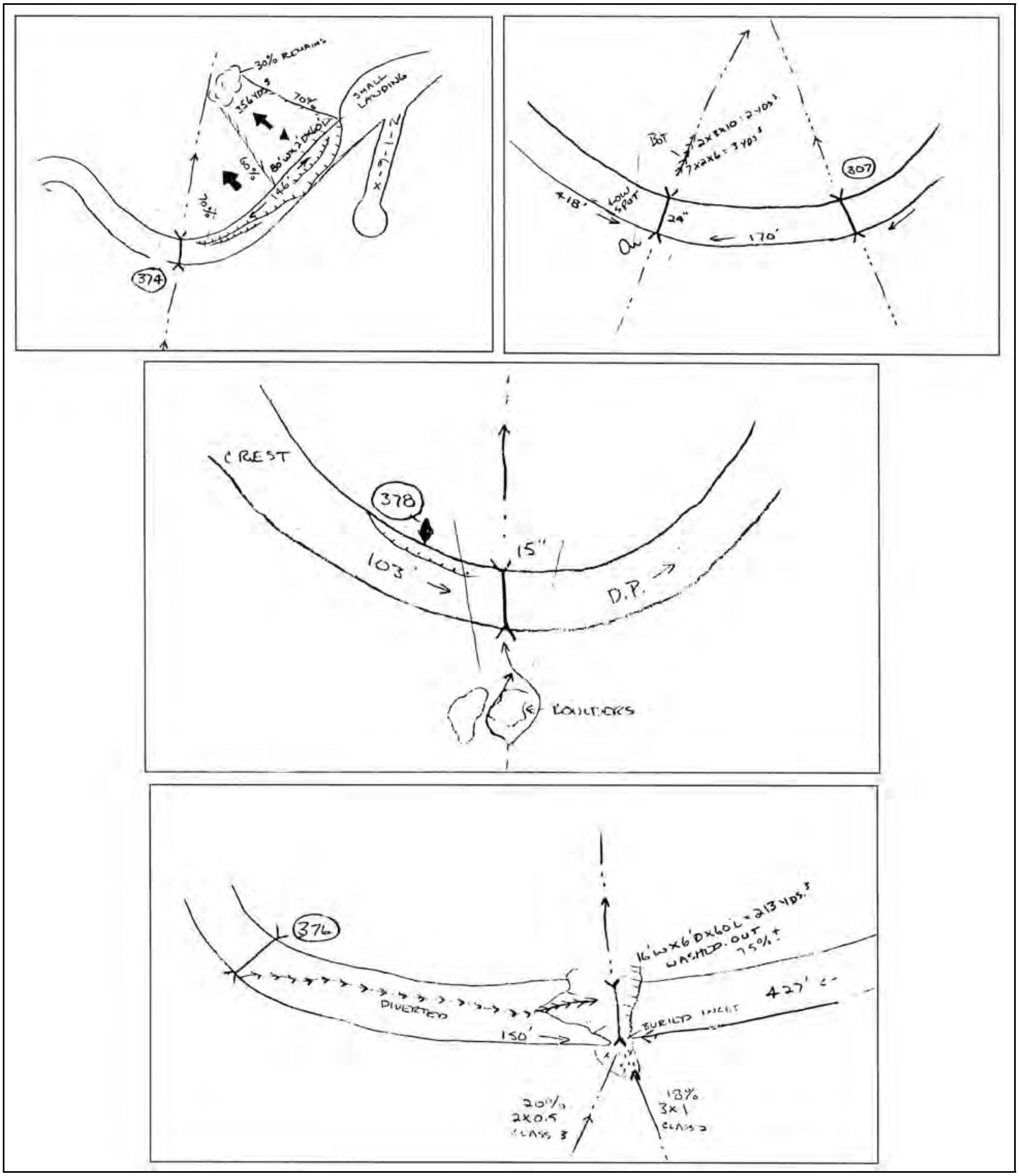


Figure X-3. Sample sketch maps of potential restoration sites, as portrayed on the *Upslope Inventory Data Form*.

Map Data

As field inventory proceeds, the potential sites identified can be numerous. Map the location of each site on a Mylar overlay, on the most recent aerial photo or map of the assessment area. Laminated copies of air photos work well for this purpose (Figure X-4). Enlarged aerial photos work well to map sites accurately. If aerial photos are not available, map site locations on the best available large-scale topographic or road map. For site identification, include GIS map coordinates or GPS satellite coordinates, where possible.

Use a standardized set of mapping symbols for recording site locations on air photo overlays or maps (Table X-3). Include these same symbols on field site marker flagging ribbons to identify the site and designate its type. Sketch in as accurately as possible abandoned roads not shown on the map.

Geology maps are available for the entire state and CGS Watershed Maps are available for many of the coastal areas. The maps are intended for the public for uses aimed ultimately at the reduction of erosion and landsliding, and the enhancement of water quality. The maps and explanations will enable users to: 1) recognize and "flag" areas of potentially unstable ground, and 2) foresee and minimize potential problems in these areas. The maps should be most useful for identifying unstable and erosion-prone areas on a regional scale, and in the preparation of large scale, long-range management plans that use geologic information to minimize environmental impacts. The maps are not a substitute for on-the-ground site-specific studies, but rather for identification of possible problem areas that may require consultation with a professional geotechnical specialist.

The watershed maps provide essentially the same information for each of the watersheds studied. Physical characteristics that can be correlated to landslide potential, soil erosion potential, and stream bank erosion potential are mapped at a scale of 1:24,000. The maps may be purchased from the California Geologic Survey, and are available for downloading in PDF format at http://www.consrv.ca.gov/cgs/thp/watersheds.htm.

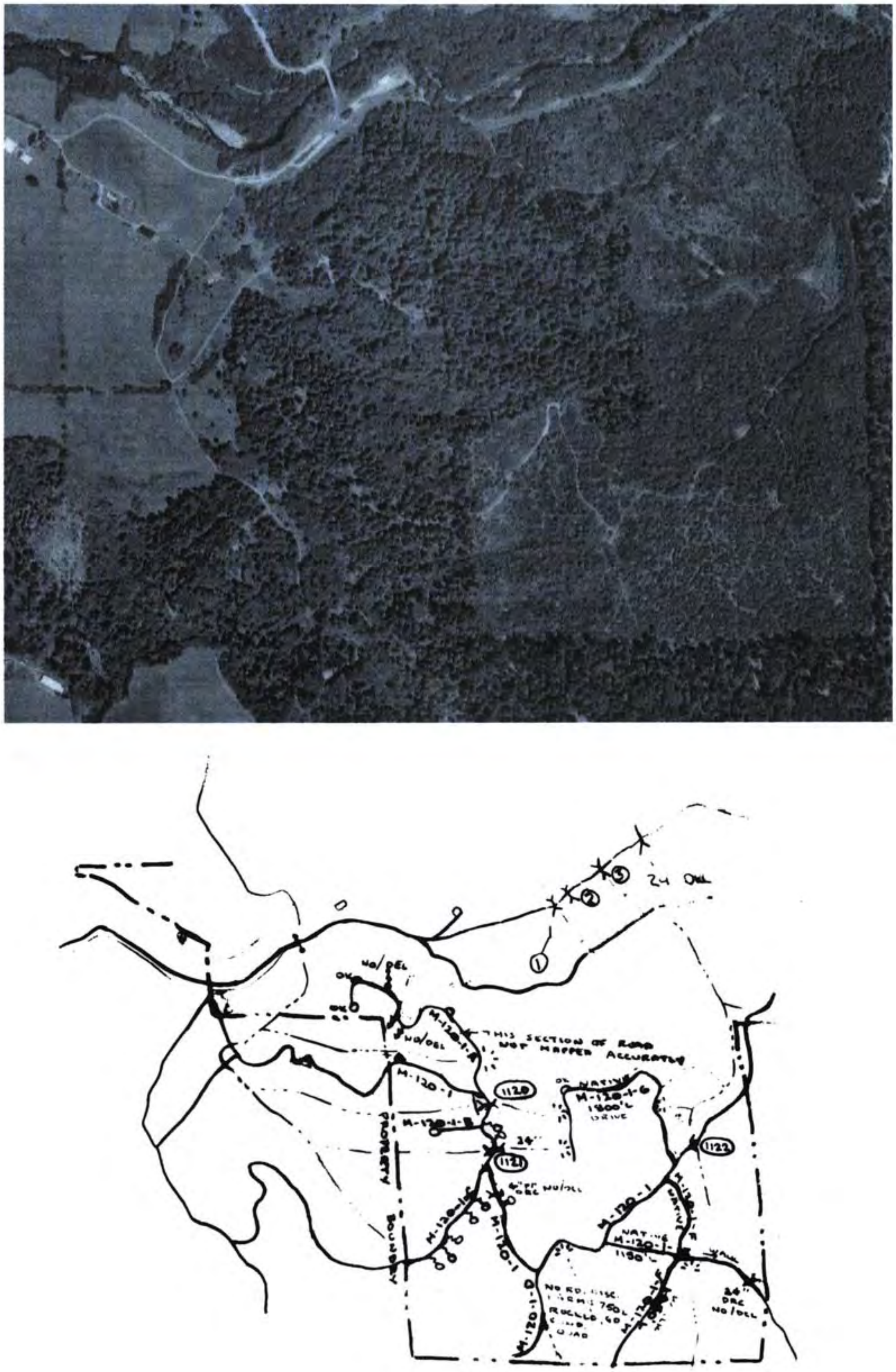
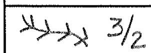


Figure X-4. Aerial photo and matching copy of Mylar overlay map showing roads and sites.

Standardized mapping symbols for use on site sketches, air photo overlays, report maps and flagging in the field.

Symbol		Site map symbols
		Site Number
	Stream crossing	Culverted stream crossing
	Stream crossing	Humboldt log crossing
	Stream crossing	Ford or armored fill
	Stream crossing	Unculverted stream crossing (unculverted fill)
	Stream crossing	Bridge
	Landslide	Potential landslide with delivery potential
	Landslide	Potential landslide with low or no delivery potential
	Landslide	Past landslide with delivery
	Landslide	Past landside with no delivery
	Other	Gully (with width/depth dimensions in feet)

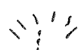
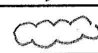
General map symbols			
	Ditch relief culvert		Spring or seep
	Plugged culvert (stream crossing/ditch relief culvert)		Swale or headwall swale
	Road (maintained or open)		Waterbar
	Abandoned road		Cross road drain
	Gate		Rolling dip
	Class 1 stream		Earth berm
	Class 2 stream		Scarps (with visible offset)
	Class 3 stream		Cracks (little or no visible offset)

Table X-3. Standardized mapping symbols.

The Inventory Process

The field inventory process is straightforward, once the assessment preparation is completed. Visit each site once. Collect all data needed to describe, quantify and recommend potential treatments for each site on the first visit.

Inventorying Hillslope Areas and Roads

Fieldwork for sediment source assessments concentrates on inspecting hillslope areas most likely to contain sites of preventable or controllable management-related sediment delivery. This may include a variety of managed areas. Usually, most of the treatable sites are located on road systems where problems are abundant and access for treatment is good. Therefore, the assessment requires a walking inventory of all active and abandoned roads in the assessment area. All existing and potential sediment delivery sites that fit the minimum sediment delivery criteria are then identified and quantified in the *Upslope Inventory Data Form*. If it meets the minimum definition of a site then it should be mapped, inventoried and added to the database. At this point, make no assumptions about which sites will or will not be treated.

Inventorying Stream Channels

A second component of the erosion assessment involves stream channels. Usually, bank erosion sites are the primary stream channel locations of future erosion and resultant sediment delivery to streams. Regardless, it is generally not practical to survey all the stream channels in a sub-watershed due to poor or difficult access. However, DFG can often provide stream inventories as described in *Part III* of this manual for fish bearing streams.

High priority areas for conducting stream bank inventories are: stream channels where reasonably good equipment access exists from nearby roads, open areas proximate to the stream, and reaches along larger Class 1 streams. In areas where access is a problem, conducting a sample inventory may determine if stream channels are likely candidates for future cost-effective restoration projects, and worthy of further inventory and analysis.

Completing the Upslope Inventory Data Form

Use the *Upslope Inventory Data Form* to record the location, nature and magnitude of sites of future or potential sediment delivery, and include the description of recommended treatments to prevent erosion and/or sediment delivery. Develop the erosion prevention and erosion control prescriptions concurrent with the identification and inventorying of sites of current and future sediment delivery in the watershed.

There is no substitute for practical experience in the selection and construction of effective erosion control treatments. Previous work supervising or operating heavy earth moving equipment and labor crews provides grounding for what is possible to accomplish. With more experience, the better this judgment becomes. With a job fully described by a completed upslope assessment, many heavy equipment operators can provide feedback on project feasibility, safety, appropriate equipment types, and reasonable production rates (times) and costs. Refer to restoration implementation methods and cost-estimating techniques, later in *Part X*, to complete the analysis.

The *Upslope Inventory Data Form* is on page X-29. For detailed instructions to complete the form, see Appendix X-A.

Data collected includes information in the following categories:

- **General site data***:* Collect and record general site information, including site number, site location, road name, maintenance status, name(s) of inventory crew, date of inventory, and other relevant data site location and site description information.
- **Site characterization***:* Characterize problem areas by their type (e.g., stream crossing, gully, landslide, etc.) and by variables that describe their main characteristics. Completely fill out the data form for the relevant problem type. That is, for stream crossings, complete the 23 data fields listed under stream. Do not fill out questions under the landslide category. For landslides, complete only those questions listed under landslide. The data form requires the user to collect qualitative and quantitative data for:
    - Landslide sites – 4 data fields;
    - Stream crossings – 23 data fields;
    - Fish passage– 3 data fields.
- **Erosion quantification***:* Evaluate the erosion potential (likelihood of erosion). Measure the site for potential future erosion, and estimate sediment delivery volumes.
- **Comment(s) on problem***:* Fully explain site conditions, apparent processes, relationships or quantities to more completely describe individual answers provided in the data form. Concisely describe the nature of the problem, as a quick abstract of the site and its problems.
- **Treatment***:* Estimate of the urgency or priority for treating the erosion site. Identify possible treatment options. Describe and quantify the erosion prevention and erosion control treatments identified as the most likely to correct the problem(s). The treatment section of the data form contains the most common types of erosion prevention and erosion control treatments encountered, as well as measures that quantify the number or magnitude of the proposed treatments (e.g., cubic yards of rock armor or length of outsloping). Note: if you have identified a failure area of unknown type and depth (see footnote on data form), treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.
- **Heavy equipment excavation data***:* Provide a quantitative calculation of excavation volumes. Identify the volume of the spoil material to be used or stored locally, or if it must be endhauled by dump trucks. Excavation volumes and the excavation production rate are important elements of this section, as they will determine the estimated equipment times that will be required to complete the site work (pages X-39 and X-40).
- **Equipment and labor hours***:* Based on the tasks performed, the volumes excavated and moved, and the equipment and labor production rates outlined above. List the number of hours required for each piece of heavy equipment and for labor.
- **Comment(s) on treatment***:* Note any details in the proposed treatments that a contractor or equipment operator needs to know to complete the treatment. Include any specific information or insights that describe how to perform the job. Provide this comment section to the operator or contractor to guide them in completing the details of the project work for each site. It might include such information as the number of needed dump trucks, the endhaul distances and spoil locations, the specific labor tasks to be completed and other notes on completing the work at that particular site.

- **Survey data***:* On the back of the data form, fill in the spatial measurements for all stream crossings inventoried in the project area. For stream crossings only, enter the survey data. Use these measurements to calculate potential erosion volumes and excavation volumes required to perform the decommissioning or upgrading treatments. The equations for calculating these volumes are in Measuring and Estimating Future Erosion Volumes.
- **Site sketch***:* Make a sketch of the site, including any obvious landmarks and features that will identify the relationships between features described in the data form. Include such elements as roads, streams, springs, slope gradients, drainage structures (e.g., culverts) and erosion features. Examples of site maps are included in Figure X-3. Use standardized mapping symbols (Table X-3).

UPSLOPE INVENTORY DATA FORM

ASAP (Y, N)______

GENERAL	Site no:	Treat (Y/N):	Watershed:	Quad:	
	GPS:		CALWAA:	Photo:	
	T/R/S:		Road name/#:	Drivable (Y/N):	
	Mileage:		Inspector(s):	Date:	Year built:
	Surface: □ rock □ native □ paved		Status: □ maintained □ abandoned □ decommissioned		
	Proposed: □ upgrade □ decommission			Sketch (Y/N):	
PROBLEM	Stream crossing (Y/N):		Landslide: □ fill □ hill □ cut	Roadbed: □ bed, □ ditch, □ cut	
	□ ditch relief culvert		□ gully	□ bank erosion	Road related (Y/N):
	Other non-road related site: □ home □ agricultural □construction □ mining □ other site				
LANDSLIDE	□ road or landing fill		□ hillslope debris slide[1]	□ other hillslope landslide (depth unknown)[1]	
	□ cutbank slide		□ potential failure	□ past failure	Slope (%):
	Distance to stream (ft):				
STREAM	□ culvert	□ bridge	□ Humboldt	□ fill	□ ford	□ armored fill
	□ excavated crossing		% excavated:		
	Ditch road length (ft): Left:		Right:	Culvert diameter (in):	
	Pipe condition (O, C, R, P): Inlet:		Bottom:	Outlet:	□ separated
	Headwall (in):		Culvert slope (%):	Stream class (1,2,3):	
	Culvert rust-line (in): Inlet:		Outlet:	Culvert undersized (Y, M, N):	
	Washed out (%):		Diversion potential (Y/N):	□ currently diverted	
	Road grade (%):		Plug potential (H, M, L):	Plugged (%):	
	Channel gradient (%):		Channel width (ft):	Channel depth (ft):	
	Sediment transport (H, M, L):		Drainage area (acres):		
FISH PASSAGE	Culvert outlet drop (in):		Bankfull drop (in):		
	Pool size bankfull width (ft):			Pool size bankfull depth (ft):	
EROSION	Erosion potential (H, M, L):		□ potential for extreme erosion		
	Volume extreme erosion (<500, 500-1,000, 1-2K, 2-5K, >5K):			Past erosion (yd^3) (optional):	
	Past delivery (%) (optional):		Total past delivery (yd^3):		
FUTURE EROSION	Future erosion (ft): Width:		Depth:	Length:	Future erosion(yd^3):
	Future delivery (%):		Total future delivery (yd^3):		

COMMENT(S) ON PROBLEM:

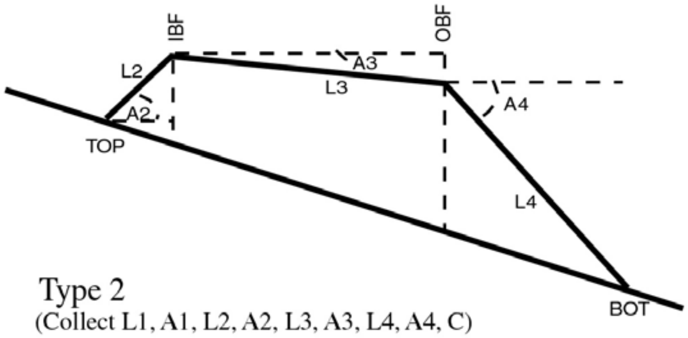
TREATMENT	Immediacy (H, M, L):		Complexity (H, M, L):		
	check culvert size (Y/N):		□ bridge	□ no treatment	Mulch (ft^2):
TREATMENT OPTIONS	□ excavate soil	□ critical dip	□ ford	□ armored fill	Sill height (ft):
	Sill width (ft):	□ trash rack	□ Add downspout: Length (ft):		Diameter (in):
	□ repair culvert	□ clean culvert	□ install/replace culvert		
	Culvert: Diameter (in):		Length (ft):	□ flared inlet: Diameter(in):	
	□ reconstr. fill	□ armor fill face (U, D, B):		Armor area (ft^2): U: D:	
	□ clean or cut ditch, (ft):		□ remove ditch, (ft):		
	□ outslope road, (ft):		□ outslope & remove ditch, (ft):		
	□ outslope & retain ditch, (ft):			□ inslope road, (ft):	
	□ rolling dip, (#):		□ remove berm, (ft):		
	□ ditch relief culvert, (#):		Length (ft):	□ rock road surface, (ft^2):	
	□ cross road drain, (#):		□ other:		
HEAVY EQUIPMENT EXCAVATION DATA	Total vol. excavated (yds^3):		Volume put back in (yds^3):		
	Volume removed (yds^3):		Volume stockpiled (yds^3):		
	Volume endhauled (yds^3):		Distance endhauled (yds^3):		
	Excavation production rate: (yds^3/hr):				
EQUIPMENT HOURS	Excavator:	Dozer:	Backhoe:	Grader:	Loader:
	Dump truck:		Labor:	Other:	

COMMENT(S) ON TREATMENT:

[1] *Consultation with a licensed geotechnical specialist is required to estimate slide volumes and to evaluate or develop treatment options. The location of these features should be noted on the field form and on maps, but the inventory crew should not estimate the sediment volumes for calculation of cost-effectiveness.*

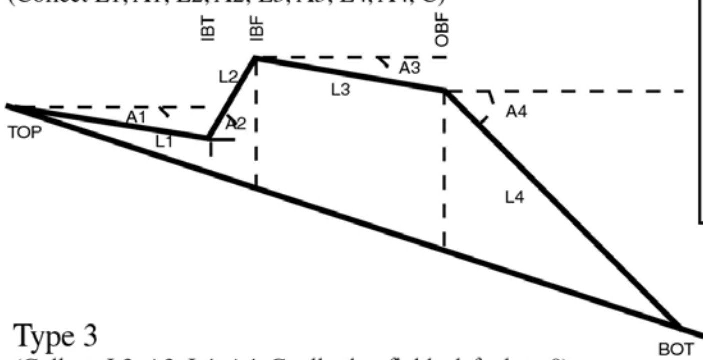
Type 1

(Collect L2, A2, L3, A3, L4, A4, C, all other fields default to 0)



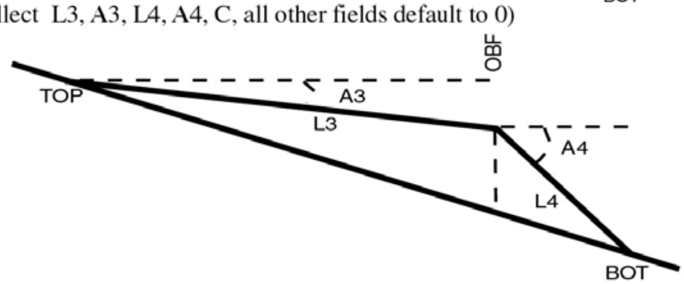
Type 2

(Collect L1, A1, L2, A2, L3, A3, L4, A4, C)



Type 3

(Collect L3, A3, L4, A4, C, all other fields default to 0)



Field data

Length of sediment fan (L1): _____ ft

Angle of sediment fan (A1): _____ degrees

Length of inboard fillslope (L2): _____ ft

Angle of inboard fillslope (A2): _____ degrees

Length of road bed (L3): _____ ft

Angle of road bed (A3): _____ degrees

Length of outboard fillslope (L4): _____ ft

Angle of outboard fillslope (A4): _____ degrees

Channel width (C): _____ ft

Sketch

Completing the Stream Bank Inventory Data Form

Use the *Stream Bank Inventory Data Form* to assess past, ongoing and potential stream bank erosion, including anything that can be said about the nature, cause, and magnitude of the problem, and potential treatment options. In addition, use the inventory form to identify and classify erosion problems along stream channels, prioritize potential work sites, and prescribe specific treatments aimed at protecting stream channels and fish habitat. *Part III* describes methodologies for stream channel classification and inventory protocols for assessment of stream habitat, large woody debris, and riparian inventories.

The *Stream Bank Inventory Data Form* provides the standardized DFG protocol for evaluating stream-related erosion and identifying erosion control options. Use it to evaluate all types of riparian sediment sources. Where roads are in close proximity to a stream channel, there may be individual sites described by both an *Upslope Inventory Data Form* and a *Stream Bank Inventory Data Form*. If the proposed treatments are sufficiently different, retain both forms to describe the same location. However, do not duplicate recommended treatments and treatment times. Using the *Stream Bank Inventory Data Form*, field personnel can measure, describe and make initial interpretations about landforms and erosion problems in a consistent and uniform manner. Enter the data into an electronic database. Prepare a prioritized erosion control plan.

The data collected should provide information that both quantifies sites of future erosion and leads to a cost-effective treatment of stream bank sites. The form is on page X-33. The detailed instructions for completing each field are in Appendix X-B.

The data collected includes information in the following categories:

- **General site data***:* Record the general site information, including site number, site location (station number and bank side), stream name, names of inventory crew, date of inventory, other relevant data site location, and site description information.
- **Problem type***:* Characterize the apparent nature of the problem (e.g., debris slide, hillslope failure of unknown depth, bank erosion, log jam, etc.) and by variables that describe their main characteristics, such as activity level, age, gradient of eroding hillslope, land use and the degree of stream undercutting.
- **Erosion quantification***:* Classify the erosion potential (likelihood of future erosion). Record measurements of expected future erosion and sediment delivery volumes, as well as measurements of length, width and depth of past erosion scars.
- **Comment(s) on problem***:* Explain any site conditions, processes, relationships or quantities needing more detail than the individual answers provided in the data form. In addition, use this space to describe the nature of the problem, as a quick abstract of the site and its problems.
- **Treatment***:* Evaluate and record the urgency or priority of the proposed treatment (Treatment Immediacy), the expected complexity of the project work, heavy equipment and labor needs, access difficulty, and material needs.
- **Treatment options***:* Describe and quantify the specific erosion prevention and erosion control treatments thought most likely to correct the problem identified. List the recommended treatment(s) for the site, including excavation volumes (except as noted for debris slides and deeper hillslope failures), structures, fencing, and likely vegetation

measures. The treatment section of the data form contains many common types of erosion prevention and erosion control treatments for stream banks. If necessary, design specific solutions for sites that require unique erosion control treatments. Describe these treatments in the Comment(s) on Treatment section. Provide a full accounting of material needs for the project. Note: if you have identified a failure area of unknown type and depth (see footnote on data form), treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.

- **Equipment and labor hours:** Based on the required tasks, the excavation volumes, and the equipment and labor production rates, list the number of hours required for each piece of heavy equipment and for the labor to construct structures and/or plant the site.
- **Comment(s) on treatment***:* Note any details in the proposed treatments that a contractor or equipment operator needs to know to perform the treatment. Include any specific information or insights that describe how to complete the job. Provide this information to the operator or contractor to guide them in completing the details of the project work for each site. Include such information as the number of dump trucks needed, the endhaul distances and spoil locations, the specific labor tasks to be completed and other notes on completing the work at that particular site.
- **Site sketch***:* Make a sketch of the site, including any obvious landmarks and features that will identify the relationships between features described in the data form. Include such elements as roads, streams, springs, slope gradients, log debris accumulations, bedrock exposures, and erosion features. Use standardized mapping symbols (Table X-3).

STREAM BANK INVENTORY DATA FORM

GENERAL	Site no:	Distance (ft):		Date:	Inspector(s):	
	Watershed:			Stream:		
	Air photo:		Location (LB, RB, B):		☐ road related	Treat (Y/N):
PROBLEM	Type:	☐ debris slide	☐ debris torrent[1]	☐ hillslope failure of unknown depth and activity[2]		
		☐ torrent / debris flow channel[1]		☐ bank erosion	☐ LDA [3]	☐ other
	Delivery:	☐ past	☐ future	☐ both	Apparent activity (A, IA, W):	
	Age (decade):		Stream bank slope (%):			
	☐ land use	☐ undercut by stream				
PAST EROSION	Width (ft):	Depth (ft):	Length (ft):		Volume (yd^3):	
FUTURE EROSION	Future erosion potential (H, M, L):		Width (ft):		Depth (ft):	
	Length (ft):			Volume (yd^3):		
COMMENT(S) ON PROBLEM:						
TREATMENT	Immediacy (H, M, L):		Complexity (H, M, L):		Equipment or labor (E, L, B):	
	Equipment access (E, M, D):		☐ local materials		☐ import materials	
TREATMENT OPTIONS	☐ excavate soil	Width (ft):	Depth (ft):	Length (ft):	Volume (yds^3):	
	☐ rock armor/buttress		rock armor size (ft or ton):		rock armor area (ft^2):	
	☐ log protection		Log size: Length (ft):		Diameter (ft):	
			Bank length protected (ft):		Bank area to cover (ft^2):	
	☐ remove logs/debris				☐ boulder deflectors	
	Deflectors (#):		Deflector (yd^3):		☐ bio-engineering	
	☐ plant erosion control		☐ riparian restoration		Area planted (ft^2):	
	☐ exclusionary fencing		Length of fence (ft):		☐ other	
EQUIPMENT HOURS	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor:	Other:
COMMENT(S) ON TREATMENT:						

[1] A debris torrent is a mudflow that originates as a debris slide and then fluidizes (through the addition of water) and flows down a stream channel. It typically ends as a deposit or dam of poorly sorted sediment and woody debris in a lower gradient section of channel. The process is the mudflow; the evidence of that process is the scoured channel through which the flow passed, and the sediment and debris that is deposited at the end of the flow path. The activity level is typically that of the potential debris slide that would form the source of the mudflow. Note: if you have identified a potential hillslope debris slide, treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.

[2] If a failure of unknown type and depth is identified, treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.

[3] LDA is a log jam or accumulation of logs and woody debris in the channel; that is causing bank erosion or other erosion and sediment delivery problems.

Sketch on back.

Measuring and Estimating Future Erosion Volumes

A critical step in conducting a sediment source inventory is the quantification of erosion and sediment delivery volumes. Sediment delivery volumes and excavation volumes are the key variables needed for the computation of treatment cost-effectiveness and creating a watershed restoration plan. Excavation volumes are important for the derivation of heavy equipment times and costs for restoration work.

Surface Erosion Volumes

It is difficult to estimate sediment delivery volumes from surface erosion processes, because different soils have markedly differing propensities for erosion, and because surface erosion is a chronic process that may occur every storm. Use the following surface lowering rates (erosion rates in feet/year) to provide a gross estimate of erosion from bare soil areas:

- Cutbanks and continually bare soil areas Low-0.01; Moderate-0.03; High-0.05
- Native surfaced (unimproved, dirt) roads 0.03
- Rock surfaced roads 0.02

Any unusual circumstances, such as high amounts of runoff or the presence of highly erodible soils, such as sand, may increase the surface-lowering rate. Use local site conditions and field evidence when assigning these rates. Calculate chronic surface erosion volumes from persistently bare areas on an annual basis, assuming overall conditions and use patterns remain unchanged. Estimate sediment delivery volumes from surface erosion processes as follows:

- Q_s = [(A x E)/27] x T x D, where
- Q_s = sediment delivery (yds^3) from surface erosion;
- A = exposed area (ft^2);
- E = erosion or lowering rate (feet/year);
- T = time (years);
- D = delivery ratio (percent of erosion that is delivered to the stream).

For example, estimate 10 years of sediment delivery from a 500-foot section of actively used, rock-surfaced, 18 feet wide insloped road; that is 10 feet high; with a 50% bare, moderately erodible cutbank; that drains to the inlet of a stream crossing with a culvert, as follows:

- Road surface: A = 500' x 18' = 9,000 ft^2
  E = 0.02 ft/yr
  T = 10 years
- Cutbank: A = (500' x 10') ft^2 x 0.50 (only 50% of the cutbank is bare and eroding)
  E = 0.03 ft/yr
  T = 10 years
- Q_s = [((500 x 18) x 0.02)/27 + ((500 x 10x0.50) x 0.03)/27] x 10 years x 100%
  = (6.7 + 2.8) yds^3 x 10 years x 100%
  = 95 yds^3 (assumes 100% delivery from the contributing areas)

This generalized methodology of estimating sediment delivery from road surfaces allows for an order-of-magnitude estimate of sediment delivery that is suitable for use in evaluating the cost-effectiveness of proposed restoration work. Modify assumptions and rates according to local conditions. Sediment delivery rates for surface erosion can be variable. If the area encompassed by the analysis is limited to that which drains directly into a stream channel, delivery rates of 100% are reasonable.

Fluvial Erosion Volumes

Estimate future fluvial erosion volumes for the following:

- The expansion of existing gullies (including culvert outfall erosion);
- The creation of new gullies (usually from predicted stream diversions);
- Stream crossing washouts;
- Stream bank erosion.

<u>Existing Gullies</u>

Existing, active gullies can continue to enlarge by lengthening, widening and deepening until they become stable. These final dimensions, and hence future erosion, involve estimating future increases in gully width and depth. If flow conditions are unchanged, then the potential for future gully expansion can be inferred based on observed dimensions and behavior. If the gully is no longer down cutting, most erosion will be limited to gradual bank retreat and collapse. In this case, future erosion consists of vertical gully walls (side slopes) laying themselves back to a stable slope angle of about 1:1. If the gully still exhibits potential for future down cutting, then estimate how much deeper the gully will get over the length of gully. The gully will still be assumed to eventually develop 1:1 side slopes, and the amount of additional down cutting can be quantified as a rectangle (i.e., length x width x depth).

<u>New or Future Gullies</u>

In cases where it is predicted that a new gully will form, such as from a predicted stream diversion, then gully dimensions and lengths must be estimated from analogous sites nearby, or from thoughtful and well documented assumptions. Estimating future gully erosion is very difficult because the future path of the gully is hard to predict, gully erosion rates are generally unknown and variations in soil depth and erodibility, which control gully volumes, vary greatly. Estimates of gully erosion must be reasonable compared to similar documented sites nearby or in comparable areas. Delivery rates are typically high (75% - 100%) for gullies formed by stream diversions, but the figure should be supported by site observations and conditions.

<u>Stream Crossings</u>

Measure stream crossing fills to determine washout volumes, excavation volumes, and equipment times needed to perform various upgrading or decommissioning tasks. Crossing geometries are complex; therefore, estimating the volume of fill material contained in stream crossings requires a systematic approach and technique. There are three acceptable methods:

- Using field measurements, determine average dimensions and multiply width, depth and length to estimate volume (divide ft^3 by 27 to get yds^3);
- Taking systematic field measurements, use equations of plain geometry and end-area computations to calculate crossing volumes;

- Utilizing simple field surveys and a specialized computer program perform volume calculations and design treatments.

The more rigorous and systematic the computational method, the better will be the outcome of the calculations and volume estimates. Use the diagrams, measurements and equations shown in Figure X-5 and Figure X-6 to develop a quantitative estimate of stream crossing volume. Figure X-7 and Figure X-8 give examples of Type 1 and 2 volume calculations. The *Upslope Inventory Data Form* contains the data fields needed to perform volume calculations for each of three types of stream crossing geometries (Type 1, Type 2 and Type 3).

Stream Crossing Washouts

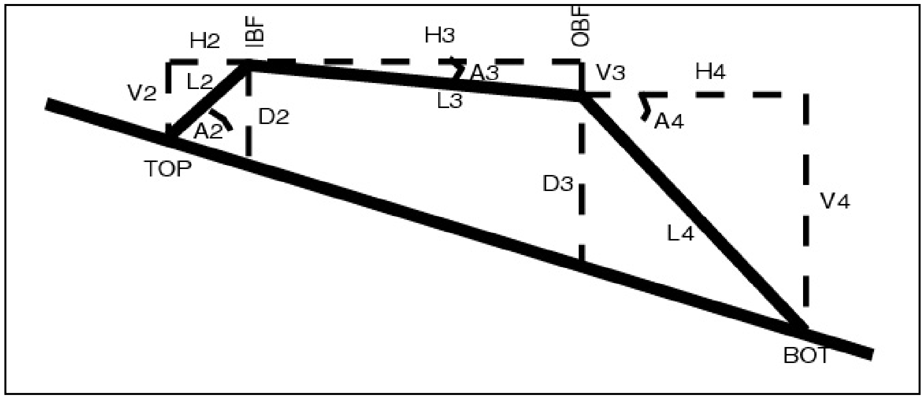
Base the predicted volume of a stream crossing washout on field measurements and geometric calculations that determine the volume of fill in the crossing (Figure X-5 and Figure X-6). Unless there are local indications to the contrary, assume that the gully, which forms from a full stream crossing washout, will eventually scour down to and assume the original pre-road channel profile. In addition, assume that it will have the same width dimensions as the natural high flow channel upstream from the crossing, and that the left and right side slopes to the washed out crossing will form a 1:1 slope (45E or 100%). From these assumptions, use geometry to calculate the predicted washout volume. Because the majority of potential sediment delivery sites in a watershed may occur at stream crossings, the accuracy and reproducibility of the volume estimate is critical. Perform simple tape and clinometer surveys, combined with geometric calculations, to ensure accuracy and reproducibility. Assume 100% delivery of sediment to the stream for washed out stream crossings.

Material used to fill-in a stream channel when a road is constructed is often irregular in shape. Generally, most of the fill would eventually be lost if the culvert plugged and the crossing fill washed out. Use simple geometry to develop an estimate of the stream crossing volume for the three basic types of stream crossings (Figure X-5 and Figure X-6). The volume of fill material contained in a Humboldt crossing is sometimes significantly more difficult to estimate because of uncertainties in the depth and volume of the logs and slash buried when the crossing was built. The volume of material in landings constructed in stream channel valleys prior to implementation of the Forest Practices Act (1973) is also difficult to estimate using simplified field measurement techniques. This is primarily because the original stream valley configuration has been obliterated by earthmoving.

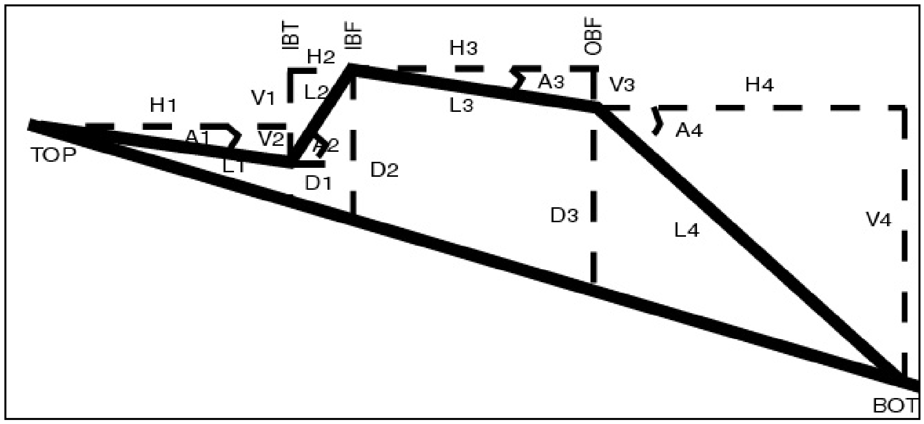
Stream Bank Erosion

Base the predicted erosion volume at each stream bank site on documented site conditions and measurements that support logical assumptions and observed bank retreat rates or erosion dimensions from comparable sites nearby. Assume all stream bank erosion will result in 100% sediment delivery (since the erosion is occurring within a stream channel). Calculate stream bank erosion by assuming a bank retreat rate (i.e. depth of erosion landward from the creek) and multiplying this by the length and height of the eroding bank.

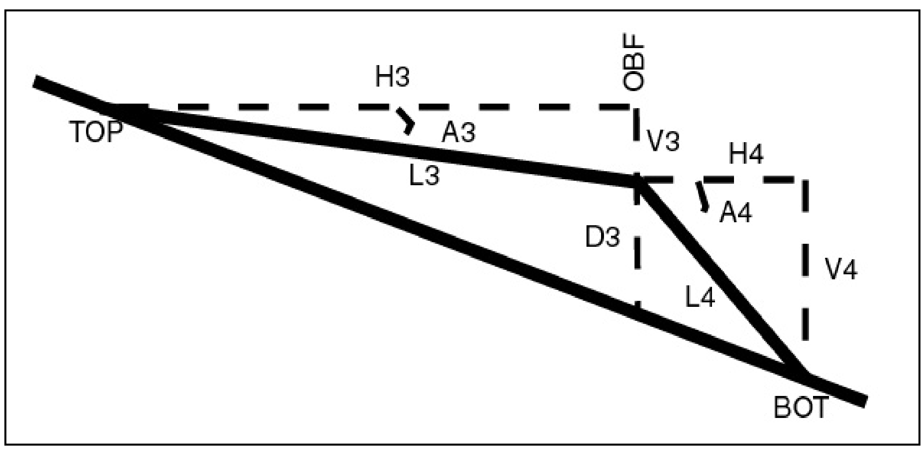
Type 1
(Collect L2, A2, L3, A3, L4, A4, C, all other fields default to 0)



Type 2
(Collect L1, A1, L2, A2, L3, A3, L4, A4, C)



Type 3
(Collect L3, A3, L4, A4, C, all other fields default to 0)



Field data		
	Length of sediment fan (L1):______ft	Angle of sediment fan (A1):______degrees
	Length of inboard fillslope (L2):______ft	Angle of inboard fillslope (A2):______degrees
	Length of road bed (L3):______ft	Angle of road bed (A3):______degrees
	Length of outboard fillslope: (L4):______ft	Angle of outboard fillslope (A4):______degrees
	Channel width (C):______ft	

Figure X-5. Geometric designs for determining typical stream crossing volumes and excavation volumes for upgrading and decommissioning the three main types of crossings.

Calculations	
Horizontal components	H1 = L1(cosA1) = ______′*(cos(______)) = ______ft H2 = L2(cosA2) = ______′*(cos(______)) = ______ft H3 = L3(cosA3) = ______′*(cos(______)) = ______ft H4 = L4(cosA4) = ______′*(cos(______)) = ______ft
Vertical components	V1 = L1(sinA1) = ______′*(sin(______)) = ______ft V2 = L2(sinA2) = ______′*(sin(______)) = ______ft V3 = L3(sinA3) = ______′*(sin(______)) = ______ft V4 = L4(sinA4) = ______′*(sin(______)) = ______ft
Fall rate	F = (V1+V2+V3+V4)/(H1+H2+H3+H4) = (______+______+______+______)/(______+______+______+______) =____ft
Depth calculations	D1 = V1-(F*H1) = ______-(______*______) = ______ft D2 = (V1+V2)-(F*(H1+H2)) = ______-(______*(______+______)) = ______ft D3 = (V1+V2+V3)-(F*(H1+H2+H3)) = ((______+______+______)-(______*(______+______+______)) = ______ft
Cross section area calculations	XSA1 = C*D1+$(D1)^2$ = (______*______)+$(\_\_\_\_\_\_)^2$ = ______ft^2 XSA2 = C*D2+$(D2)^2$ = (______*______)+$(\_\_\_\_\_\_)^2$ = ______ft^2 XSA3 = C*D3+$(D3)^2$ = (______*____)+$(\_\_\_\_\_\_)^2$ = ______ft^2
Volume Calculations	
Type 1 Crossing	Vol TOP to IBF (T2) = 1/3*(XSA2*H2) = 1/3*(______*______) = ____ft^3 Vol IBF to OBF (T3) = 1/2*(XSA2+XSA3)*H3 = 1/2*(______+______)*______) = ______ft^3 Vol OBF to BOT (T4) = 1/3*(XSA3)*H4 = 1/3*(______*______) = ____ft^3
Type 2 Crossing	Vol TOP to IBT (T1) = 1/3*(XSA1*H1) = 1/3*(______*______) = ____ft^3 Vol IBT to IBF (T2) = 1/2((XSA1+XSA2)*H2) = 1/2*(______+______)*______ = ______ft^3 Vol IBF to OBF (T3) = 1/2*(XSA2+XSA3)*H3 = 1/2*(______+______)*______ = ______ft^3 Vol OBF to BOT (T4) = 1/3*XSA3*H4 = 1/3*______*______ = ______ft^3
Type 3 Crossing	Vol TOP to OBF (T3) = 1/3*(XSA3)*H3 = 1/3*(______*______) = ____ft^3 Vol OBF to BOT (T4) = 1/3*(XSA3)*H4 = 1/3*(______*______) = ___ft^3
Total Volume Calculation	T(t) = (T1+T2+T3+T4)/27 = (______+______+______+______)/27 =____ yds^3

Figure X-6. Calculations for determining typical stream crossing volumes and excavation volumes for upgrading and decommissioning the three main types of crossings.

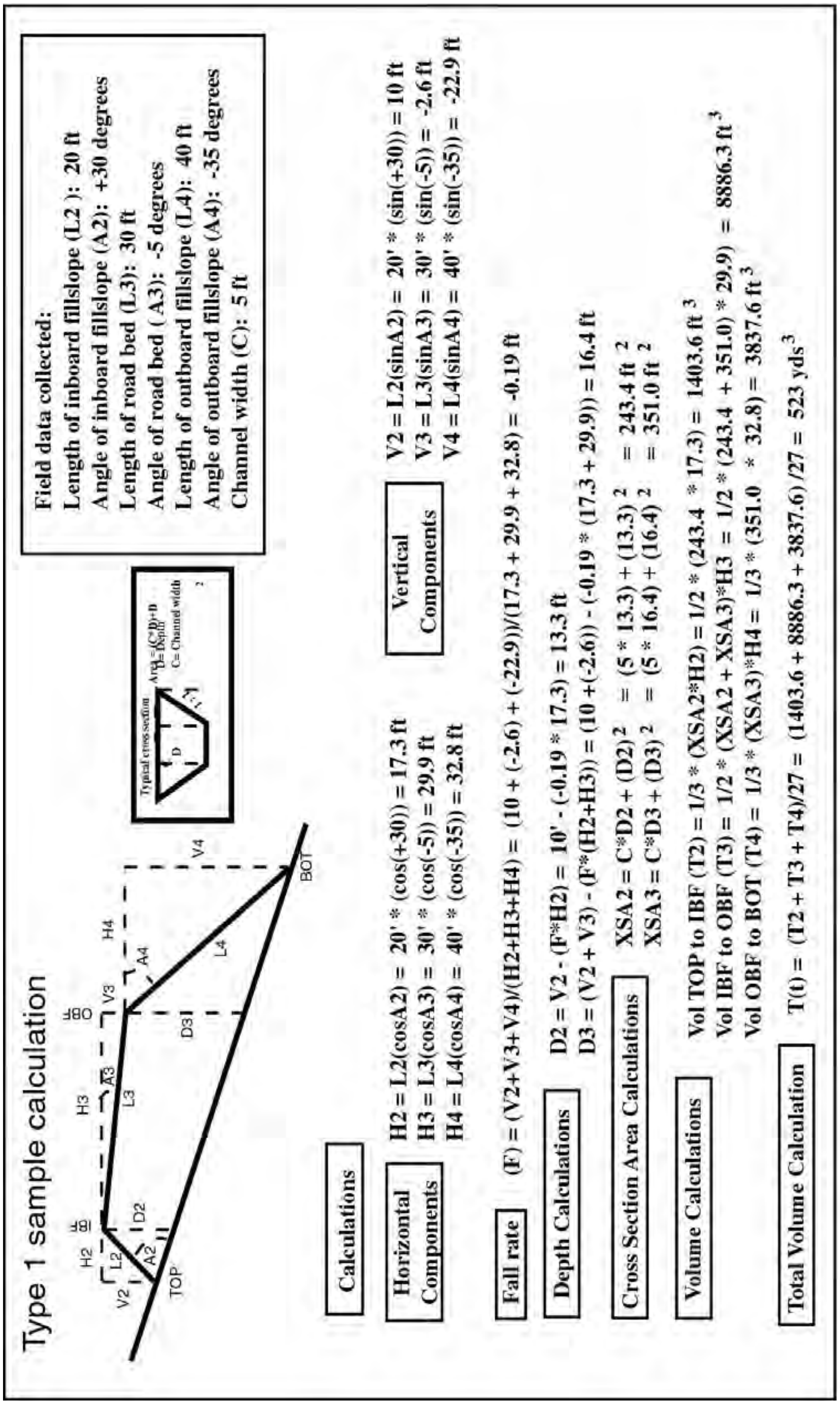


Figure X-7. Sample calculations showing derivation Type 1 stream crossing volumes.

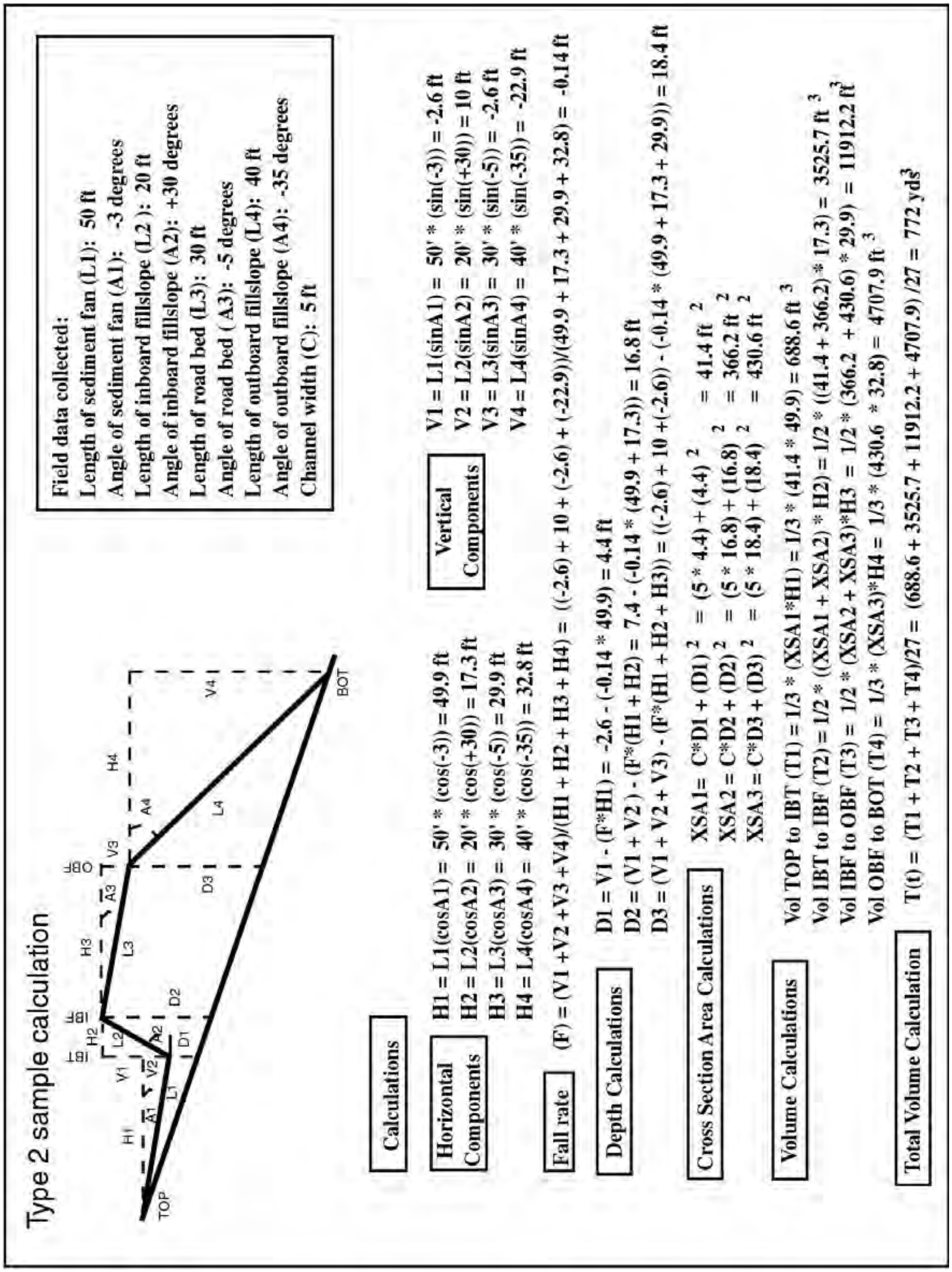


Figure X-8. Sample calculations showing derivation Type 2 stream crossing volumes.

Landslide Erosion Volumes

Landslide stabilization is generally outside the scope of this document. CGS Notes 50 (CGS 1999) and 40 (CGS 1983-1995) provide descriptive information on larger landslide types in steep forested terrain, and where these have been mapped as a part of the Watershed Mapping Project, respectively. These can be used for general planning purposes, and to identify watershed areas that have been mapped as unstable. They are generally not suitable for the measurement of landslide volumes, as the slides that have been identified and mapped are large and outside the scope of straightforward erosion and sediment control practices. However, the volumes of some of the simplest and smallest types of landslides can be measured from voids or "holes" left in the ground after the failure occurs or from field evidence of the boundaries of such landslides before they completely fail and move off site (e.g., small slides that occur on road fillslopes).

Except for debris flows and hillslope failure areas of unknown depth (as previously noted), compute future landslide volumes from estimated length, width and depth measurements taken in the field. The estimated sediment delivery to a stream is difficult to estimate and can range from 5% to 95%. Factors such as the distance the sediment must travel to the stream, hill shape and slope, soil moisture, vegetation and other factors influence the expected range of sediment delivery. A useful technique is to ask if the slide would deliver more or less than fifty percent of the potential slide mass to the stream. Often, the answer is obvious and it will provide a focus for making finer estimates by continuing to divide the remaining volumes in a like manner until the answer becomes uncertain. At that point of uncertainty, stop the division process and use the last confident answer for the estimate of delivery volume. This simple line of questioning will generally produce an acceptable estimate for determining sediment delivery volumes at each potential landslide fill failure. All but the smallest landslides can be very complex features and the development of effective treatment options more often than not will require consultation with a licensed geotechnical specialist.

Over-steepened Road and Landing Fills

Over-steepened fills typically consist of un-compacted sidecast materials, bulldozed onto steep, potentially unstable fillslopes. Unstable sidecast usually involves limited volumes of sediment when they fail by debris sliding, and these quantities can be estimated easily using simple geometric measurements of length (down slope), width (distance along the road) and average depth. The most common type of preventable or controllable landslide is the failure that develops from road or landing sidecasting on steep slopes. It is also the most common and most treatable source of road-related sediment delivered to streams in many watersheds.

The volume of a potential road-related sidecast failure is not difficult to estimate because the minimum average depth of the potential slide is typically the average depth of the sidecast material placed on the hillslope. The length of the potential slide is the length of the fillslope's sidecast material from the crown scarp to the base of the fill. Estimate the potential landslide width based on the boundaries of the over-steepened and visibly unstable sidecast material, or based on visible cracks and scarps that bound the potentially unstable material.

Headwater Swales (Potential Landslides)

Unlike simple sidecast failures, debris slides from steep headwater swales are more difficult to predict. They usually incorporate original ground beneath the road fill and often grow much larger as they move down the steep swales and channels, scouring debris from the channel bed. This makes their final volumes frequently much larger than that estimated at the initiation site itself. Often, the occurrence and volume of such slides is highly uncertain and requires professional geologic analysis. Because it is difficult to accurately identify and quantify such sites of extreme erosion, note their potential location on the field form and on maps, but do not estimate their volumes for calculating treatment cost-effectiveness. Later in the process, query the database for the sites that exhibit a potential for extreme erosion and include them in the development of the final implementation plan only after review by a licensed geotechnical specialist.

Large Earthflows and Landslides of Unknown Depth and Activity

The future volumetric yield of deep-seated landslides can be equally difficult to estimate largely because they move episodically, at unpredictable rates and they occasionally self-stabilize over time. These types of landslides are often natural features and may not be affected or caused by a road or other land use (the road may be simply going along for the ride). Evaluating and developing treatment options will require consultation with a licensed geotechnical specialist. Typically, there are few cost-effective treatments that will slow or prevent these slides from moving or delivering sediment to the stream.

ANALYSIS AND REPORTING OF ASSESSMENT DATA

Use data analysis to convert field inventory information into conclusions. Use the conclusions to assemble a prioritized summary report (Appendix X-C). Set up the database, enter and clean the data, then complete the analysis. Analysis steps include generating erosion volume calculations, treatment volume calculations, costing out projects, cost-effectiveness analyses and sorting for prioritization prior to initiating restoration work.

Database Management

Data analysis can be complicated, but it is a critically important part of an assessment project that leads to restoration. To efficiently sort, analyze and prioritize a large number of work sites in an assessment area it is important to utilize an electronic database. To prepare a database for data analysis;

- **Set up database structure**: Set up the database structure on paper, based on the field forms presented on pages X-29 and X-33 and then program the electronic database. Perform this step as a part of the initial preparations for the watershed assessment.
- **Complete any blank data fields:** Fill any blank database fields left unanswered from the field inventory prior to data entry and analysis. This could include data that was not available during the field inspection, such as drainage area measurements or volume calculations that were available only after the field inventory, as well as inadvertent omissions (which might require a second field visit).
- **Enter data in database:** Enter the data for analysis. Analysis of partial data sets may be useful to break down the assessment area into smaller management units, such as an individual landowner, a logical hillslope unit or high priority sub-watershed as stand-alone elements of the larger assessment area. This is most useful when conducting very large watershed assessments. In this manner, individual restoration plans can be developed for the smaller management area as the larger assessment effort is still underway, and

prioritized treatments can begin in areas where early assessment work has already been completed.

- **Clean data:** Once entered, perform preliminary data searches to identify any blank data fields and any mistakes in data entry. Data cleaning is the last step prior to analysis. Perform data cleaning to make sure the necessary data is both present and internally consistent. Electronic data searches (reports) involving a number of related data fields (such as all questions related to stream crossings, or all questions related to treatments) should be viewed on the screen or in printed format as data tables so that any data inconsistencies or blank data fields will be visibly obvious. It may take several data searches, involving a variety of interrelated fields and combinations of fields to determine if all the data is there, and that it is present in the correct format.
- **Revisit selected sites and complete database:** Enter data that is missing or inconsistent and needs correction. Errors in data entry are easy to correct. Inadvertent omissions during field inventory work can sometimes be clearly determined from the other information that is on the paper form. If important data is missing from the form or it is clearly inaccurate a re-inspection of the site is necessary. For efficiency, it is generally best to schedule site re-inspections after all data cleaning has occurred.

Analyzing the Inventory Data

Data analysis can only occur when all the inventory information has been collected, properly entered in the database, and cleaned. The use of a database allows for rapid data analysis. Perform searches to isolate the nature, frequency and magnitude of a host of problems and treatments. Specific searches might include analyses that look at the frequency and cause of potential sediment delivery associated with each sediment source (landsliding, fluvial erosion and surface erosion). Searches might include an analysis of all stream crossings, looking for the frequency of undersized culverts, stream crossings with a diversion potential, or active culvert outlet erosion, among others.

Data tables developed for the summary report contain information regarding the number of sites recommended for treatment, erosion potential, treatment immediacy (priority), sediment savings, recommended treatments, excavation volumes, estimated heavy equipment and labor hours and costs. Proposed restoration plans may be grouped a variety of ways, for example geographically, according to the number of high priority sites they contain, the expected volume of future sediment delivery, or the number of undersized culverts on stream crossings with a high diversion potential. Appendix X-C contains examples of a number of assessment data tables that are useful for displaying the results of the sediment source inventory.

Estimating Costs

Use the sediment source assessment to develop cost estimates by employing the following steps:

- Problem identification - determine the population of potential treatment sites;
- Problem quantification - accuracy in calculating excavation volumes is critical in predicting heavy equipment times and project costs (Figure X-5 and Figure X-6);
- Determine equipment needs - select heavy equipment based on desired capabilities and types. Picking the wrong equipment can severely inflate costs above predicted levels;

- Estimate production rates and equipment times – selection of appropriate equipment production rates is critical in determining heavy equipment times for each site;
- Estimate equipment costs - use locally appropriate rates for heavy equipment rental (cost/hour), and a logistic multiplier of 20% to 30% for prescribed site treatments (number of hours x 0.2 or 0.3). This should cover equipment travel times, consultations with the operator and most unforeseen complications. Finally, develop cost estimates that cover all needed road drainage work between sites;
- Estimate road opening costs (hours x cost rate) for either upgrading or decommissioning abandoned roads or for treating off-road sites. Access costs will be dependent on maintenance status and degree of revegetation on the abandoned road;
- Estimate equipment mobilization costs - mobilization costs include lowboy transportation for moving heavy equipment to the project area and are dependent on equipment availability and lowboy rental rates;
- Calculate materials costs including culverts, road rock, riprap sized rock, filter fabric, seed, mulch, tools, etc.;
- Calculate labor costs and apply to the labor hours itemized on the data forms for each site. Use a locally reasonable labor rate (cost/hour);
- Calculate indirect costs including coordination, ordering, field layout, technical oversight (such as by restoration specialists, or professional engineers and geologists) reporting, monitoring, administrative and contracting costs. This requires an assessment of the hours for each task and the labor rate applied to the work. The required amount of on-the-ground supervision time with the heavy equipment or with labor crews will depend on the experience of the work crews. Inexperienced operators and laborers need more oversight.

Predicting Cost-effectiveness

Define the cost-effectiveness of treating a restoration work site as the average amount of money spent to prevent the delivery of one cubic yard of sediment from entering the stream system (Weaver and Sonnevil 1984). Cost-effectiveness is determined by dividing the cost of accessing and treating one site, or group of sites, by the volume of sediment delivery prevented to a stream channel. For example, if it would cost $3,500 to access and treat an eroding stream crossing that would have delivered 250 yds^3 (had it been left to erode), the predicted cost-effectiveness would be $14/$yd^3$ ($3500/250 yds^3). The key elements in determining cost-effectiveness are a fair and accurate estimate of future sediment delivery (in the absence of treatment) and a reasonable estimate of treatment costs.

Controls on Cost-effectiveness

A variety of factors control the ultimate cost-effectiveness of the restoration work that is being proposed (Weaver et al 1981). Some of these are predictable and controllable, and others are not. Ultimately, factors that affect either the cost of the work, the potential volume of sediment delivery or the effectiveness of sediment control treatments will control cost-effectiveness. The more that is done to reduce costs, decrease sediment delivery and increase treatment effectiveness, the greater will be the cost-effectiveness of the restoration project.

Costs

Of all the factors controlling cost-effectiveness, cost factors are the most amenable to manipulation. Controls on restoration costs include many obvious factors and some more subtle elements. These include:

- Goals and objectives of the restoration: goals and objectives establish the level of effort that will be undertaken, and ultimately control cost-effectiveness;
- Hourly equipment rental or contract rates: all else equal, the higher the rental rate, the lower will be the cost-effectiveness of the resultant restoration work;
- Choice of heavy equipment types and sizes;
- Skill and experience of the equipment operator;
- The magnitude of indirect costs, such as administration, contracting, overhead, profit, supplies and other indirect expenses that diminish cost-effectiveness;
- A large influence on treatment cost-effectiveness can result from incorrect identification of the problem, incorrectly estimating potential sediment delivery volumes, and/or recommending inappropriate or ineffective treatments;
- The design standards of the treatment: culvert sizing and excavation geometry (side slope steepness for decommissioned crossings have a substantial influence on restoration costs - the higher the standard, the higher the cost);
- The method of contracting including fixed price, hourly rental, or cost-plus. There is often a significant difference between total restoration project costs under fixed price (minimum bid) contracting and hourly equipment rental; the former frequently being more costly;
- Road reopening and other mobilization costs: these include the costs of clearing and opening access on abandoned roads and for hauling equipment to or within the project area. The higher these indirect expenses are, the greater their negative effect on cost-effectiveness;
- Choice of specific treatments used to prevent or control erosion: even if a number of methods are equally effective at preventing or controlling sediment delivery, the more costly approaches will be less cost-effective;
- Secondary treatments: if secondary erosion control treatments (e.g., check dams, rock armor or other hand labor treatments) are recommended, primary project cost-effectiveness will diminish because these treatments are typically expensive compared to the amount of sediment prevented from delivery to a stream channel (Weaver and Sonnevil 1984).

Sediment Delivery Estimates

Variables that affect estimated sediment delivery and project cost-effectiveness include the interpretation of a potential site, the inventory methods, assumptions, and measurement accuracy reported and used. Inflated sediment delivery volumes exaggerate the sediment savings and cost-effectiveness. Similarly, if the volume of future delivery is understated, then the project will not look as cost-effective as it might actually be. Achieve controls on sediment delivery estimates using appropriate:

- Volume calculation methods (assumptions and methods for calculating or estimating potential failure volumes for landslides, and potential erosion volumes for stream crossings, gullying and surface erosion). Volume calculations should be repeatable and sufficiently accurate;
- Sediment delivery estimates (methods and assumptions for determining the delivery ratio for potential landslides, fluvial erosion and surface erosion processes);
- Sediment loss assumptions (assumptions made about how much erosion and sediment delivery would actually occur at a site before the problem was corrected);
- Erosion rate and amortization assumptions (assumptions made about the rate of erosion and the duration over which erosion and sediment delivery is calculated, especially for large landslides, gullying, stream crossing washouts, bank erosion and surface erosion).

Treatment Effectiveness
The effectiveness of erosion prevention and erosion control measures has a significant influence on sediment delivery to stream channels from inventoried sites. Certain techniques are nearly 100% effective at preventing sediment delivery (such as completely excavating a potentially unstable fillslope). Others are partially effective (e.g., disconnecting road surface runoff from stream channels to cut off road drainage and prevent fine sediment delivery). Measure treatment effectiveness by the volume of sediment prevented from delivery to a stream, not on the amount of dirt moved by heavy equipment or by the volume of soil erosion that is controlled or prevented. Treatment effectiveness varies according to the process and the erosion prevention technique that is applied.

Surface Erosion
Surface erosion processes are sometimes controllable and preventable (through the application of mulching and seeding). More importantly, controlling sediment delivery from surface erosion sites is usually highly effective (through diversion and dispersion of runoff).

Fluvial Erosion
A number of cost-effective treatments can effectively prevent most gullies. For example, dewatering existing gullies can be nearly 100% effective in preventing continued erosion and sediment delivery. Gully control is less effective and more costly than gully prevention, and preventing sediment delivery from an eroding gully is very difficult.

Landslides
Landslide size and accessibility influence treatment cost-effectiveness. Streamside landslides, non-road landslides (i.e., poor access) and large landslides have low treatment cost-effectiveness and are very difficult to treat. Treating small potential landslides or excavating a large proportion of the material on larger landslides can result in a high level of effectiveness.

Evaluating Treatment Priorities

Evaluate treatment priorities by considering factors and conditions associated with each potential sediment delivery site:

- Delivery volume - the expected volume of sediment to be delivered to streams;

- Erosion potential - the potential for future erosion (high, moderate, low);
- Access and access costs - the ease and cost of accessing the site for treatments;
- Treatment costs - recommended treatments, logistics and costs;
- Treatment immediacy - the urgency of treating the site;
- Treatment cost-effectiveness - money spent per cubic yards saved.

Proposed work should meet pre-established cost-effectiveness criteria, and this often forms the basis for restoration prioritization. However, other local factors may also be considered. For example, factors such as the protection of potable water supplies, sensitive resources at risk, or other beneficial uses may assume a significant role when developing final restoration priorities. The prioritization criteria will be a function of the goals of the restoration project.

Prioritizing Restoration by Cost-effectiveness

Cost-effectiveness calculations directly and indirectly integrate a number of the most commonly employed factors used for prioritizing restoration work. By using the cost-effectiveness formula, a comparison of proposed projects is possible using the same criteria: reducing accelerated erosion and keeping the greatest volume of eroded sediment out of the watershed's streams for the least amount of money. The sites selected for eventual treatment are the ones expected to generate the most cost-effective reduction in sediment delivery to the drainage network and the mainstem stream channel. The larger the potential future contribution of sediment to streams, the more important it becomes to evaluate the project for cost-effectiveness.

After prescribing treatments and evaluating all costs, employ cost-effectiveness calculations and other criteria to prioritize all the sites for actual treatment. Use cost-effectiveness as a tool to prioritize potential treatment sites throughout the assessment area. Sites, or groups of sites, that have a predicted marginal cost-effectiveness value for the particular region, or have a lower erosion potential or treatment immediacy, or low sediment delivery rates, are less likely to receive funding from agencies that administer cost share grant programs. Address these sites when conducting future management activities, or if heavy equipment is performing routine maintenance or restoration work on nearby, higher priority sites.

Criteria for Cost-effective Treatments

For consideration of priority treatment, a site should typically exhibit:

- Potential for significant sediment delivery to a stream channel that directly or ultimately results in delivery to a fish-bearing stream. Significance of delivery is guided by the minimum inventory volume established for the watershed assessment;
- A high or moderate treatment immediacy;
- Favorable cost-effectiveness. Project cost-effectiveness is different for similar projects in different areas of California. This rate varies regionally, and changes over time due to inflation and changes in related costs. For example, the cost of similar projects is generally lower in the northern-most counties such as Humboldt or Del Norte as compared to the Bay Area from Sonoma to Monterey County. Furthermore, in the case of high value refuge streams and/or watersheds with listed species, domestic water supplies or

other high value downstream resources, exceptions to cost-effectiveness criteria can be justified. Consultation with DFG fisheries staff can help with this determination.

Site Groupings

In most cases, apply cost-effectiveness to a group or groups of sites so that the most cost-effective groups of projects are undertaken first. For example, during road decommissioning, groups of sites are usually considered together because there will be only one opportunity to treat potential sediment sources along the road. Even if an individual site is highly threatening to the protected resources, recommending treatment priorities based on the cost-effectiveness of one site is generally discouraged. This would lead to a costly shotgun approach to restoration.

Treatment of Abandoned Roads

Another factor influencing a site's treatment priority is the difficulty (cost and environmental impact) of reaching the site with the necessary equipment to treat the potential erosion. Many sites found on abandoned or un-maintained roads require brushing and tree removal to provide access to the site(s). Other roads require minor or major rebuilding of washed out stream crossings and/or existing landslides in order to reach potential work sites farther out the alignment. Road reconstruction adds to the overall cost of erosion control work and reduces project cost-effectiveness. Potential work sites with lower cost-effectiveness, in turn, may be a lower priority. However, just because a road or potential work site is abandoned and/or overgrown with vegetation is not sufficient reasoning to discount its assessment and potential treatment. Treatments on heavily overgrown, abandoned roads are often both beneficial and cost-effective.

Prioritizing Restoration Projects

Once treatment priorities and cost-effectiveness standards are established, it is important to review the restoration plan and prioritize projects for implementation. Not all sub-basins within a large watershed will merit the same type or intensity of protection or restoration measures. Through field inventories, identify areas where there is a potential for cost-effective watershed protection and restoration for fisheries recovery.

Design protection and restoration options for sites in watersheds with the most potential of restoring productive conditions and protecting against future catastrophic damage or persistent degradation. For most sediment assessments, a large number of potential treatment sites are identified and classified into individual treatment priorities. Strategies for prioritizing groups of sites for treatment include:

Prioritize Sub-watersheds

Prioritize and treat sub-watersheds according to their biological importance, not necessarily according to the magnitude of the potential threat that exists in the basin. High quality sub-watersheds may only need a small amount of upslope restoration work or erosion prevention but it is critically important to perform this work and secure the drainage before moving to other sub-watersheds.

Prioritize Hillslope Units

There are many ways to group sites in a watershed or sub-watershed for treatment. Each watershed may warrant a different approach to grouping sites for treatment. This will depend on the sensitivity of the resource, the nature and magnitude of the upslope erosion threat and access to the sites. All groupings should be practical; that is, they should consist of groups or clusters of sites in relatively close proximity and be treatable in a timely, coordinated and cost-effective manner. For example:

- Treatment immediacy – Group based on the identified clustering of high priority units in the watershed. Treat these cluster units according to the magnitude and immediacy of the threat they pose (high priority clusters contain concentrations of high priority sites, but may also include other lower priority sites). Examples might include roads or groups of roads that contain many high priority sites, or many sites immediately adjacent Class 1 stream channels. This strategy will focus on the most immediate threats to the aquatic system, but the unit groups might not be the most cost-effective ones that could be addressed.
- Threat of future sediment delivery-Group based on their volumetric threat to the stream system, as determined by the inventory results.
- Logical treatment units - Sites can be grouped on the basis of logistic considerations, similar work effort requirements, natural topographic boundaries, equipment access points, restoration type (e.g., road decommissioning or road upgrading), or other factors. This is the most basic grouping, and in fact all groupings should fit the definition of logical treatment unit.
- Cost-effectiveness - Group sites based on the average cost-effectiveness of restoration treatments that have been calculated from the inventory and prescription data. This strategy assures the most bang for the buck with restoration funds, but it does not assure treating the highest biological priority units first.

Prioritize Critical Sites

Identify, target and treat individual, extremely high priority sites that if not immediately treated are likely to fail and deliver significant volumes of sediment to the stream system. These sites are likely widely dispersed across the watershed. They may be termed “ASAP” sites. In watersheds with high value aquatic resources, it may be worth going after individual, isolated sites even though there may be a decrease in the relative cost-effectiveness of this restoration strategy due to the higher logistic costs (e.g., multiple staging and increased equipment hauling).

Preparing the Summary Report

Reports for upslope inventory and assessment projects should contain the following information: (Appendix X-C).

- Project identification #
- Project location (descriptive location)
- Map of watershed (location map, showing relationship of project area to the region)
- Map of project area with inventoried sites and roads, which shows:

  - Base information, (streams, roads, sections, contours (optional), scale, north arrow, labels for stream names, road names and cultural features)
  - All roads within the inventory area with current maintenance status:
    - Maintained roads, and
    - Abandoned (un-maintained) roads
  - All stream crossings by type (Humboldt, culvert, unculverted fill, armored fill, ford or bridge)
  - Potential and active landslides with sediment delivery potential if left untreated
  - Ditch relief culverts and other ditch drains
  - Gullies and other fluvial erosion features
- Map of all sites recommended for treatment (with site numbers)
- Map of all sites according to treatment priority (high, moderate, low)
- Project report which contains the following:
  - Introduction (setting, problem, purpose of assessment project)
  - Methods (office, field inventory and data analysis - discuss map data and database)
  - Results and discussion of sediment source assessment
  - Results of transportation planning (discussions with landowner)
  - Future erosion and sediment delivery data (if sites were left untreated)
  - Restoration plan
  - Description of overall treatment plan (upgrading and decommissioning)
  - Road upgrading (show and describe roads planned for upgrading)
  - Road decommissioning (show/describe roads for decommissioning)
  - Describe treatments and sites recommended for treatment, by road
  - Stream crossings, landslides, surface erosion treatments
  - Cost analysis, including:
    - Estimated equipment rates (for all heavy equipment)
    - Estimated labor rates (cost/hr)
    - Total estimated site costs (all site costs added together)
    - Equipment move-in and move-out costs (lowboy) for project
    - Other project costs not listed above (specify)
    - Total estimated costs for entire project (equipment + labor + materials + other)
    - Cost-effectiveness analysis
    - Total estimated sediment savings (delivery prevented in yds^3)
    - Total project cost-effectiveness (cost/yd^3 of sediment delivery prevented).
- Project report appendices including database and data sheets from field surveys, containing the following information for each site recommended for treatment:
  - Site # (as flagged or marked in the field)

- Problem type (stream crossing, landslide, roadbed, ditch relief culvert, gully, other)
- Problem description (narrative or data describing the apparent nature of the problem)
- Erosion activity (active and/or potential)
- Erosion potential (likelihood of erosion, if not treated - high, moderate, low)
- Future erosion (yds^3 of erosion likely to occur if problem is not treated)
- Future delivery (yds^3 of eroded sediment that would be delivered to a stream left untreated)
- Recommended treatment (quantitative description of proposed treatments, e.g., yds^3 of soil to be excavated, or classification of treatment type from a list of possible standard treatments)
- Treatment immediacy or priority (high, moderate, low)
- Equipment times (hours for each category of equipment used at each site)
- Labor times (for each site)
- Materials per site (e.g., culvert, downspout, rock, etc.).

IMPLEMENTING RESTORATION WORK

Restoration Strategies

Upland watershed restoration can take several basic forms: prevention (through avoidance or altered management practices), control, mitigation and/or cleanup. The goal of upslope restoration is to prevent or substantially reduce sediment delivery to streams from accelerated erosion sources. Accomplish this through the implementation of protection measures, restoration measures, and improved land use practices designed to result in more natural sediment yield rates. As with other forms of watershed conservation practices, erosion prevention is usually far more effective and cost-effective than trying to control erosion once it has begun.

Prevention

Accomplish prevention by altering and improving land use practices that would otherwise result in sediment delivery to streams; avoiding sediment producing activities or locations; and treating existing potential sediment sites. The latter includes traditional upland watershed restoration, erosion prevention and erosion control, as described throughout *Part X*.

Reduce the risk of failure or erosion by treating existing sediment sites. This type of preventive restoration, to reduce or eliminate erosion, includes decommissioning of abandoned or unnecessary roads, excavation of potentially unstable fillslopes and small landslides, upgrading road stream crossings, installing critical dips to prevent stream diversions, and dispersing surface runoff.

Erosion Control

Employ erosion control to reduce accelerated sediment delivery to a stream. However, traditional erosion control techniques are naturally limited in their ability to be widely effective and cost-effective. Erosion control is only applicable to erosion processes that are actively occurring, and not to sediment sources that have not yet developed. It is difficult to conduct erosion control for processes that are episodic and for processes that generally cannot be cost-effectively controlled (e.g., large landslides). Some processes are just too large or complex to control once they have begun. Reserve control treatment for erosion processes that are amenable to cost-effective treatment.

Mitigation and Clean-up

These strategies are limited in their utility. Mitigation to counter balance the expected impacts of sediment producing land use activity is difficult. Clean up may be impossible to apply in many circumstances (sediment is difficult to remove once it is in the stream channel) and is typically of limited effectiveness.

Modification of Land Use Practices

The most cost-effective tools for minimizing future erosion and sediment delivery to streams are preventive land use practices and protection measures that limit watershed disturbances. Certain combinations of land use practices and site variables (soils, slope gradient, bedrock geology, slope position, etc.) have been documented to contribute to, or influence, the magnitude or location of watershed erosion. As the result of the watershed assessment and collection of inventory data, recommended modifications to land use practices may provide passive protection to downstream aquatic resources, especially from impacts that occur during infrequent floods.

Practical protection measures related to road networks should address issues such as improved road location and design standards; limiting operations on steep inner gorge slopes, other suspect geomorphic locations and riparian corridors; improved road construction and drainage practices; proper stream crossing installation; frequent road maintenance; and road decommissioning. Seasonal road use restriction is a passive measure to lessen the potential for sediment-related impacts to stream channels. Protection measures for grazed lands include; grazing allocations, riparian planting and fencing, localized enclosures, and other seasonal restrictions.

Road Related Restoration Techniques

Roads are typically a common and disproportionately significant source of accelerated sediment delivery in managed watersheds. Most significant and common erosion problems occurring along roads are predictable and cost-effective to prevent or treat.

There are two basic techniques for road risk reduction and restoration:

- Decommissioning (closure);
- Upgrading.

Following are generic treatment descriptions for a variety of preventive treatments for both decommissioning and upgrading roads. These treatments are collectively referred to as “storm-proofing” (Figure X-9) (Weaver and Hagans 1999). The treatments described for roads or hillslopes have been tested, documented and evaluated in similar erosion control and erosion prevention projects. They have been shown to be generally effective in reducing sediment delivery from managed forest and ranch lands when used in a properly planned and constructed project (California State Parks 2001; Harr and Nichols 1993; Sonnevil and Weaver 1981; USDA

Forest Service 1996; USDI Park Service 1992; Weaver and Hagans 1996; Weaver and others 1981; Weaver and others 1987a,b; Weaver and Sonnevil 1984). In every case, the road upgrading and decommissioning treatments listed in *Part X* must be informed by, and customized by, an evaluation of the characteristics of each potential treatment site.

Road Decommissioning

Decommissioning is the same as road closure. It can be permanent or temporary, but the treatments for both are similar. Decommissioning is defined as removing those elements of a road that reroute hillslope drainage and present slope stability hazards. Another term for this is "hydrologic obliteration" (USDA 1993). It involves such tasks as decompacting road surfaces and installing road surface drainage (e.g., cross road drains or road out sloping) (Figure X-10 and Figure X-11), excavating unstable sidecast and road fill (Figure X-11), and fully excavating stream crossing fills (Figure X-12) (not just culvert removal). Decommissioning essentially involves reverse road construction, except that full topographic obliteration of the roadbed is rarely required to accomplish sediment prevention goals. In order to protect the aquatic ecosystem, hydrologically decommission the road by dispersing runoff, reestablish drainage patterns and remove or stabilize any potential sources of sediment delivery along the alignment. Estimating the sediment savings and treatment cost-effectiveness of such projects will help identify which roads in the watershed are truly the best targets for decommissioning (Table X-4).

<u>Roads with High Priority for Decommissioning</u>
Relative to potential threats to the aquatic ecosystem, certain roads frequently qualify as a high priority for decommissioning. These include poorly built roads in riparian areas, on steep inner gorge slopes, across unstable or highly erodible soils, in tributary canyons where stream crossings and steep slopes are common, roads with high short-term or long-term maintenance costs and requirements, and abandoned roads containing large or numerous sediment delivery sites.

<u>Roads with Low Priority for Decommissioning</u>
Roads that are of low relative priority for decommissioning includes those that follow low gradient ridges, traverse large benches or low gradient upland slopes, and have few or no stream crossings. Roads no longer needed for land or resource management may or may not be a high priority for removal depending on where they are located in the watershed. These would include dead-end spur roads with no stream crossings located high on the hillslope.

Road Decommissioning Treatments

The following tabulated and diagrammed treatments do not represent rigorous specifications, but rather descriptions of basic techniques that must be informed by site-specific evaluations.

Decommissioning consists of three basic tasks.

- Complete excavation of stream crossing fills, including 100 year flood channel bottom widths and 2:1 or otherwise stable side slopes;
- Excavation of unstable or potential unstable sidecast materials that could otherwise fail and deliver sediment to a stream;
- Road surface treatments (ripping, outsloping and/or cross draining) to disperse and reduce surface runoff.

Road Decommissioning Effectiveness

The effectiveness of road decommissioning tasks is usually expressed over two time periods: 1) the volume of sediment that has been prevented from being delivered to stream channels (long term effectiveness) and 2) the volume of sediment that is eroded from the decommissioned sites and delivered to local stream channels in the first several years after decommissioning activities (short term effectiveness). The goal of a decommissioning project is to maximize long-term effectiveness (sediment savings) and to minimize short-term sediment release from the site.

Treatment of road surface runoff (hydrologic connectivity) and excavation of potentially unstable fillslopes have been shown to be highly effective sediment control techniques (PWA 2005). Excavating stream crossings using protocols outlined in *Part X* also proved highly effective (PWA 2005). Most short-term sediment loss from decommissioned sites originated at excavated stream crossings. The primary sources of this sediment delivery, accounting for 91% of the soil loss, were channel incision, surface erosion, and slumps on the sideslopes of excavated stream crossings. Operator error (mostly consisting of leaving unexcavated fill in the stream crossing) accounted for 40% of the potentially avoidable erosion. The remaining 60% of sediment loss was judged to be unavoidable. The single most effective erosion prevention practice, measured by the reduction of post-decommissioning erosion and sediment delivery, was the correct application of recommended treatment prescriptions as outlined in *Part X*.

Role of Emergent Groundwater

Emergent groundwater along roads scheduled for decommissioning plays an important role in the eventual effectiveness of the road closure treatment. Perform road erosion inventories during the wet season, when springs on the roadbed and cutbank are most likely to be active and identifiable. If inventories are conducted during dry summer conditions, hydrophyllic (water loving) vegetation or mottled and discolored soils can be used to indicate the presence of seeps and springs.

Design treatments of wet areas to allow free drainage of springs and other emergent water and connection of these flow sources with downslope channels and swales. Do not place spoil material against cutbanks or cover springs that occur on the roadbed; spoil endhauling may be required. Some springs may not be visible during the assessment phase of the project, even if conducted during wet winter conditions. For example, some natural springs are buried during road construction and are only revealed when the road is decommissioned (typically during dry summer months). Excavated stream crossing sideslopes occasionally expose pre-existing springs, and these sources of emergent water can cause soil saturation and gullying or slope instability. In cases where embankment materials are saturated, as evidenced by winter surveys, excavation may be indicated even where no other signs of potential failure are identified. At the same time, excavation methods must be designed for wet and potentially hazardous conditions where equipment or laborers are working near wet cuts and fills[1]. Saturated materials need to be properly stored where they will not enter a watercourse.

[1]Applicable worker health and safety regulations include but are not limited to sections: 29, the Code of Federal Regulations (CFR) 1926.650, 601 (b)(6) of and Title 8, Sections: 1540, 1541, 1541.1 of the California Code of Regulations.

Characteristics of Storm-proofed Roads

Storm-proofed stream crossings

- All stream crossings have a drainage structure designed for the 100-year flow (with debris).
- Stream crossings have no diversion potential (functional critical dips are in place).
- Stream crossing inlets have low plug potential (trash barriers & graded drainage).
- Protect stream crossing outlets from erosion (extended, transported or dissipated).
- Culvert inlet, outlet and bottom are open and in sound condition.
- Undersized culverts in deep fills (greater than backhoe reach) have emergency overflow culvert.
- Bridges have stable, non-eroding abutments and do not significantly restrict 100-year flood flow.
- Fills are stable (unstable fills are removed or stabilized).
- Road surfaces and ditches are “disconnected” from streams and stream crossing culverts.
- Class I stream crossings meet DFG and NMFS fish passage criteria (Part IX).

Storm-proofed fills

- Unstable and potentially unstable road and landing fills are excavated or structurally stabilized.
- Excavated spoil is placed in locations where it will not enter a stream.
- Excavated spoil is placed where it will not cause a slope failure or landslide.

Road surface drainage

- Road surfaces and ditches are “disconnected” from streams and stream crossing culverts.
- Ditches are drained frequently by functional rolling dips or ditch relief culverts.
- Outflow from ditch relief culverts does not discharge to streams.
- Gullies (including those below ditch relief culverts) are dewatered to the extent possible.
- Ditches do not discharge (through culverts or rolling dips) onto active or potential landslides.
- Decommissioned roads have permanent drainage and do not rely on ditches
- Fine sediment contributions from roads, cutbanks and ditches are minimized by utilizing seasonal closures and installing a variety of surface drainage techniques including berm removal, road surface shaping (outsloping, insloping or crowning), rolling dips, ditch relief culverts, water bars and other measures to disperse road surface runoff and reduce or eliminate sediment delivery to the stream.

Figure X-9. Common characteristics of storm-proofed roads.

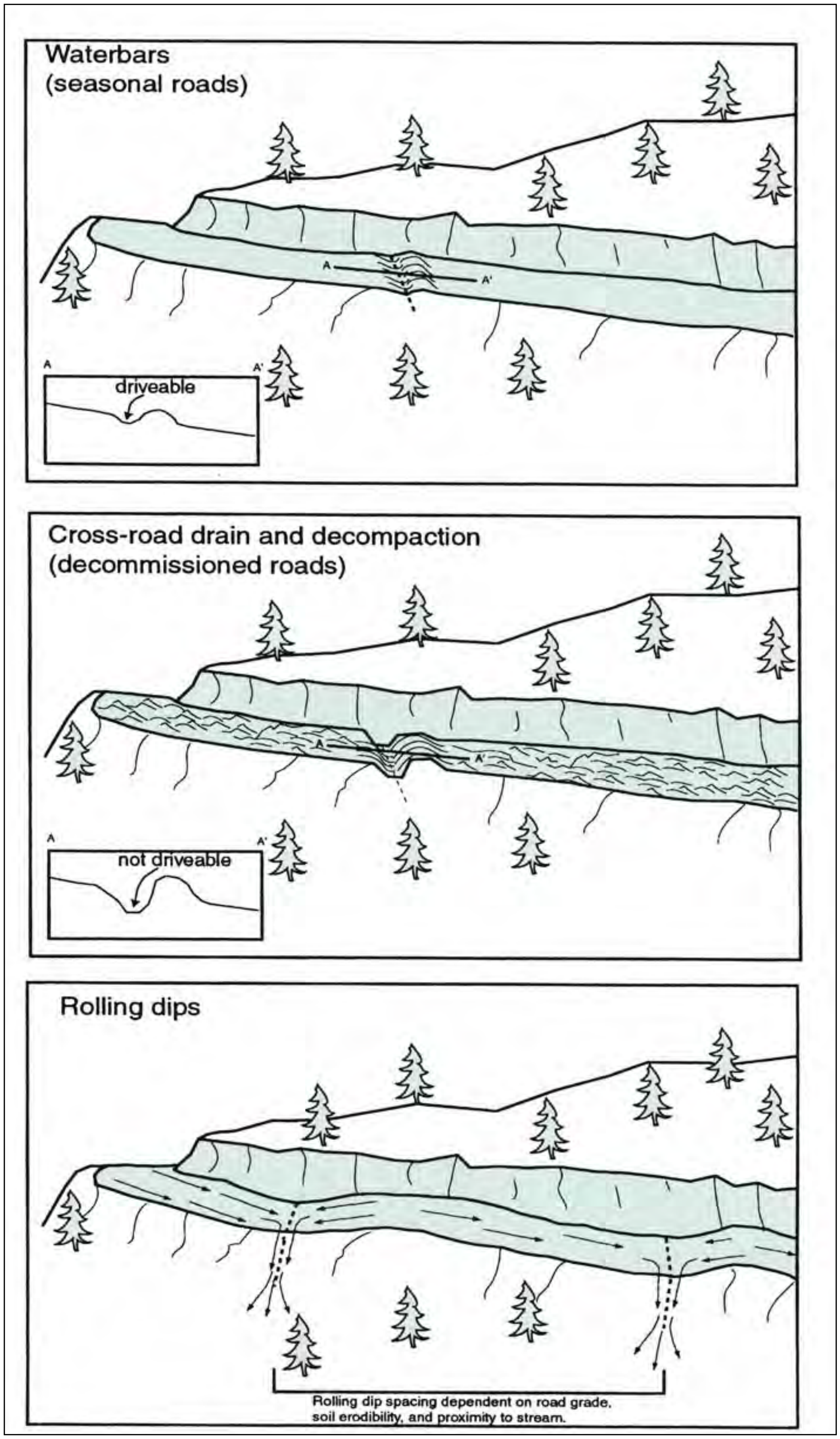


Figure X-10. Techniques for dispersing road runoff.

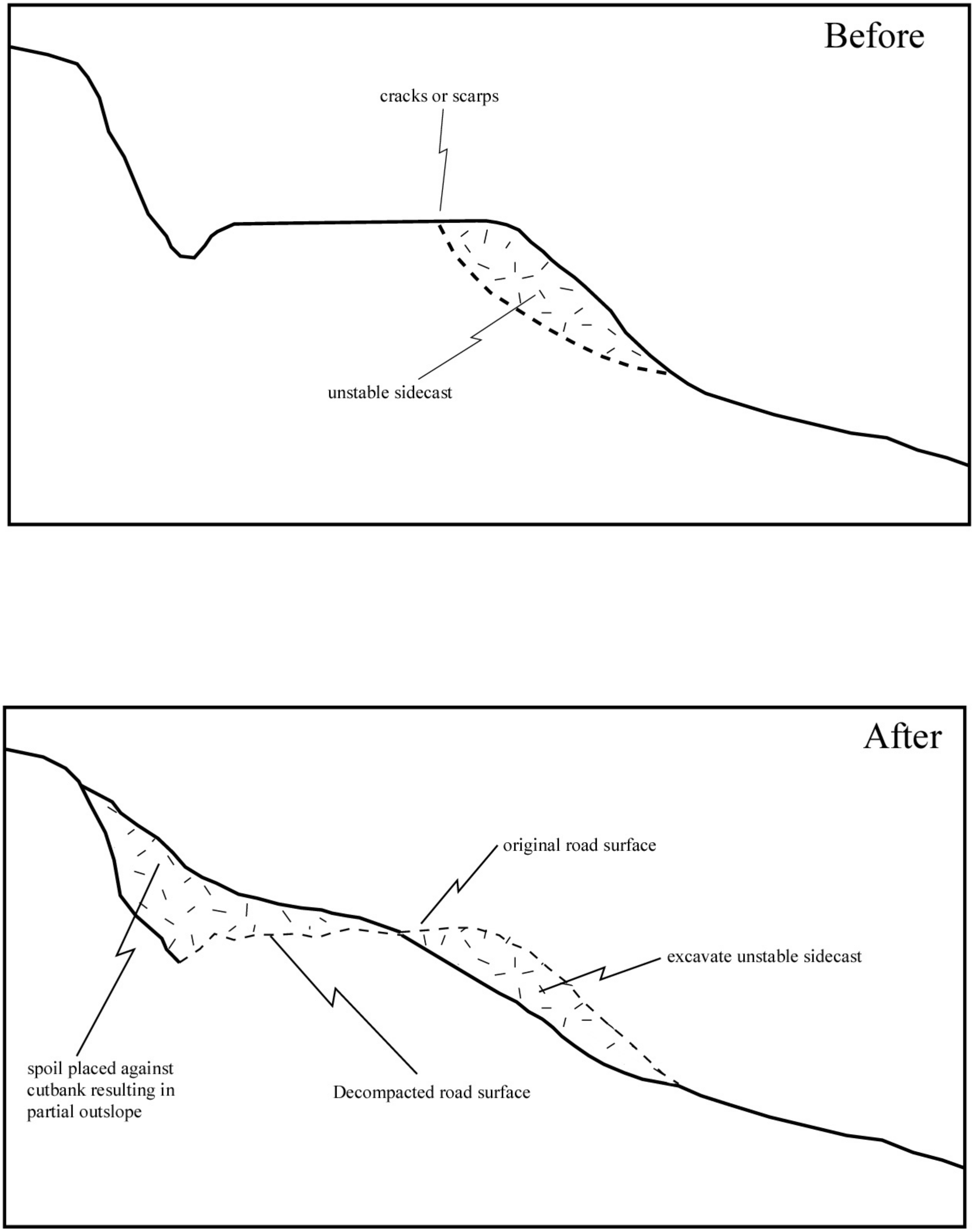
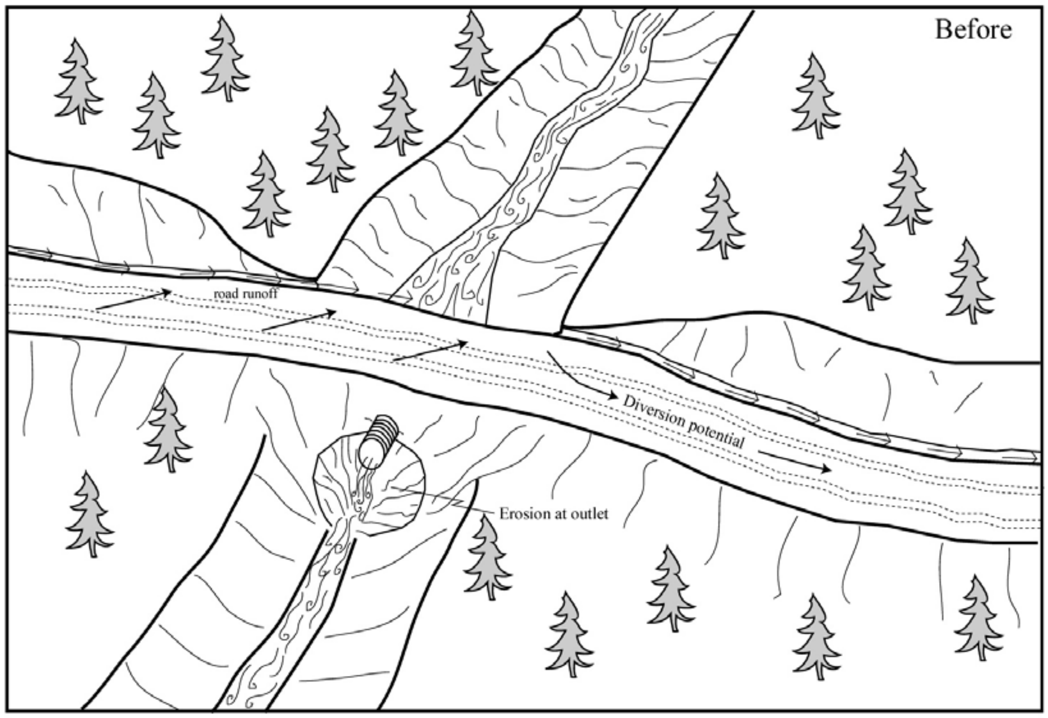


Figure X-11. Partial outsloping for road decommissioning.

Condition

- Diversion potential
- Road surface and ditch flows drain to stream
- Undersized culvert high in fill with outlet erosion and elevated plugging potential



Treatment

- Road surface decompacted
- Cross road drains on old road
- Stream crossing fill completely excavated
- Excavated spoil used to outslope adjacent road

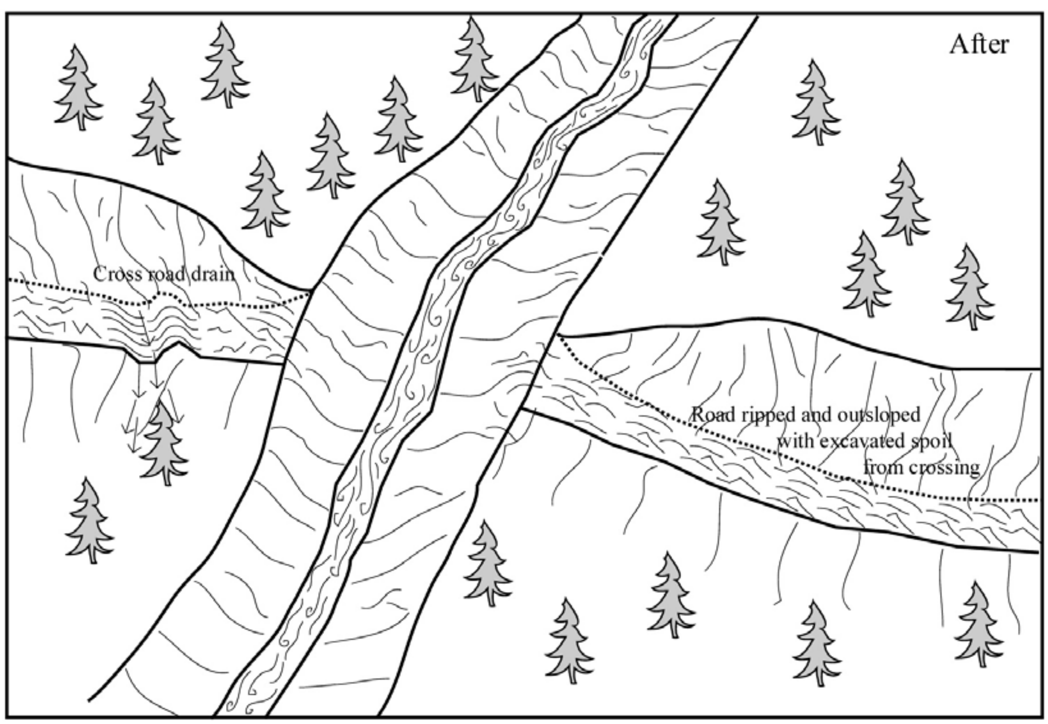


Figure X-12. Typical stream crossing excavation on a decommissioned road.

Treatment	Typical Application	Typical Actions	Typical Costs[1]
Ripping or Decompaction	Improve infiltration; decrease runoff; assist revegetation	Rip roads, landings and compacted areas with multiple passes to average depth of 18".	\$1,000 - \$2,000/mile
Construction of cross-road drains	Drain springs; drain insloped roads; drain landings	Drains deeper and wider than waterbars, extending from cutbank to outside edge of road (captures ditch flow).	\$1/ft (\$25-\$50 ea)
Partial outsloping (local spoil site; fill against the cutbank)	Remove minor unstable fills; disperse cutbank seeps and runoff	Road should be ripped before adding spoil for outsloping. Springs should not be covered. Ditches can be filled.	\$2,500 - 12,500+ /mile
Complete outsloping (local spoil site; fill against the cutbank)	Used for removing unstable fill material where nearby cutbank does not include seeps or springs	Road should be ripped before adding spoil for outsloping. Springs should not be covered. Ditches can be filled.	\$10,000 - 75,000+/mile
Exported outsloping (fill pushed or hauled away and stored down-road)	Used for removing unstable road fills where cutbanks have springs and cannot be buried	Spoil site should be located in stable area where sediment will not be delivered to stream.	\$2 - \$5/yd^3, depending on haul distance
Landing and fillslope excavations (with local spoil storage)	Used to remove unstable material around landing perimeter	Landing should be ripped and spoil placed on inside half of landing. Springs should not be covered.	\$2 - \$5/yd^3, high organics can increase costs
Stream crossing excavations (with local spoil storage)	Complete removal of stream crossing fills (not just culvert removal)	Excavate all fill from crossing, down to original channel bed with straight or concave profile; original or 2:1 side slope gradient; natural channel width	Averages \$3 - \$10/yd^3 but can vary considerably
Truck endhauling (dump truck)	Hauling excavated spoil to an offsite spoil disposal site	Haul to a stable site not near stream channels. Place spoil where it is stable and will not deliver to a stream.	\$2 to \$5/yd^3 on top of basic excavation work

[1] These are estimated treatment costs for equipment working at a site. Heavy equipment treatments performed using D-7 tractors and hydraulic excavators with average 2 yd^3 bucket size. They do not include transportation, moving from site-to-site, overhead, project supervision by or consultation with restoration or professional geotechnical specialists, layout, or any other costs. Costs can vary considerably from these typical figures, depending on operator skill and experience, equipment types, local site conditions, and regional location. Example costs are from 2004 data for north coastal California and are not based on prevailing wage rates. Production rate data from from PWA (unpublished) and NPS (1992).

Table X-4. Typical techniques and costs for decommissioning forest and ranch roads.

Road Upgrading

Managed watersheds need roads to provide for long-term resource management and access to private properties or recreational areas. Good land stewardship requires road systems be protective of fish habitat and the aquatic ecosystems in the watershed. Transportation planning requires that landowners or land managers consider the erosion consequences of retaining the road and the expressed needs for management activities. Retained roads should be located on stable terrain, where the risk and impacts of fluvial erosion, stream crossing failure, storm damage and mass soil movement is low. Roads should be largely self-maintaining or require low levels of maintenance. To facilitate this, many existing roads will likely need to be upgraded.

For fisheries protection and restoration, the goal of road upgrading is to minimize the contributions of fine sediment from roads and ditches to stream channels, as well as to minimize the risk and impacts of episodic erosion and sediment delivery when storms and floods occur.

Road upgrading or storm-proofing involves a variety of treatments designed to make a road more resilient to runoff from large storms and flood flows (Figure X-9 and Table X-5)(Weaver and Hagans 1999). The most important of these include upgrading stream crossings for the 100-year flood flow, elimination of stream diversion potential, removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of road surface runoff. Newly constructed roads may not need as much corrective treatment as older roads. For example, timberland owners and foresters are now required by the Forest Practice rules, as amended by the California State Board of Forestry and Fire Protection in 2000, to design all new and reconstructed permanent watercourse crossings to accommodate an estimated 100-year flood flow, including wood and sediment loads. They are also required to design stream crossings such that there is no chance of future stream diversion.

Road Upgrading Treatments

In general, road upgrading consists of stream crossing upgrades, excavation of selected unstable or potential unstable fillslopes, and dispersion of road runoff (Figure X-9).

The following guidance, typical diagrams and tables summarize common road upgrading techniques, including road surface shaping (insloping and outsloping), berm removal, rolling dips, ditch relief culverts, and non-fish bearing culvert installation. For more detail, see *Handbook for Forest and Ranch Roads* (PWA 1994) or the corresponding video *Forest and Ranch Roads* (MCRCD 2003).

Treatment	Ideal Equipment	Sample Cost Rate[1]	Sample Application Rate and Assumptions	Sample Cost[2]
Outslope road and fill ditch	Grader with rippers	$85/hr	500ft/hr for 20' wide road	$170/1000 ft
Rolling dip	Dozer with rippers	$85/hr	1 hr each (30-40’ long on flat roads) 2 hrs each (50-100’ long on steep roads)	$85 - $170 each
Remove berm or clean ditch	Grader	$85/hr	1000'/hr (no trees on berm or in ditch)	$85/1000 ft
Rock road (1.5" minus crushed)	Dump truck spread	$17 – $40/ yd^3 - delivered	4" deep x 20' wide = 250 yds3/1000 ft road	$4,250 - $10,000/1000 ft
Install ditch relief culvert (assumes 40' of 18" culvert	Back hoe or Excavator[2] and Laborer	$65/hr $125/hr $30/hr	3 hours each + $8.50/ft + $18 coupler + $90 labor	$645 to $825 each
Stream crossing installation (36" x 40' culvert with 200 yd^3 fill)	Excavator Tractor Water truck and Laborer	$125/hr $85/hr $85/hr $30/hr	$1,520 culvert (w/coupler) + $875 excavator + $595 dozer + $170 water truck + $90 labor + $100 tamper	$3,270 each
Culvert downspout installation	Hand labor and Equipment (>24")	$30/hr $125/hr	20' x 24": 2 hrs labor 40' x 36": 3 hrs labor + 1 hr excavator	$60 + materials $375 + materials
Straw mulch bare soils areas	Labor	$30/hr $5/bale straw	1 bale/600 ft^2 - 700 ft^2 + spreading @ 4 bales/hr	$19-$22/1000 ft^2
Complete road upgrading	Excavator, Tractor and Dump trucks	$125/hr $85/hr $65/hr	Average mid-slope road requiring stream crossing upgrades	$15,000 - $40,000/mile

[1] Costs can vary considerably from these typical figures, depending on operator skill and experience, equipment types, local site conditions and regional location. Example costs are from 2004 data for north coastal California and are not based on prevailing wage rates. Production rate data from PWA (unpublished).

[2] Costs are variable depending on materials costs, equipment types and rental rates, and operator experience. Culvert cost assumptions (<= 24” - 16 gauge galvanized culvert, >=30” – 12 gauge galvanized culvert): 18" - $8.50/ft; 24" - $11.50/ft; 36" - $29/ft; 48” - $38/ft; 60" - $48/ft. Some treatments (e.g., outsloping road and filling the ditch) may be performed for different rates using tractor instead of grader. Dozer and dump trucks are often needed on culverted stream crossing installations larger than 200 cubic yards.

Table X-5. Example logistics and costs for a variety of upgrading task for forest and ranch roads.

Stream Crossing Upgrading

- Eliminate stream diversion potential by dipping the entire stream crossing fill or by installing a critical dip (Figure X-13). A critical dip is a rolling dip that is constructed on or close to the down-road hinge line of a stream crossing that displays a diversion potential.
- Upgrade stream crossings by installing culverts sized for the 100-year flood flow, including sufficient capacity for expected wood and sediment (Figure X-13 and Figure X-14). These requirements are determined by both field observation and calculations using a procedure such as the Rational Formula (PWA 1994; Dunne and Leopold 1978) for small watersheds (<100 acres), or regional regression equations developed for ungaged watersheds up to several hundred acres in size (Waananen and Crippen 1977; Cafferata et al. 2004).[2] Where necessary, install inlet protection (trash barriers) to prevent culvert plugging on non-fish bearing streams.
- Place culverts in line and on grade with the natural stream channel above and below the crossing site (Figure X-14). This minimizes the probability of culvert plugging. In streams with resident or anadromous fish, or where there is a requirement to provide for passage of non-fish aquatic species, culverts must be embedded in the natural stream channel according to specific guidelines (DFG Manual, Part IX). If non-fish stream crossing fills are exceptionally deep (beyond backhoe reach from the road surface) then a full round downspout can be installed to take the stream flow to the base of the fill and discharge it into the natural stream channel. At the point of return flow from the pipe to the natural stream channel, some form of energy dissipation and erosion protection may be required to control scour at the culvert outfall (Figure X-14).
- Replace large high-risk culverts with bridges. Consider replacing any culvert greater than 72 inches in diameter with a bridge, especially in Class 1 streams.
- Replace culverted fills with hardened fords or armored fills (Figure X-15 and Figure X-16) on non-fish bearing streams where regular winter inspections and culvert maintenance is not feasible, or on steep gradient stream crossings where the culvert plug potential will always be high.

Stream Crossing Culvert Installation for Non-fish Bearing Streams

- Align culverts with the natural stream channel orientation to ensure proper function, prevent bank erosion and minimize debris plugging problems.
- Place culverts at the base of the fill and at the grade of the original streambed or install a downspout past the base of the fill (Figure X-13 and Figure X-14). Down-drain (or downspout) assemblies should only be installed if there are no other options.

[2] Technical references for rainfall and runoff data include the California Data Exchange Center http://cdec.water.ca.gov, the Department of Water Resources http://wdl.water.ca.gov (under construction), the Department of Forestry http://cdf.ca.gov/projects/esu/esulooup.asp and the Western Regional Climate Center http://www.wrcc.dri.edu/summary/climsmnca. Software for performing peak flow calculations is also available (e.g., USGS Peak Frequency Software, http://water.usgs.gov/software/peakfq.html and USGS National Flood frequency Software, http://water.usgs.gov/software/nff.html

- Culverts should be set slightly below the original stream grade so that the water drops several inches as it enters the pipe.
- Culvert beds should be composed of rock-free soil or gravel, evenly distributed under the length of the pipe.
- Compact the base and sidewall material before placing the pipe in its bed.
- Lay the pipe on a well-compacted base. Poor basal compaction will cause settling or deflection in the pipe and can result in separation at a coupling or rupture in the pipe wall. If compaction is problematic, then the potential sagging after burial can be accounted for by maintaining an upward camber between 1.5 to 3 inches per 10 feet culvert pipe length.
- Backfill material should be free of rocks, limbs or other debris that could dent or puncture the pipe or allow water to seep around the pipe.
- Cover one end of the culvert pipe, then the other end. Once the ends are secure, cover the center.
- Tamp and compact backfill material throughout the entire process, using water as necessary for compaction.
- Backfill compacting will be done in 0.5 – 1.0 foot lifts until 1/3 of the diameter of the culvert has been covered (Figure X-14). A gas powered tamper or sheep's foot roller should be used for this work.
- Armor inlets and outlets with rock, or mulch and seed with grass as needed (not all stream crossings need to be armored).
- Install a trash rack (only on non-fish bearing streams) upstream from the culvert inlet where there is a high hazard of floating debris plugging the culvert.
- Push layers of fill over the crossing to achieve the final design road grade, at a minimum of one-third to one-half the culvert diameter.

Trash Racks

All trash racks require on-going maintenance. Two efficient trash rack designs include:

- On streams with culverts 48 inches diameter or greater, build a grate or sieve across the entire channel to collect the large material that would otherwise plug the culvert inlet. Locate the trash rack anywhere from five to 25 feet upstream from the culvert inlet.
- On streams with culverts under 48 inches diameter, set a single post vertically in the steam bed, centered directly upstream from the culvert inlet, and located one culvert diameter distance upstream from the inlet. Size the post and set the post deep into the streambed to withstand the size of woody debris transported by the stream during extreme runoff events.

<u>Ten steps to building an effective armored fill stream crossing</u>
Install armored crossings (Figures X-15 and X-16) in areas where debris torrents are common, can be expected or where small steep gradient streams cross the road. Armored fill crossings are for sites where it will be very difficult to prevent frequent culvert plugging due to high amounts of transported sediment and debris. The treatment requires excavating a portion of the fill in the stream crossing and leaving a very broad dip in the axis of the natural channel, with long and

gently sloping ramps into and out of the stream crossing. This treatment may be most appropriate along roads built on a floodplain and terrace, or where roads cross steep gradient stream channels with relatively small depths of fill at the outboard edge of the road.

Before prescribing or building an armored fill, make sure the site is appropriate for the structure. Evaluate the suitability of the site for an armored fill, making sure the stream is not too big and the fill is not too deep. The stream should be a relatively small Class 2 or Class 3 stream (a fish-bearing Class 1 in not appropriate) and the fill depth at the outside edge of the road should not exceed about six (6) feet in depth. Once the site is determined to be potentially suitable, there are ten basic steps to converting the stream crossing to a stable armored fill.

1) Evaluate design and construction requirements - The four most important concepts to understand when constructing an armored fill are: a) constructing a broad and deep rolling dip through the road where the stream is to cross, b) excavating a keyway in the outer half of the roadbed, down the fillslope and across the toe of the fillslope to hold the rock armor, c) selecting rock armor that is suitably sized to resist transport by the stream during design flood flows, and d) placing the rock armor. Proper shaping of the excavated road fill, proper armor sizing, and good armor placement will reduce the likelihood of crossing failure.

The rock must be placed in a broad "U" shaped excavation across the channel and the roadbed so that the streamflow will always stay confined within the armored area; even during the 100-year design flood flow. If the flow gets around (outside) the rock armoring on the road surface or on the armored fillslope, it will quickly gully around and through the remaining road fill.

A range of interlocking rock armor sizes should be selected and sized so that peak flows will not pluck or transport the armor off the roadbed or the sloping fill face of the armored fill (e.g., see Racin et al., 2000). There are two key places where rock size and rock placement is critical: 1) at the base of the armored fill where the road fill meets the natural channel and 2) at the break-in-slope between the outer roadbed and the upper fill face. The largest rocks must be used at the toe to support or buttress the armor placed on the fillslope above it. This will provide toe support for the rest of the armor and reduce the likelihood of it washing downslope. Armor placed at the slope break at the top of the fillslope is also critical in that it will provide the stable "base level" for the creek as it crosses the road surface and accelerates down the fill face.

2) Remove drainage structures - Remove any existing drainage facilities in the fill, including culverts and Humboldt logs or large organic debris in the stream crossing fill (Figure X-16; cross sections A-B).

3) Dip the roadbed - Construct a broad rolling dip across the roadbed, centered at the crossing, which is large enough to contain the expected 100-yr flood discharge while preventing flood flow from diverting down the road or around the rock armor (Figure X-16; cross sections C-D; E-F). For many crossings, the broad dip typically averages two to three feet deep along the "thalweg" or axis of the dip.

4) Excavate the keyway and armored area - Excavate a two to three foot deep "bed" into the dipped road surface and adjacent fillslope (to place the rock in) that extends from approximately the middle of the road, across the outer half of the road, and down the outboard road fill to where the base of the fill meets the natural channel. Peak flow calculations for the 100-year discharge (e.g., using the rational formula) should be performed to determine the proper width of the armored area through the roadbed and on the fillslope. Typically, for small Class 2 and Class 3 channels, the required armored width at the outside edge of the road has been found to be at least five times the estimated peak flow width of the natural channel upstream of the crossing. At the base of the fill, excavate a three (3) foot deep keyway trench extending across the channel bed (Figure X-16; cross sections G-H; I-J).

5) Install fabric lining - Install geo-fabric within the trenched keyway at the toe and extending up the excavated fillslope and across the excavated part of the roadbed; anywhere rock armor is to be placed (Figure X-16; cross sections G-H). Bury the top of the fabric in a trench across the roadbed to key in the fabric. The fabric will support the rock armor in wet areas and prevent winnowing of the fine sediments and road fill beneath the rock armor when the stream flows over the armored fill.

6) Armor the basal keyway - Put aside the largest rock armoring to create two buttresses. Use the largest rock armor to fill the basal trench and create a buttress at the base of the fill. This should have a "U" shape to it and it will define the outlet where flow leaves the armored fill and enters the natural channel (Figure X-16; cross sections K-L).

7) Armor the fill - Backfill the fill face with the remaining rock armor making sure the final armor is unsorted and well placed, the armor is two coarse-rock layers in thickness, and the armored area on the fill face also has a "U" shape that will accommodate the largest expected flow (Figure X-16; cross sections K-L).

8) Armor the top of the fill - Install a second trenched buttress for large rock at the break-in-slope between the outboard road edge and the top of the fill face. The level of the armor rock placed in this "buttress" at the top of the fill face will define the base level of the stream as it crosses the roadbed (Figure X-16; cross sections M-N).

9) Armor the roadbed - Backfill the rest of the roadbed keyway with the unsorted rock armor making sure the final armored area on the roadbed has a "U" shape (Figure X-16; cross sections O-P) that will accommodate the 100-year design flood flow.

10) Inspect and maintain the crossing - Monitor the armored fill for the first several winters and make maintenance repairs to any armor that may have moved during peak flow periods. Maintain the flood flow capacity of the armored fill on the roadbed (Figure X-16; cross sections O-P) by grading alluvial deposits and debris off the road as needed.

Erosion Control Measures for Culvert Installation

Use a combination of mechanical and vegetative measures to minimize accelerated erosion from stream crossing and ditch relief culvert installation. Erosion control measures may include:

- Minimizing soil exposure by limiting excavation areas and heavy equipment disturbance.

- Installing filter windrows of slash at the base of the road fill to minimize the movement of eroded soil to down slope areas and stream channels.
- Insloping the road prism at newly constructed or upgraded stream crossings to minimize fillslope erosion caused by road runoff.
- Protecting bare slopes created by construction operations until vegetation can stabilize the surface. Minimize surface erosion on exposed cuts and fills by mulching, seeding, planting, compacting, armoring, and/or benching prior to the first fall rains.
- Storing extra or unusable soil in long-term spoils disposal locations that are not subject to excessive moisture, steep slopes, archaeological sites, listed species, or proximate to a watercourse.
- If there is running or standing water, pumping or diverting water past the crossing and into the downstream channel during the construction process.
- Installing straw bales and/or silt fencing where necessary to control runoff and sediment movement within the construction zone.

Excavation of Unstable Fillslope

Remove unstable sidecast and fill materials from steep slopes (Figure X-17), steep headwater swales, and along road approaches to deeply incised stream channels, where there is potential for sediment delivery. Worker safety in potentially hazardous areas, where slopes are steep, wet and potentially unstable, must be in conformance with applicable worker safety regulations (e.g., see Caltrans 1990).[3]

- Excavate small volumes of unstable fill along the outside edge of the road, turnout or landing if it has the potential to fail and be delivered to a stream channel.
- Unstable fill that has little or no potential to fail or be delivered to a stream need not be excavated if fish habitat protection is the only goal.
- Excavate fill material in an arc-shaped downslope profile, so as to remove as much of the unstable mass as is possible.
- Store excavated spoil materials in a location where eroded sediment will not enter a watercourse.

[3] Wherever workers have to enter an area where the banks or cuts are greater than five feet in height (functionally a trench), the banks of such areas will need to be properly sloped, benched, or shored (trenching needs to be in compliance with all applicable worker health and safety regulations including but not limited to sections: 29, the Code of Federal Regulations (CFR) 1926.650, 601 (b)(6) of and Title 8, Sections: 1540, 1541, 1541.1 of the California Code of Regulations.

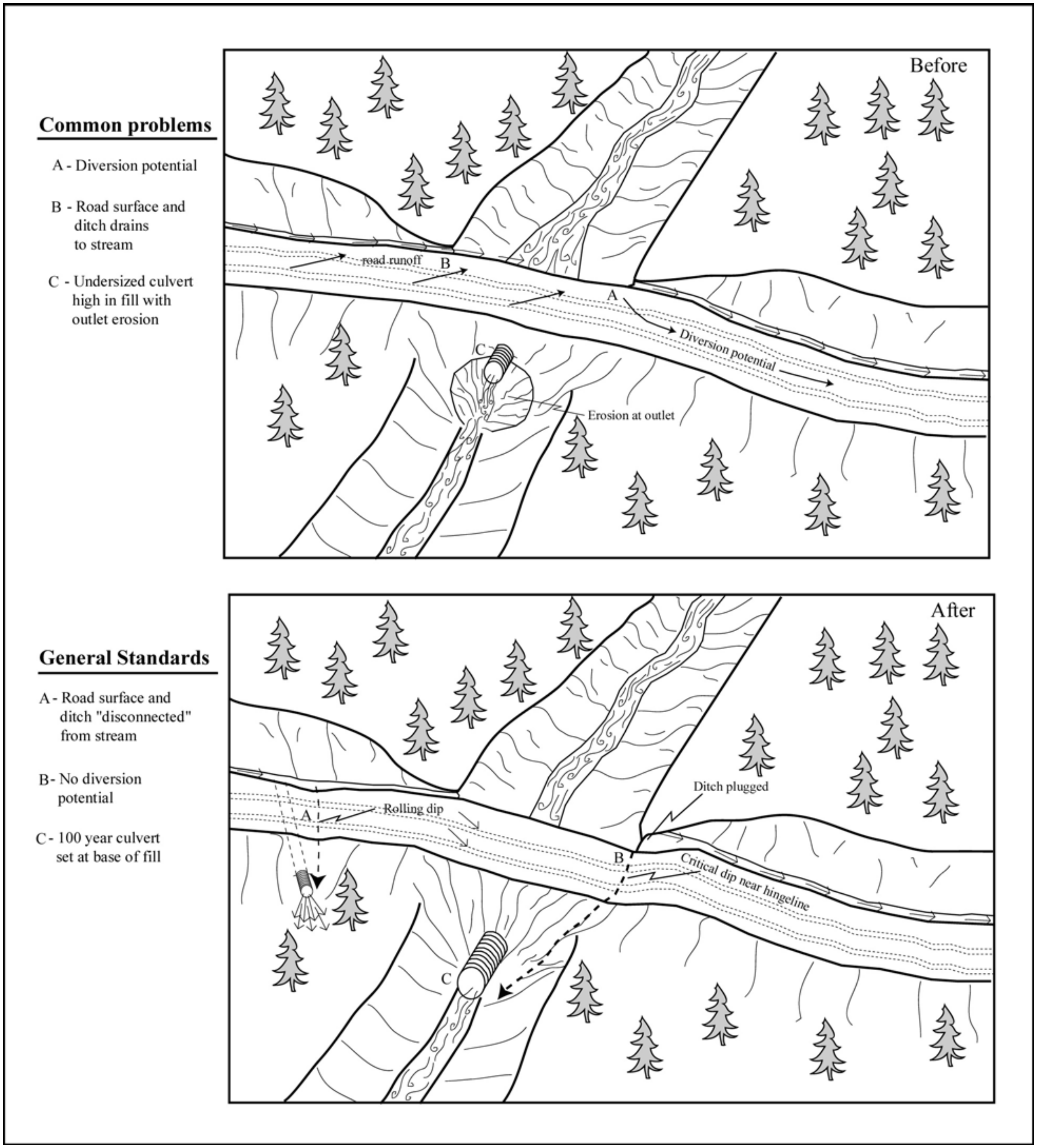


Figure X-13. Typical upgraded stream crossing.

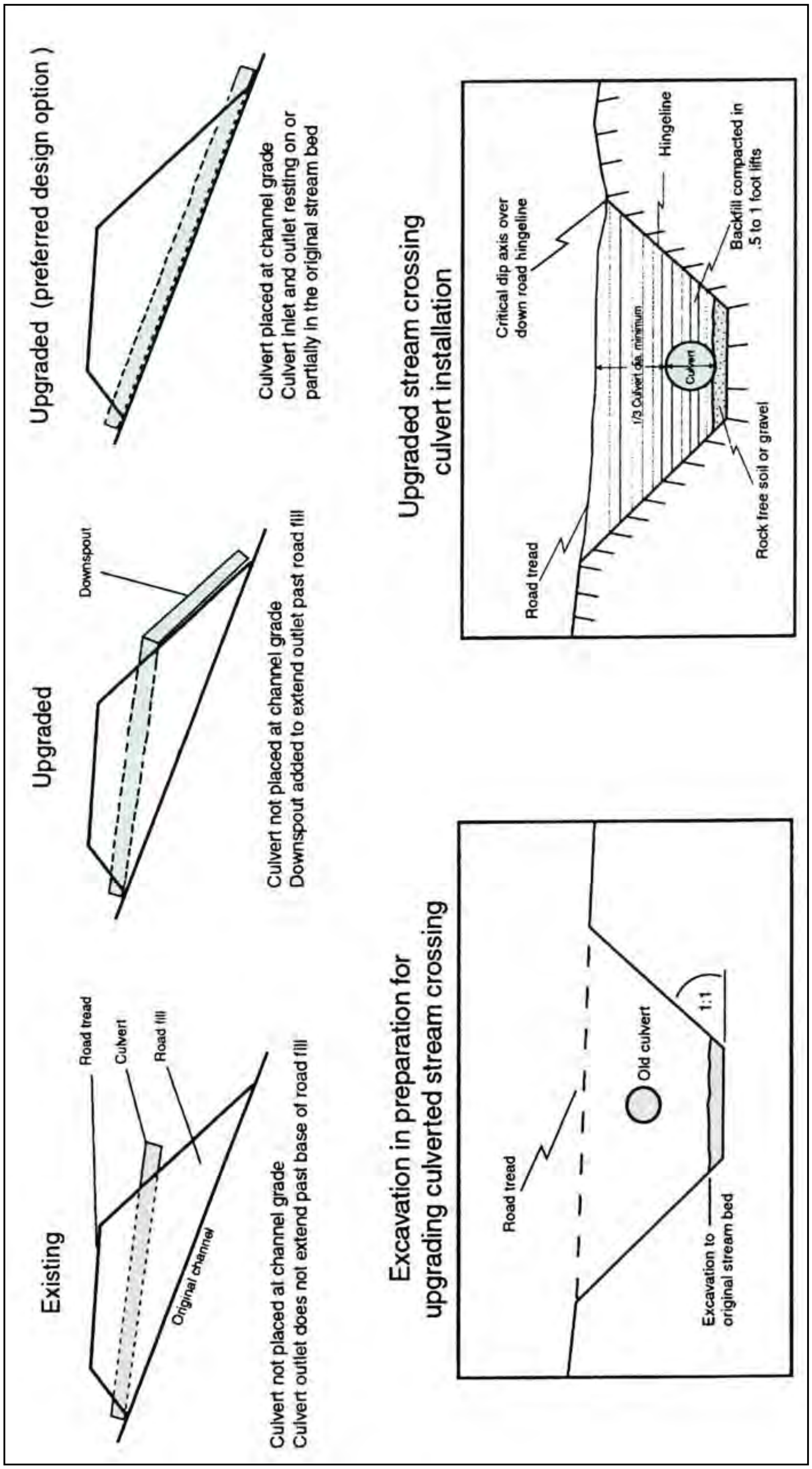


Figure X-14. Typical culvert installation on non fish-bearing streams.

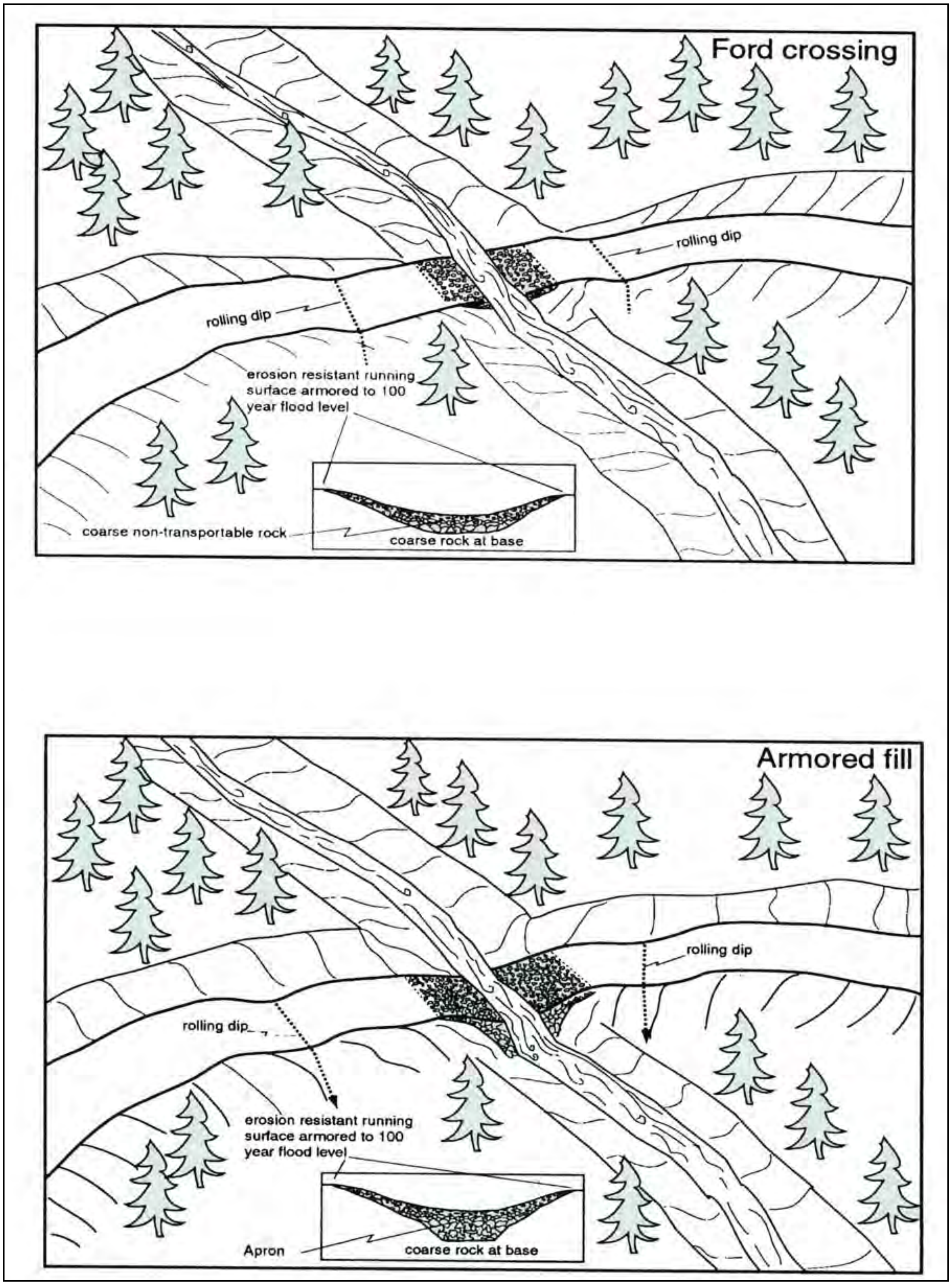


Figure X-15. Typical ford and armored fill stream crossings.

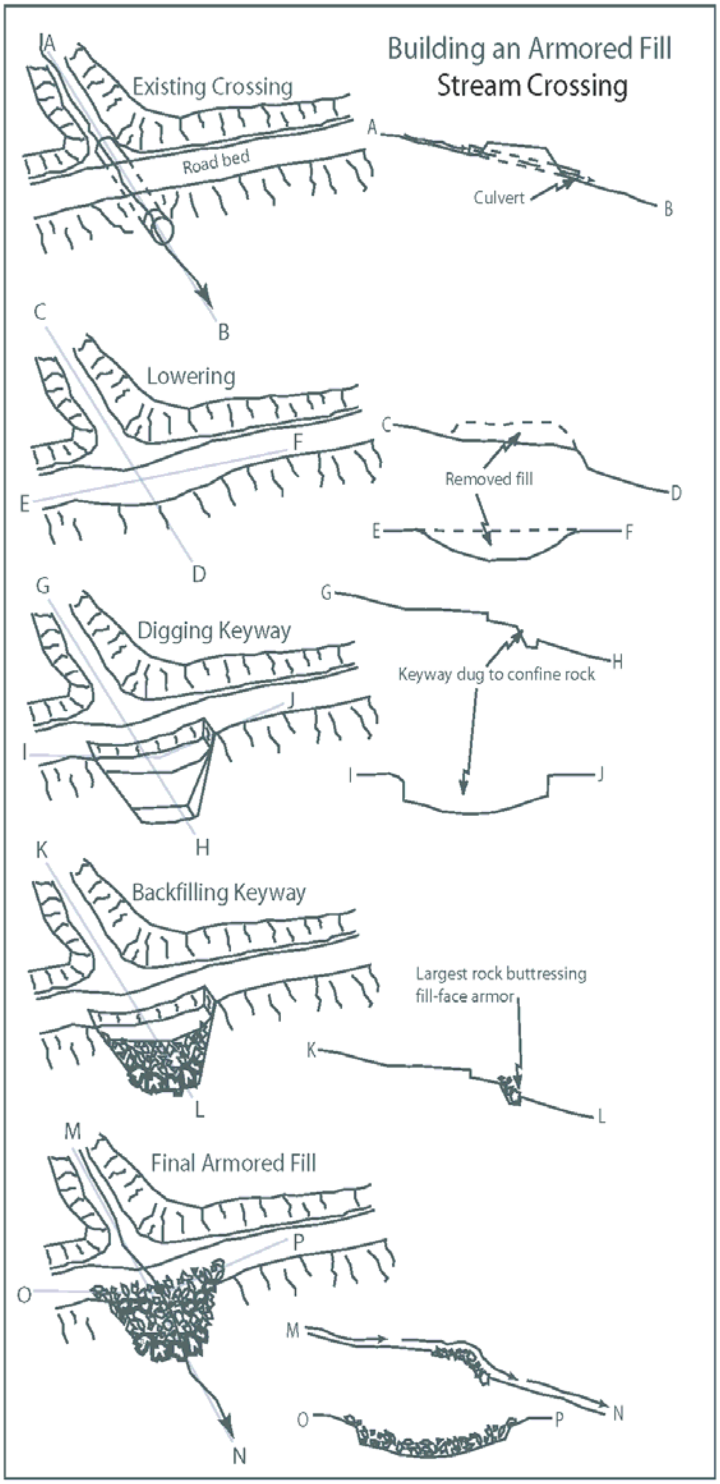


Figure X-16. Design elements of a typical armored fill crossing. Note: where geotextile fabric may interfere with passage of amphibians in any Class 2 or 3 crossing, bury geotextile fabric with at least 6 inches of rock. Do not expose geotextile fabric in the bed of fish-bearing stream channels.

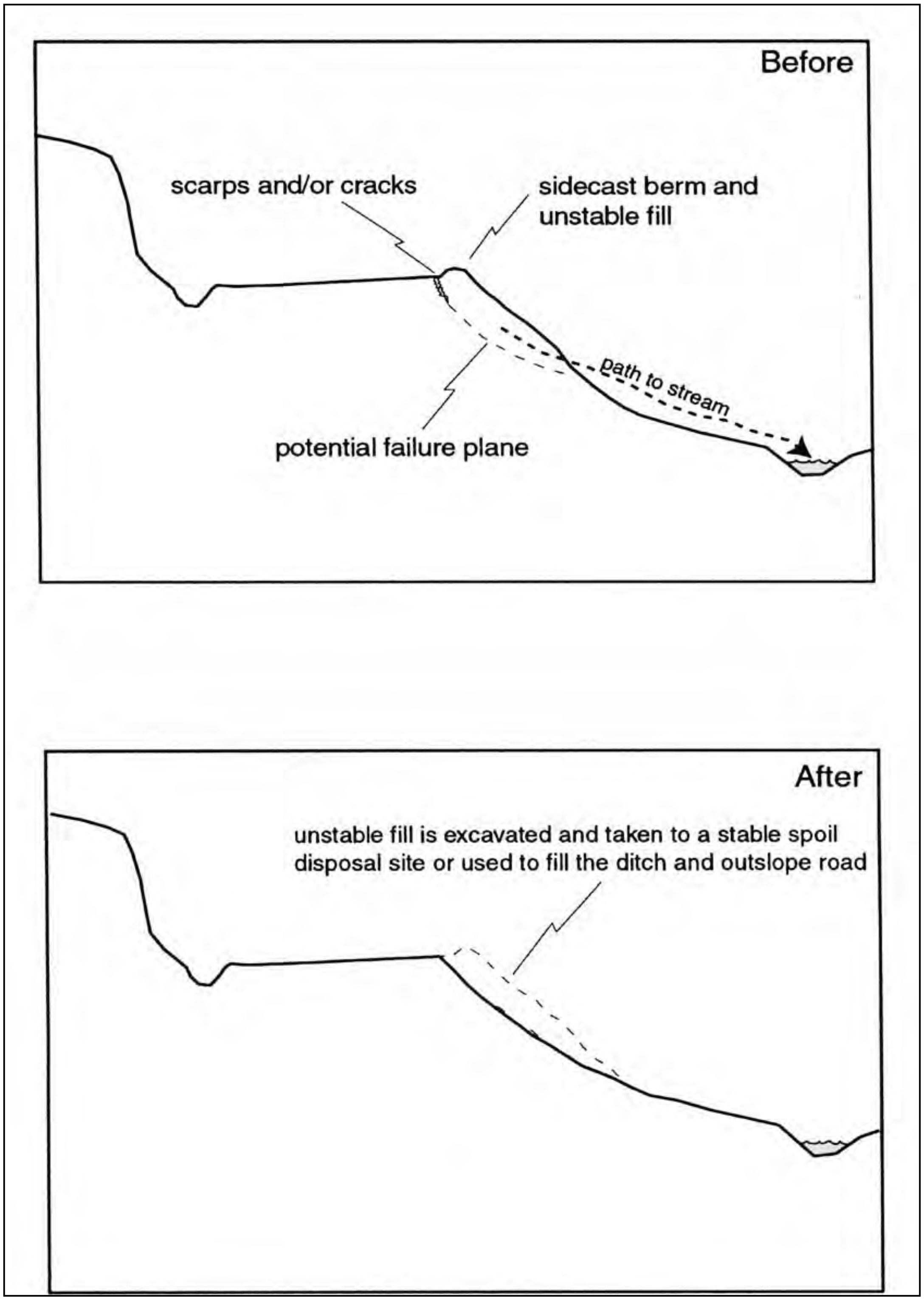


Figure X-17. Removal of unstable sidecast materials.

Dispersion of Road Runoff

Disperse and disconnect road surface runoff from streams. Road cutbanks and road ditches are known to deliver substantial volumes of fine sediment to streams in some watersheds (e.g., Reid 1981; Reid and Dunne 1984) and they have been found to significantly affect watershed hydrology (Wemple 1994). Relatively simple treatments can be performed to upgrade road drainage systems to significantly reduce or largely eliminate this source of fine sediment delivery to streams. Sediment may be minimized by utilizing seasonal closures or traffic restrictions, and dispersing road runoff. Choose from a variety or combination of surface drainage techniques including berm removal (Figure X-19), water bars (Figure X-10), road surface shaping (outsloping, insloping or crowning (Table X-6), ditch relief culverts (Figure X-19), rolling dips (Figure X-19), and other measures that effectively disperse road surface runoff and reduce or eliminate sediment delivery to the stream. To be effective, they must effectively disperse most road runoff and ditch flow before it reaches the stream. It is critical that all road surface drainage techniques effectively drain the road surface and be drivable for the expected traffic.

Spring and seeps along the road may occur in the roadbed or on the inside cutbank. Drain these sources of emergent groundwater to minimize damage to the road bed and to control sediment delivery to local stream channels. Drain roads with common or high volume springs with frequent ditch relief culverts. Culvert spacing must be close enough to prevent downslope gully erosion or hydrologic connectivity to nearby streams. Drain emergent water from the roadbed using such techniques as French drains and drainage blankets.

Road Shaping (outsloping, crowning and insloping)

- Where suitable and appropriate, road outsloping is the preferred method of road shaping for protecting water quality and minimizing fine sediment delivery to streams.
- Outsloped roads drain their surface runoff to the outside edge of the roadbed and onto the fillslope (provided there is no berm) (Figure X-19). The degree of outslope is typically at least 2% for low gradient roads (<4%) but increases as road grade increases (Table X-6), with consideration for driver safety.
- Outsloped roads may or may not have an inside ditch. If the cutbank is wet or has springs during part of the year, a ditch will be necessary to drain emergent water to a ditch relief culvert or rolling dip.
- Insloped roads can be converted to outsloped roads in several ways. If there is no spring flow in the ditch and the ditch can be filled, the insloped road can be ripped and regraded with the spoil material generated on the outside half of the road being used to fill the ditch and provide the outslope shape to the roadbed. Alternatively, fill can be imported to fill the ditch and outslope the roadbed. If an inside ditch needs to be maintained, because emergent groundwater and seeps are present along the cutbank, either of these construction techniques can be used to outslope the roadbed without filling the ditch.
- Crowned roads drain both to the outside of the road onto the fillslope, as well as to the inside of the road into a ditch (Figure X-19).
- The crown or high spot in the road cross section is often the center of the road, but it can be shifted towards the inside third of the road decrease the amount of road runoff that is delivered to the ditch.
- Steep roads (greater than about 14%) are difficult to drain, so crowned road shapes are sometimes employed to improve road drainage and to increase vehicle safety. However, it

is imperative that an appropriate number of ditch relief culverts and/or rolling dips be used to drain the ditch on steep roads.

- Insloped roads are used where water cannot be discharged over the outside fillslope because of soil erodibility, fillslope instability or potential water quality problems, or where cutbanks are very unstable (Figure X-19).
- Insloped road surfaces typically slope at 3% to 4% towards the ditch, but the degree of inslope will increase as the grade of the road increases in order to drain road runoff into the ditch (Table X-6).
- Insloped roads need a ditch to carry road runoff and spring flow from the cutbank and from upslope areas to the nearest ditch relief culvert or rolling dip where it can be discharged to the hillslope.
- Insloped roads with ditches are one of the most common ways in which roads are hydrologically connected to streams in a watershed. Thus, to the maximum extent possible, insloped roads should be frequently drained onto the hillslope, using ditch relief culverts or rolling dips, where runoff will not enter a stream channel.

Outsloping pitch for roads up to 12% grade		
Road Grade	**Outslope Pitch for Unsurfaced roads**	**Outslope Pitch for Surfaced Roads**
4% or less	3/8” per foot	1/2” per foot
5%	1/2” per foot	5/8” per foot
6%	5/8” per foot	3/4” per foot
7%	3/4” per foot	7/8” per foot
12% or more	1” per foot	1/4” per foot

Table X-6. Outsloping pitch for roads up to 12% grade.

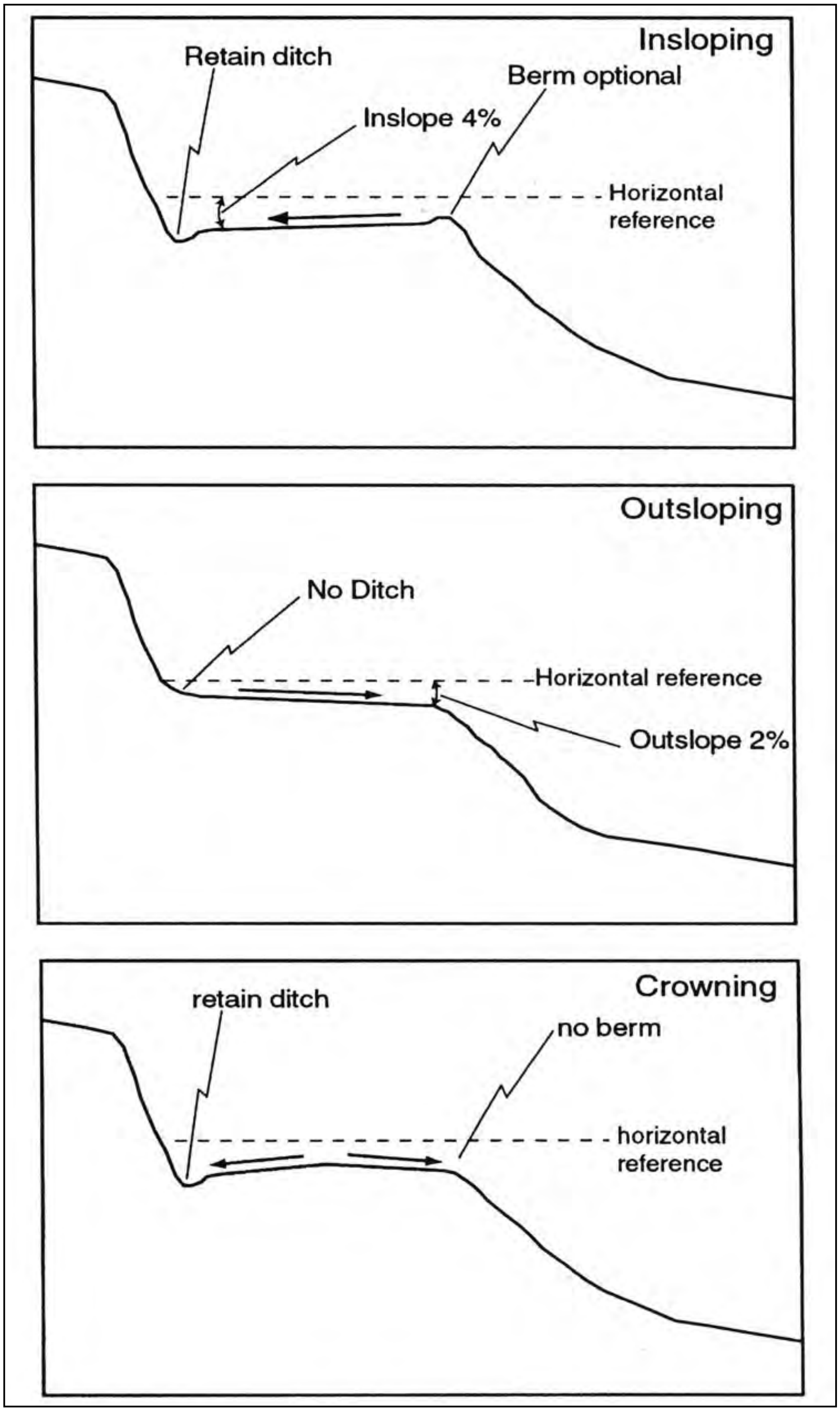


Figure X-18. Utilizing road shape to reduce surface runoff rates.

Berm Removal

- Road berms on insloped roads do not affect road drainage and can usually be left in place with little negative effect.
- Berms located along the outside edge of a crowned or outsloped road prevents road runoff from leaving the roadbed. This often results in roadbed erosion or gully erosion where the concentrated runoff is discharged off the road.
- On steep gradient roads, berms are sometimes used as a real or perceived safety measure to keep vehicles from sliding off the road. In other places, berms are sometimes intentionally used to keep road runoff from discharging onto an erodible, unstable or potentially unstable fillslope. Some berms are simply the end-product of years of grading that have left a continuous or discontinuous berm of road grader spoil material along the outside edge of the roadbed, so that the grader operator can use it to pull back onto the roadbed during future maintenance work.
- Berm breaks are locations where the berm is not intact and road runoff is allowed to discharge onto the slopes below the road. The runoff from berm breaks can be discharged directly onto the fillslope or directed into a culverted or sheet metal berm drain that is used to carry the runoff some distance downslope or to the base of the fillslope (Figure X-19).
- If they are not needed, or if they are causing road drainage and erosion problems, road berms on crowned and outsloped roads can be either partially or completely removed. On low gradient roads, berms can often be completely removed. On steeper roads, where safety is an issue, the berm can be frequently breached with short gaps spaced 30 to 100 feet apart. A semi-continuous berm is thereby left for safety reasons and the road is frequently drained (Figure X-19).
- Depending on the slope steepness and proximity of the road to a stream, berms can be removed by excavation or sidecasting. Sidecasting should not be used if there is a possibility that spoil or eroded sediment could enter a watercourse.

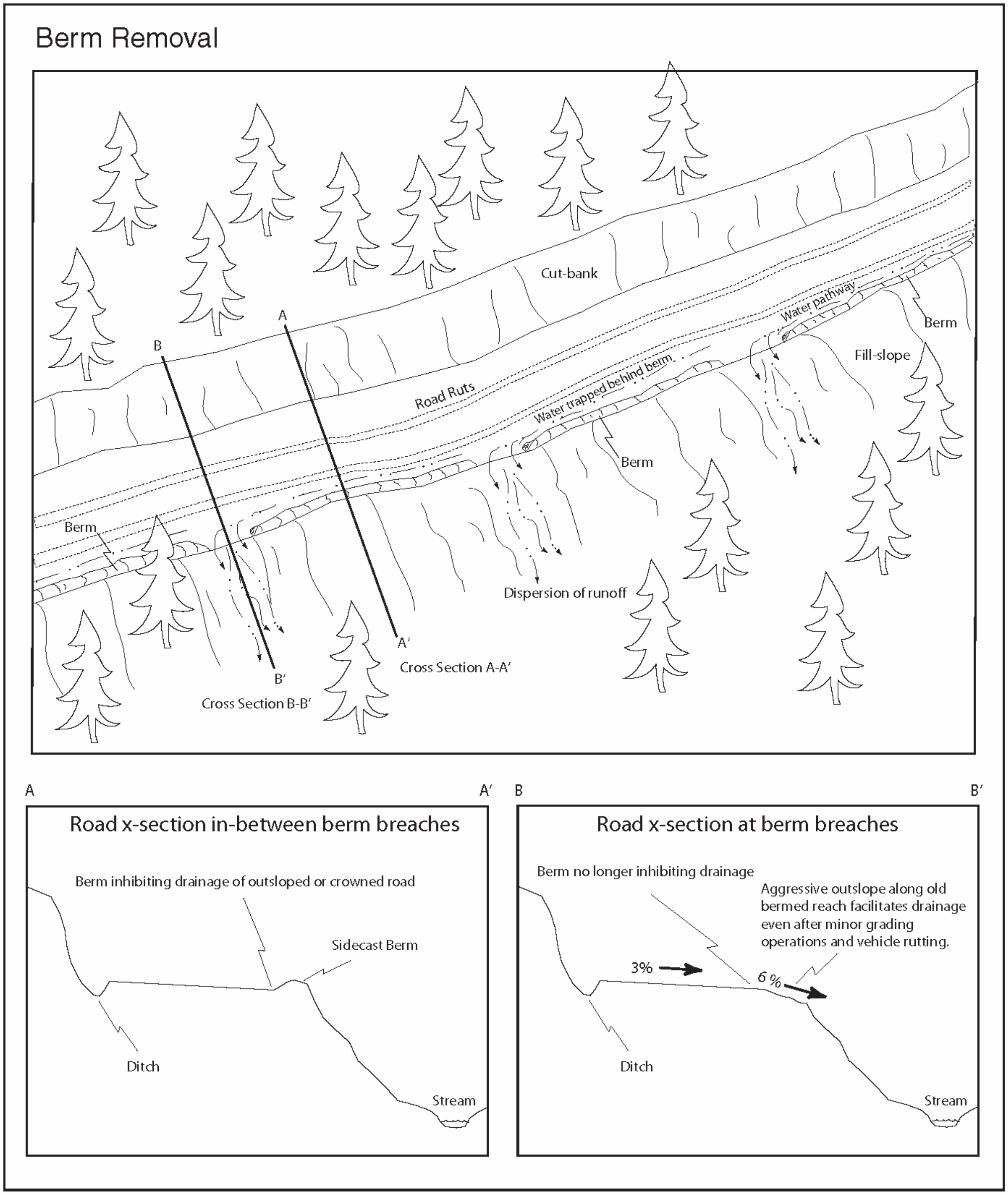


Figure X-19. Berm removal for improved drainage on outsloped and crowned roads.

Ditch Relief Culverts

- Install ditch relief culverts at an oblique (typically 30 degree) angle to the road so that ditch flow does not have to make a sharp angle turn to enter the pipe (Figure X-20). On low gradient roads (<5%), where ditch flow is slow, ditch relief culverts can be installed at right angles to the road.
- Install ditch relief culverts (DRC) to outlet at, and drain to, the base of the fill (preferred option) (Figure X-20).
- If it cannot be installed at the base of the fill, install the DRC with a grade steeper than the inboard ditch draining to the culvert inlet, and then install a downspout on the outlet to carry the culverted flow to the base of the fillslope (Figure X-20).
- Downspouts longer than 20 feet should be secured to the hillslope for stability. Full round downspouts are preferred over half-round downspouts.
- Ditch relief culverts should not carry excessive flow such that gullying occurs below the culvert outlet. Use field evidence and culvert spacing tables (e.g., PWA 1994) to provide guidance on proper culvert spacing along upgraded roads.
- Do not discharge flow from ditch relief culverts onto unstable or highly erodible hillslopes.
- If the ditch is on an insloped or crowned road that is very close to a stream, consider using outsloping to drain the road surface. The ditch and the ditch relief culvert would then convey only spring flow from the cutbank, and not turbid runoff from the road surface.

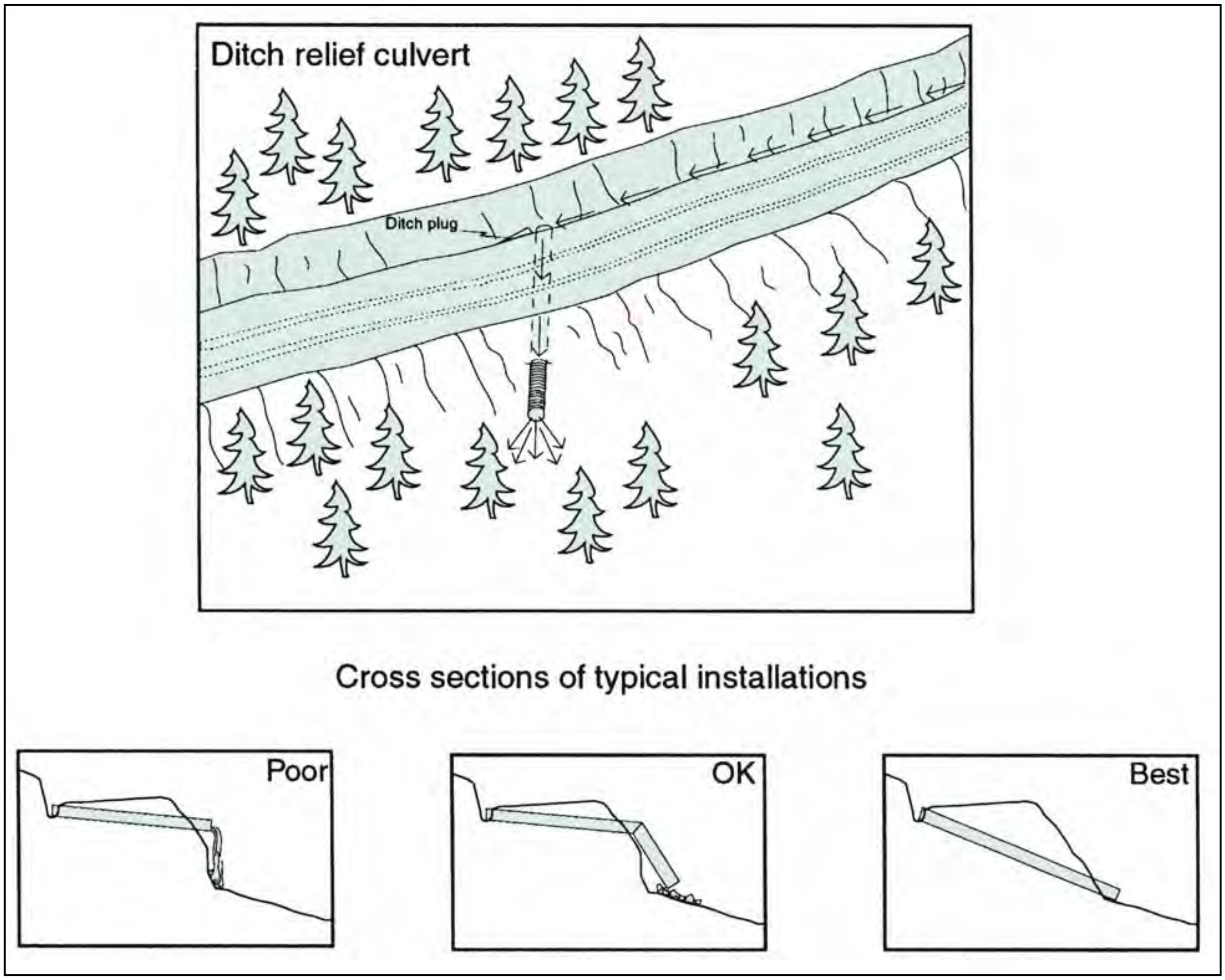


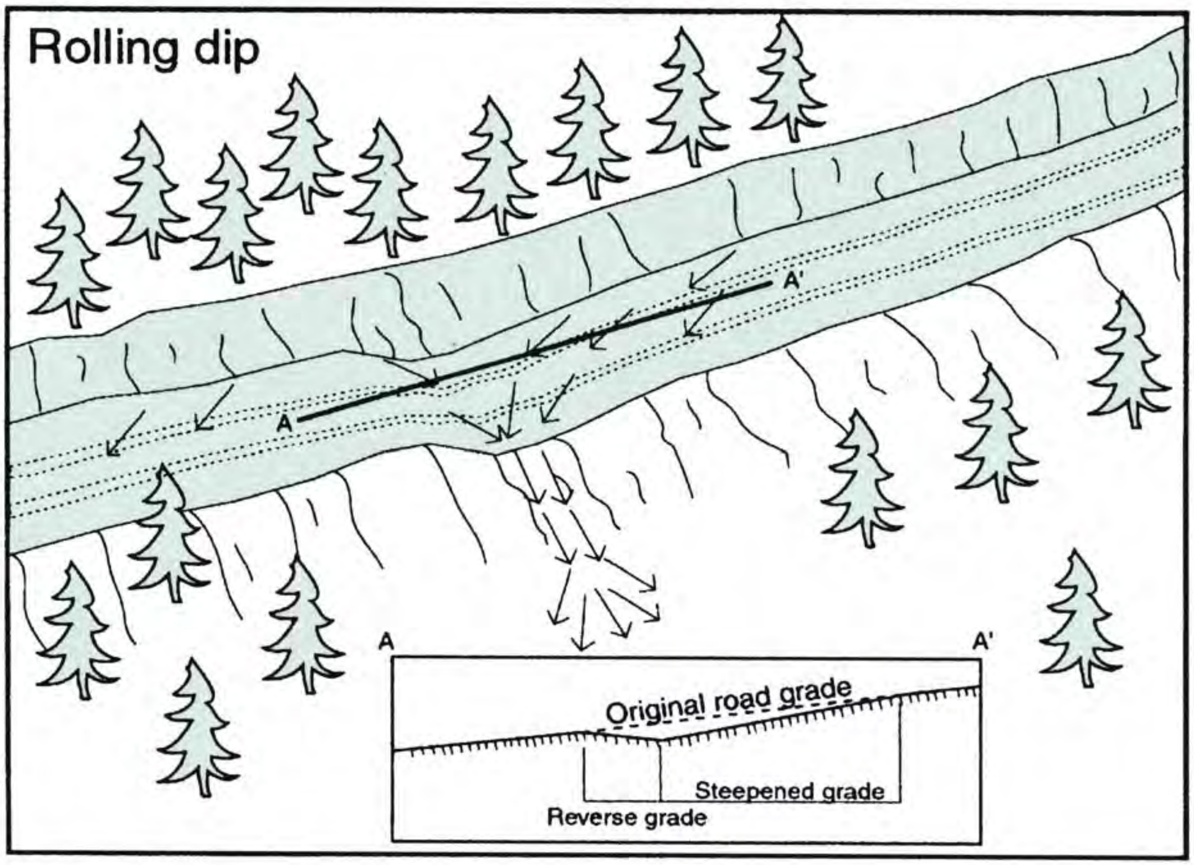
Figure X-20. Typical ditch relief culvert installation.

Rolling Dip Installation

- Install rolling dips in the roadbed as needed to drain the road surface. Rolling dips can be sloped either into the ditch (use sparingly) or to the outside of the road edge (preferred design) as required to properly drain the road and disperse surface runoff.
- Rolling dips should be located frequently enough to prevent erosion on the hillslope below the road and placed where they will not cause instability or gullying. To the extent that they can be, outboard sloping rolling dips should be coincident with natural drainage swales that are well-vegetated. They will likely need to be constructed at many other locations as well.
- Do not discharge rolling dips or ditch relief culverts into swales that show signs of instability or active landsliding.
- If the rolling dip is designed to divert both road surface and ditch runoff, block the down-road ditch with compacted fill. Ditches that carry a large volume of spring flow should probably be drained using ditch-relief culverts rather than rolling dips.
- Rolling dips are usually built directly across the road alignment with a cross grade at least one percent greater than the grade of the road (so that it will drain).
- Excavate the rolling dip with a medium size bulldozer (D-7 size) with rippers or with a grader.
- Begin excavation of the dip approximately 50 to 100 feet up-road from the proposed axis of the dip (Figure X-19). Progressively excavate material from the roadbed, with the grade becoming steeper, until reaching the axis (Figure X-21).
- Determine the depth of the dip, by the grade of the road (Figure X-19). In all cases, rolling dip dimensions must be consistent with the type of vehicles that will be using the road (Figure X-21).
- On the down-road side of the rolling dip axis, install a grade change to prevent runoff from continuing down the road. Carry the rise in grade for about 15 to 25 feet, or more, and then fall back to the original slope (Figure X-21). The axis of the dip must be a broad “u” shape to facilitate good driveability.
- In all cases, the rolling dip must be driveable and not significantly inhibit traffic and road use. It must also effectively drain the road surface.

Road grade %	Upslope approach (distance from up-road start of rolling dip to trough) (ft)	Reverse grade (distance from trough to crest) (ft)	Depth below average road grade at discharge end of trough (ft)	Depth below average road grade at upslope end of trough (ft)
<6	55	15-20	0.9	0.3
8	65	15-20	1.0	0.2
10	75	15-20	1.1	.01
12	85	20-25	1.2	.01
>12	100	20-25	1.3	.01

Table X-7. Table of rolling dip dimensions.



Note: Rolling dips must drain the road surface and be driveable for the expected traffic.

Figure X-21. Use of rolling dips to reduce ditch erosion and surface runoff.

Upslope Restoration Treatment Production Rates

Upslope restoration treatments consist of both heavy equipment and manual labor tasks. Heavy earth moving tasks, such as landslide excavations and road upgrading or decommissioning, often entail 80% to 95% of the total project costs. Upslope restoration project manual labor consists of such tasks as: culvert installation, installation of trash racks and culvert downspouts, flared inlet assembly and installation, gully control, stream bank protection, planting, seeding and mulching. On individual sites, there is generally a mix of heavy equipment and manual labor work.

Heavy Equipment Guidelines

Restoration involving heavy earth moving equipment can involve a wide range of equipment types. The key is to match the size of the equipment with the size of the job. If the job requires extensive excavation, large equipment can move greater amounts of material faster than smaller equipment for an overall cost saving, even though hourly cost rates are higher. If space or excavation volumes are limited, smaller equipment will be most cost-effective. The three most commonly used equipment types for road restoration are:

- Hydraulic excavator, with 1.5 to 3 yd^3 bucket and thumb;
- Crawler tractor (D5, D6, or D7 size, with hydraulic rippers and a U-blade, 3-way blade or 6-way blade);
- Dump truck (10 yd^3).

Other equipment frequently used on upslope restoration projects include backhoes, road graders, front-end loaders, compactors, water trucks, tractors with a winch, D-8 sized tractors and 20-30 yd^3 off-highway dump trucks.

Safety

A complete discussion of worker safety requirements, including those for laborers and equipment operators, is beyond the scope of this document. However, common sense practices and basic accident prevention techniques are required of all contractors, workers and supervisory personnel on a restoration project site. Safety should be the prime consideration on all jobs. Equipment operators know their personal limitations and strengths, and supervisory personnel should not request operators to perform tasks that are beyond their ability or comfort level. Department of Fish and Game grants contain specific provisions regarding required safety measures that must be followed during the conduct of State grants. Among others, these include:

- Pre-work safety sessions and grant requirements
- Development of a workers safety plan in case of accidents including appropriate first aid kits, ear plugs for work around heavy equipment, hard hats, high visibility clothing or safety vests, and appropriate field clothing and protective gear
- Fire safety plan; charged and appropriately sized fire extinguishers, emergency fire fighting hand tools (like a Pulaski fire axe), and spark arrestors on heavy equipment (or require turbo charged machinery)
- Equipment oil and fuel spill prevention plan and spill response kits
- Communication tools, including CB radios for travel on back roads to and from the work site and development of pre-determined hand signals during equipment operation

It is also recommended that erosion control practitioners have basic training and certifications in first aid and cardiopulmonary resuscitation (CPR). Specialized training in swift water rescue (for work on larger streams), wildland firefighting, emergency medical technician and confined space awareness (for trenches and culverts) can also be useful for some projects and personnel.

Equipment Production Rates

Most upslope restoration involves some type of excavation work. Excavation is involved in some types of landslide treatments, culvert installations and culvert replacements, and stream crossing installations for road upgrading, as well as decommissioning tasks such as stream crossing excavations, road outsloping, and excavations associated with road fill failures. Listed below are example production rates used to estimate job times and costs. Production rates include all work associated with excavations, not just digging dirt. Adjust time according to actual excavator production rates.

Stream Crossing Excavations
Excavator with 1.5 yd^3 bucket and thumb:

- Direct excavating of soil, 50 – 75 yd^3 per hour;
- Excavating extensive organics (such as Humboldt stream crossings) or excavating complicated long, deep and/or steep crossing fillslopes, 35 – 50 yd^3 per hour.

Sidecast Fill Excavations
Excavator with 1.5 yd^3 bucket and thumb:

- For clean sidecast dirt, 100 -120 yd^3 per hour;
- For sidecast with extensive organic debris or if many trees exist to work around, 50 - 100 yd^3 per hour.

Compaction

Proper compaction is very important in a variety of restoration project activities including: culvert installation, armored fills, rolling dips, and development of spoil disposal sites. Compaction during the dry summer months, when most restoration work is accomplished, will likely require the use of water trucks and artificial wetting of dry soil materials.

Pumping and Flow Diversion

Project work in live streams requires that the work site be dewatered and flow diverted around the site when equipment is working. Dewatering is performed to keep soils and excavated materials as dry as possible during work activities, and to reduce the potential for causing excessive erosion and downstream water quality impacts. If streams in the project area are live (flowing) delay instream work until the last possible moment, so that flows have dried up or are at a low point for the season. It is always best to work in dry streambeds.

Dewatering can be accomplished on small streams by diverting flow around the project site. Flows can be diverted with pumps or passive (gravity) systems such as side channels, constructed canals, or flexible pipe. Flow diversions require careful consideration of the backwater effects on diversions, pump capacities, diversion-channel capacities, and the need for temporary erosion protection to prevent scour at the point where the water is returned to the natural channel downstream of the project site.

On larger streams, coffer dams can be used. Cofferdams are temporary watertight dams that may be used to impound the flowing water so that it can then be diverted around the project site. Coffer dams can be constructed by excavating into the alluvial stream bed (to capture both surface flow and intergravel flow) or by building a small dam to block flow in the channel. The diverted flow is then returned to the natural stream channel downstream of the work site.

Regardless of the technique employed, dewatering systems should be able to divert the one-year flows anticipated during the period of construction (i.e., the greatest flow with a 100-percent chance of occurring during the construction period). The possibility that the system will be overwhelmed by storm flows should also be planned for in the dewatering design.

In Class 1 streams, install screens upstream and downstream of the affected reach, then have a qualified fisheries biologist remove all fish and amphibians, prior to initiating flow diversions and dewatering. Similarly, a plan must be in place to recover any fish that might be left behind when the water is gone. Contact the Department of Fish and Game prior to initiating flow diversions in Class 1 streams. Dewater streams by gravitational diversion of stream flow in flexible pipes, or by using gas-powered pumps that can lift water out of and around the work site. Unless the stream reaches have been isolated and cleared of fish, pumps used in fish-bearing streams will require screens designed to DFG and NMFS specifications to prevent loss of fish. Whenever pumps are used, backup pumps and hoses should be available on-site in case of equipment breakdown. Pumps require on-site management; if pumps will be used only during the standard work week, then a plan for gravity diversions during nights and weekends will need to be in place until the site work is completed.

Specifically designate personnel to monitor and maintain each site diversion so as to minimize the potential for construction-related sediment releases. Limit diversions to the dry season operating period (before October 15) and only install diversions when weekly weather forecasts do not call for rain. Install silt fences, straw bales or other flow-filtering measures in the channel to reduce turbidity and suspended sediment when flow is reestablished through the work site. Strictly follow all requirements listed in the DFG 1600 Streambed Alteration Agreement for each site.

Mulching, Seeding, Planting

Cost-effective labor techniques include mulching, seeding and planting. Completely cover bare soil areas where surface erosion may deliver sediment to a stream with mulch, such as weed free straw. Rates of about 4,000 pounds per acre, or approximately 50 bales/acre of straw meet this standard. Use mulch to cover seed to improve microclimatic conditions for germination and seedling survival. Seeding and mulching rates are highly variable, depending on the seed mix used. Consult your local extension office, Natural Resource Conservation Service (NRCS), Resource Conservation District (RCD), or seed supplier for recommended rates of application and local site conditions. Mulching, seeding and planting are often good cost share jobs for landowners and volunteers.

Typical Road Upgrading and Road Decommissioning Costs

Costs for road upgrading and road decommissioning are highly variable and depend on a host of factors (Weaver and Hagans in press). General cost-estimating rules are not available, and extrapolating documented costs from an actual project to another is risky without close evaluation. See Tables X-3 and X-4 for generalized, estimated costs for a number of road upgrading and road decommissioning tasks. Table X-8 gives estimated cost ranges for road reaches developed from watershed inventories and actual forest and ranch road projects completed in northern coastal California between 1995 and 2000.

Road restoration activity	Typical unit costs[1]
Road upgrading (watershed-wide average, 100-year design)	$15,000 - $40,000/mile
Road upgrading (high priority road - moderate to high difficulty)	$45,000 - $75,000/mile
Road decommissioning (range of roads from ridge spurs to moderate complexity mid-slope roads)	$2,000 - $35,000/mile
Road decommissioning (moderately difficult roads)	$25,000 - $50,000/mile
Road decommissioning (difficult roads and/or full recontouring)	$50,000 - $100,000+/mile

[1] Example unit costs for road upgrading and road decommissioning are from 2000 to 2005 project data for a number of roads and road segments treated in north coastal California (PWA, unpublished).

Table X-8. Estimated road restoration cost ranges.

In general, overall road restoration costs closely correlate with the frequency of sites along the road and the volume of soil moved to perform the necessary erosion prevention and erosion control treatments. The higher the site frequency and the larger the sites, the more expensive it becomes. Widely spaced projects can significantly increase move-in/move-out costs. In addition, projects and sites requiring endhauling of excess spoil material are typically more expensive than similar projects where spoil is stored locally.

Implementation Methods

There are several ways to accomplish restoration work. These include direct contracting, equipment rental and in-house for landowners with equipment. Each method has advantages and disadvantages.

Contracting

Contracting is a common way to accomplish restoration projects. This starts by developing a written description of the job and the desired finished product, then soliciting bids to perform the work. Consider the following before deciding to contract out a project.

- Contracted restoration work requires extensive up-front planning, the development of enforceable specifications and project layout. Lay out the job as accurately (typically using surveys and grade staking) and as precisely as possible so that the contractor knows exactly what they are bidding on and what they will be responsible for in the end.

- Contractors usually bid vague projects high because they are not sure what will be required or what they may encounter.
- Any encountered changes (increases) in the job require a change-order in which the contractor may be charging a premium price.
- Preparing detailed project specifications, volume surveys and/or grade staking is a complicated and time-consuming job that represents a substantial investment in up-front time and money. This planning effort may not be possible due to personnel limitations or restricted timeframes.
- Awarding a contract to the lowest bidder is not always best. Depending on the contracting evaluation rules, this can encourage low-ball bids and may require acceptance or use of less qualified or less experienced contractors.

Equipment Rental

Under this method, hire contractors on an hourly basis (equipment with operators) and technically supervise the contractors to complete the restoration work on an hourly basis. This is termed a time-and-materials contract.

- Seek to hire equipment operators skilled and experienced in erosion prevention and control techniques.
- If equipment operators are less experienced, the on-site supervisor must be able to provide technical guidance. As described elsewhere, some types of projects will require supervision by professional geotechnical specialists. On-site supervision or oversight is important for all projects, but becomes even more critical when using inexperienced or unfamiliar operators. For reasons of safety and project cost-effectiveness, inexperienced contractors and operators should not be hired for restoration projects.
- This allows modification of work, without the need for change orders, when encountering unexpected conditions in the field. This added flexibility is often important.
- The equipment rental rate is set for all restoration work, regardless of the nature and magnitude of the project.
- Contractors are likely to provide favorable rates because they know they will be paid for all work they complete (there is little or no risk on their part).
- It is possible to replace contractors if their performance is not up to required standards.

In-house

Some landowners have in-house capability to conduct upslope restoration, especially road upgrading and decommissioning, using their own equipment. To be successful, equipment operators and supervisors must have experience with the types of restoration treatments being implemented. Because they are typically in business for other purposes (e.g., logging or ranching) restoration experience of available in-house operators may be lacking.

- Hourly rates for the use of in-house heavy equipment are frequently lower (more favorable) than for contracting or equipment rental.
- In-house capability is typically the indirect result of having heavy equipment purchased for other purposes such as logging. As such, available equipment may not be perfectly suited for the restoration work. If a special piece of equipment is required to complete the

work (e.g., a larger excavator, or a dozer with a 6-way blade and rippers, etc.), do not compromise the cost-effectiveness of the entire project by not requiring the landowner to lease or rent the proper equipment. This is often a disadvantage.

- Many landowners have old equipment that is subject to frequent breakdowns.
- In-house equipment operators and laborers who are hourly employees are more likely to work restricted hours (to avoid overtime) as compared to a contractor or owner/operator who will work full days. With a limited summer work schedule, long work hours are often a necessary component of successful restoration projects.
- Equipment shortages are likely to occur if the landowner or land manager prematurely moves the equipment off-site to conduct logging or other activities.

QUALITY CONTROL, DOCUMENTATION AND MONITORING

Quality Control Measures

Quality control measures implemented in the field before and during the on-the-ground work help ensure the most effective, efficient techniques are applied, and that projects meet the established design standards. There are a number of ways that incorrect implementation can result in ineffective projects, excessive costs and/or environmental damage. A quality control/assurance program can help prevent these occurrences. Various procedures can be instituted that will increase the probability that the proposed restoration work is effectively and cost-effectively implemented by heavy equipment contractors and labor crews.

Selecting Contractors and Operators

Trained and experienced contractors, equipment operators and technical specialists are one of the most important keys to completing effective and cost-effective upslope restoration work. High quality work is much more likely to occur by screening operators for experience, skill and the proper heavy equipment prior to selection.

Check certifications, past job experience and professional references to ensure that contractors, equipment operators, engineers and geologists that are to be selected for the job are appropriately licensed and skilled. Request and check references and job performance for similar projects. Specifications of heavy equipment required for the job should be stated and checked against those listed by the contractor or operator.

Adaptive Project Design

Prior to heavy equipment or laborers arriving to conduct restoration work, check final prescriptions and clearly flag each work site. Marking should be sufficiently explicit to provide complete guidance as to the boundaries and general prescriptions for the treatments. Review the entire project area in the field. If conditions have changed since the original prescriptions were developed, prepare revisions to the original site plans. The discovery of new sites due to changed conditions, or sites originally overlooked, require site plans and prescriptions be prepared for additional restoration treatments. Finally, identify and flag treatments for surface drainage improvements along the roadbed. These treatments include the exact location of rolling dips, crossroad drains, ditch relief culverts and other work items originally prescribed but not precisely located. If skilled operators are used, they can often perform the road drainage tasks on their own.

Pre-treatment Orientation Tour

Take the lead contractor, lead equipment operator and on-site labor supervisor on a pre-work field tour of the restoration project area to review all proposed treatments. The project supervisor who has intimate knowledge of the proposed treatment plan should lead the field inspection. Give the operator a complete treatment-log that describes the proposed treatments to be completed along the road (by milepost) or at other work areas.

Treatment Summaries

During the orientation tour, provide equipment operators and labor leaders a clearly written site-by-site summary of the treatments that are in the project work plan.

Measurable Standards

Provide contractors, equipment operators and the labor crew leader a list of typical standards, specifications, and/or technical drawings to be met for each general restoration treatment included in the project (e.g., the typical standards for a decommissioned stream crossing excavation; mulching, rolling dips and ditch relief culvert installation, etc.). These standards should be included in the site-specific treatment summaries provided to the operators.

Technical Supervision and Oversight

An important quality control practice is to have technically trained and experienced project supervisors on-site regularly during operations. Their job is to interpret and answer questions about the treatment prescriptions, to provide general guidance to the operator or labor crew leader on specific design requirements for each site, and to verify and approve completed work. Inexperienced operators should have careful and ongoing supervision until their skills, judgment and performance consistently meet expectations. Road decommissioning requires frequent inspections because access is cut-off as work proceeds. Mistakes made during road decommissioning are difficult to correct or repair. Rarely can labor crew treatments prevent or correct erosion problems caused by poor or inadequate heavy equipment work.

Documentation

Documentation and Monitoring

Documentation of work performance and monitoring of restoration effectiveness are two techniques that allow for adaptive management at a relatively short and useful time scale. For example, use documented equipment operations and productivity to institute more efficient treatment procedures. Use qualitative and quantitative monitoring of project performance in the first few years following restoration work to alter procedures and prescriptions for current and future projects. Thus, effectiveness monitoring for adaptive restoration can consist of simply reviewing the erosion response of a variety of past restoration projects and identifying techniques that have worked well and others in need of modification.

Documenting Work Activities

Document work procedures and production rates for various restoration tasks to improve the efficiency and the cost-effectiveness of on-the-ground restoration projects. Document work effort by direct observation of operations, by measuring a sample of production rates (e.g., counting dump truck loads or excavator buckets) or by requiring contractors (operators or laborers) to keep accurate records of work production on a site-by-site basis.

At a minimum, have equipment operators keep a daily record of work accomplishments (hours spent, loads hauled, etc.) on a site-by-site basis. Table X-9 provides a sample form for operators and laborers to complete on a daily basis. Compare actual work with the treatment prescriptions of the restoration plan.

Project Site Implementation Reporting

The project leader should take before and after photos from selected photo-point locations (Hall 2002), assemble and analyze production records from the operators, and check production data by surveying selected sites to determine actual volumes or by counting/timing equipment activities (Table X-9) The project leader also must review each project to confirm the quality and quantity of work performed.

The implementation report should contain many similar elements to the summary report. Report the quantities as known rather than estimates (Appendix X-D). This information forms the basis of implementation monitoring and is very important for post-project effectiveness monitoring used in evaluating the success of the upslope restoration efforts.

The completed implementation report should contain the following information:

- Project identification #
- Project location (descriptive location)
- Map of watershed (location map, showing relationship of project area to region)
- Map of project area and roads treated, which shows:
    - Base information (streams, roads, sections, contours (optional), scale, north arrow, stream labels, road names, cultural features)
    - All roads within the treatment area (whether treated or not), including symbols for current maintenance status (maintained roads, and abandoned (unmaintained) roads) and treatment status (treated and untreated)
    - All treated and untreated sites, including:
        - All stream crossings, showing which ones were actually treated
        - Potential and active landslides which were treated
        - Ditch relief culverts and other ditch drains
        - Gullies and other fluvial erosion features
- Other pertinent maps of the project area, including but not limited to geologic maps, landslide hazard maps, and fault location maps.
- Project report should contain the following information:
    - Introduction (setting, problem, purpose of restoration project)

- Site characterization, areas of concern, landslide and fault location information or other hazards and/or limitations on activities.
- Methods, including:
  - What was done (planning, gear-up, implementation, documentation, monitoring)
  - Describe documentation data that was collected (production rates, volumes, etc.)
  - Describe monitoring efforts initiated (photo points, surveys, etc.)
- Results of implementation work, including work accomplished and costs, including:
  - Description of deviations from original plan or proposal
  - Layout work completed (flagging, prescription marking, etc.)
  - Move-in and move-out, and site preparation work (e.g. road opening)
  - Description of actual treatments (keyed to the site map), including:
    - Road upgrading (show and describe upgraded roads)
    - Road decommissioning (show and describe roads decommissioned)
  - Describe treatments and sites recommended for treatment (including stream crossings, fillslopes, and surface erosion treatments)
- Cost analysis, including:
  - Actual equipment rates (cost/hr) and hours for each site
  - Actual manual labor rates (cost/hr) and hours for each site
  - Total site costs (all site costs added together)
  - Equipment move-in and move-out costs (lowboy)
  - All other project costs not listed above (specify)
  - Total costs for entire project (equipment + labor + materials + other)
- Cost-effectiveness analysis, including:
  - Total measured or estimated sediment savings (yds^3)
  - Total project cost-effectiveness (cost/yd^3 of sediment delivery prevented)
  - Explain any differences between projected and actual costs and sediment savings
- Sources of funds used in project.

DAILY AND WEEKLY HEAVY EQUIPMENT LOG															
Name of restoration project:					Date:				Road name:			Inspectors:			
Date	Site #	Site type (St = stream LS =landslide RR = road reach DR=ditch relief OT = other)	Excavator (hrs)	Dozer (hrs)	Dump truck				Grader (hrs)	Water truck (hrs)	Labor (hrs)	Backhoe (hrs)	Oth er (hrs)	Comment/ activities
					#1		#2							
					hrs	loads	hrs	loads						

Table X-9. Daily heavy equipment log (for operators).

PHOTO POINT MONITORING LOG								
Project #:			Road:		Date:		By:	Weather: Sun____ / Shade____
Site #	PP #	Time	Roll & frame # or digital #	Lens (mm)	Framing (horizontal or vertical)	Compass direction	PP location (site description)	PP description (scene description)

Table X-10. Photo point monitoring log.

Monitoring

Effectiveness Monitoring

Qualitative and quantitative site and project monitoring techniques can be undertaken with the specific objective of documenting the performance of various watershed restoration treatments or for documenting post-restoration erosion rates on treated areas. Detailed monitoring protocols for upslope erosion prevention and erosion control work is beyond the scope of this chapter.

Site Monitoring

It is not always practical to monitor all sites of a large restoration project. Prior to implementation, select a representative range of sites of varying complexity and type (e.g., stream crossings, fillslopes, road surface treatments, etc.) to monitor. Two types of monitoring can be useful:

- "Topographic" surveys - These surveys document the volume of spoil excavated, as well as erosion changes or slope movements that occur in the post-restoration period. Conduct simple surveys, using a tape and clinometer, or auto-level, before restoration activities begin. After the work is completed repeat the survey, and at irregular intervals thereafter. A tag line cross section survey (stretch a taught line across an excavated stream channel between monumented endpoints, and take measurements of the ground surface beneath the line) is an especially simple and useful way to document channel changes (erosion) following stream crossing decommissioning. Void measurement of erosional features is another way to monitor and document changes to a treated site.
- Photo points - Install monumented photo points (Hall 2002) at selected work sites to document before and after scenes of restoration work sites (Table X-10). This type of monitoring is especially useful to portray the nature of the restoration work that is undertaken. Carefully planned and executed photo documentation will graphically portray project effectiveness through time. Monitor revegetation of work sites though sample plot inventories, or more generically through photo point monitoring. Consistent photographs include site documentation, photo point number, date, time, lens, weather (sun/shade), compass direction, orientation (vertical or horizontal), landmarks and other identifying data. Re-take photo points using the original photo to duplicate the exact framing of the scene.

Process Monitoring

Although more difficult than site monitoring, geomorphic processes operating at restoration sites can also be monitored through time. Use site monitoring, such as tag line channel cross-section surveys, to monitor channel change through time. In addition, perform sediment sampling above and below work sites to document sediment delivery to stream channels from the restoration sites both before and after implementation work (Klein 2003). Process monitoring requires a relatively long term, continuing commitment of personnel and money beyond what is typically required for most intermittent site monitoring activities. In general, the closer the monitoring station is to the work site, the more likely you will be able to attribute monitoring trends to restoration actions.

Upland restoration is recognized as partly science-based and partly art. This makes the process of experimentation and extrapolation of monitoring findings difficult. In a sense, most projects contain elements that can be considered experimental. The challenge for effectiveness monitoring projects is to be able to uniquely identify restoration projects or project components that have measurable parameters that will allow comparisons to a class of projects (Switalski et al. 2003). In this way hypotheses can be successfully tested, differences identified and results extrapolated. Results will provide a better basis for design and implementation and should eventually lead to better projects.

As with any monitoring project, the study objectives (the questions to be answered) will determine the methods that are used. A complete and thorough study design will be the foundation of any successful monitoring project. Both feature and process measurements may be included in a monitoring study (Kahklen 2001, Wemple and Jones 2003). Depending on the need for associating specific stressing events with resultant geomorphic responses, process measurements may best be performed using automated data collection devices rather than manual sampling.

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GLOSSARY

Note: The following terms and words are defined in the context of upslope restoration. Additional terms, concepts and words not included here are in Appendices X-A and X-B.

Abandoned road - A road no longer maintained. An abandoned road may be still driveable although overgrown with vegetation (see *road abandonment*).

Abutment (bridge) - A solid foundation on each stream bank, which to secure the ends of a bridge. Naturally occurring rock outcrops may serve as abutments. Engineered abutments are generally constructed of concrete, logs or concrete or steel piers.

Accelerated erosion - Erosion directly or indirectly influenced by human activities or land use. Accelerated erosion is erosion which is not natural or in excess of that occurring naturally.

Active road - A road that is part of an overall road network that needs to be inspected and maintained.

Anadromous fish - Fish that are born in freshwater, migrate to the ocean to grow, then return to freshwater to breed. This includes salmon and steelhead trout, as well as several other species of fish.

Angle of repose - The steepest slope or angle, sediment will freely stay without failing or sliding down slope. The angle of repose of material without cohesion, like loose sand, is about 33 degrees. For material with some cohesion, the comparable term is the angle of internal friction. Slopes steeper than the angle of repose or angle of internal friction are likely to be unstable.

Axis - The central line of a rolling dip, critical dip, or stream channel.

Berm - A curb or dike constructed to control water and prevent roadway runoff water from discharging onto roadside slopes. Many road berms are the unintentional result of years of grading.

Borrow site - Excavation locations for sand, gravel and/or rock that is used in road construction activities. Borrow pits and rock quarries in California may be subject to the new Surface Mining and Reclamation Act (SMARA). This act requires landowners to develop site reclamation plans for many such sites (see *rock pit*).

CEQA - The California Environmental Quality Act, requires public disclosure of the environmental impacts and alternatives associated with any project, including restoration projects.

Check dam - A grade control structure used to prevent gully down cutting or to contain eroded soil from leaving a construction site. It is common to use straw bale check dams in swales, ditches, and small channels and gullies to collect and store sediment eroded from a work site. Straw bale check dams quickly decompose. They usually provide sediment storage or protection for only a single season. Permanent check dams are difficult structures to correctly build and require maintenance to function properly. Check dams treat the symptom rather than the problem.

Class I watercourse - For forestry purposes, those watercourses serving as domestic water supplies and/or those watercourses where fish are present or restorable.

Class II watercourse - For forestry purposes, watercourses where non-fish aquatic species are present.

Class III watercourse - For forestry purposes, watercourses that have no aquatic life present, but under normal high water flow conditions are capable of sediment transport downstream.

Class IV watercourse - For forestry purposes, watercourses that are human made and supply water for domestic, agricultural, hydroelectric or other beneficial uses.

Clinometer - A pocket field instrument which measures slope steepness in degrees and percent.

CMP - An abbreviation for corrugated metal pipe, often used synonymously with culvert. Typically, metal culverts are galvanized steel or aluminum. Many new culverts, especially in the 18" to 36" diameter classes, are plastic.

Cofferdam - A barrier constructed across a waterway to control the flow or raise the level of water.

Compaction - Soil where an increase in bulk density (weight per unit volume) and a decrease in soil porosity results from applied loads, vibration or pressure. Compaction is often achieved by using gas powered vibrators, rollers, or heavy equipment.

Cost-effectiveness - In upslope restoration, the amount of money spent to prevent the delivery of a cubic yard of sediment to a stream. Measure cost-effectiveness by the volume of sediment delivery prevented from entering a stream not the amount of material excavated by heavy equipment.

Crossroad drain - A deeply cut ditch, excavated across a road surface, which drains the roadbed and inboard ditch. Crossroad drains are more substantial and deeper than conventional water bars used to drain forest and ranch roads, and are steeper and more abrupt than rolling dips. Properly constructed crossroad drains will often be deep enough to prevent vehicular traffic, therefore use them to close roads. Crossroad drains are constructed (excavated) using a tractor, a hydraulic excavator, or a backhoe.

Crowned - A crowned road surface is one which slopes gently away from the centerline (or near centerline) of the road and drains to both sides of the crown. Crowning a road surface is one method of providing for surface drainage on roads built on flat terrain. The inside half of the road drains inward to the cutbank and ditch, while the outside half drains out across the fillslope.

Crown scarp - A crown scarp is a visible fracture across the top of a landslide. Lateral scarps run down the hillslope from the crown scarp. For fill failures along the outside edge of a road, crown scarps, or cracks, mark the boundary between stable materials on the inside of the road and unstable fill on the outside edge of the road.

Culvert - A transverse drain, usually a metal or plastic pipe, set beneath the road surface to drain water from the inside of the road to the outside of the road. Use culverts to drain ditches, springs and streams beneath the road alignment.

Cutbank - The artificial face or slope cut into soils or rock along the inside of a road.

Debris flow – When a rapidly moving mass of rock fragments, soil and mud, saturated with water, flows down a hillside, with more than half of the particles being larger than sand size.

Debris slide – The slow to rapid slide, of relatively dry and predominantly unconsolidated materials, moving down a hillside, involving down slope translation, with more than half of the particles being larger than sand size.

Debris torrent – The rapid movement of a large quantity of materials (wood and sediment) down a stream channel during storms or floods. This generally occurs in smaller, steep stream channels and results in scouring of the streambed.

Decommission - To remove those elements of a road that unnaturally reroute hillslope drainage or present slope stability hazards. The process of proactively abandoning a road by eliminating all significant risks of delivery until the road is needed in future years. Decommissioning may be permanent or temporary (the road will be used again), but the treatments do not markedly differ. Decommissioning involves completely removing stream crossing fills and associated drainage structures and eliminating the risk of sediment delivery from unstable road and landing fills, and providing for permanent surface drainage (see *road abandonment*, *road closure*, and *put-to-bed)*.

Decompaction - See *ripping*.

Ditch - A human-made channel constructed to drain water from one location to another. Ditches are often located on the inside of the road (at the base of the cutbank - see *inboard ditch*), but they may also be located on the outside of a road, along a berm, on both sides of a crowned road or elsewhere on a slope.

Ditch relief culvert - A culvert installed to drain water from an inside road ditch to an outside area, beyond the outer edge of the road fill. Ditch relief culverts take the flow through or beneath the road surface. Rolling dips or cross road drains can perform the same function taking water across the road in a trough.

Diversion potential - A stream crossing has diversion potential if, when the culvert plugs, the stream would back up and flow down the road or ditch rather than directly over the fill crossing and back into the natural drainage channel. If flow would divert beyond the hinge line of the stream crossing fill, the site has a diversion potential.

Downspout - A flume or trough attached (bolted) to a culvert outlet and used to convey water from the culvert outlet down over and beyond the road fill to prevent erosion. Culverts placed at the base of the road fill discharge directly into the natural channel or hillslope and usually do not require a downspout. Downspouts may be half round or full round. Use full round downspouts (rather than half round) for a downspout on a stream crossing culvert.

Drainage basin - See *watershed*.

Drainage structure - A structure installed to control, divert or to cross over water, including but not limited to culverts, bridges, ditch drains, fords, water bars, road shape (e.g., outsloping or crowning) and rolling dips.

Earthflow - A mass-movement landform and slow-to-rapid mass movement process characterized by down slope translation of soil and weathered rock over a discrete shear zone at the base, with most of the particles being smaller than sand. Referred to as a soil glacier because of similarities in movement patterns.

Endhauling - The loading and transportation of excavated material from a site, and the storage of the hauled material in a stable location where it cannot enter stream channels. Dump trucks are most commonly used. Mobile scrapers are used on large jobs.

Ephemeral stream - A stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity and whose channel is at all times above the water table.

Erodible soils - Soils that are prone to erosion by raindrop impact and surface runoff. Granular, non-cohesive soils (such as soils derived from sand dunes or decomposed granite) are especially erodible.

Erosion - The dislodgement of soil particles caused by wind, raindrop impact or by water flowing across the land surface. Erosion usually refers to processes of surface erosion (raindrop erosion, rilling, gulling and raveling) and not to mass soil movement (landsliding). Erosion is not synonymous with sediment delivery if eroded sediment re-deposits before reaching a watercourse.

Erosion control - Treatments designed to control on-going erosion caused by raindrop impact, rilling, gulling, raveling and other surface processes.

Erosion prevention - Preventing erosion before it has occurred. Erosion prevention is typically less expensive and more effective than erosion control.

Erosion-proof - See *storm-proof*.

Fill - Consists of loose soil material that is placed or pushed (often by bulldozer) into low areas or onto a natural slope, and which is then compacted and built up to form a roadbed or landing surface.

Fillslope - That part of a road fill between the outside edge of the road and the base of the fill, where it meets the natural ground surface. On a half-bench road built by sidecast construction, the fill typically extends from near the centerline of the road to the outside edge of the road and down slope to where the sidecast meets the natural hillslope.

Filter fabric (geotextile) - A synthetic fabric manufactured and designed for use in subsurface and surface drainage applications. Filter fabric is especially useful in maintaining a separation between coarse aggregate and finer native soil particles. It comes in a number of different types, with different specifications and uses. It is common to use filter fabric in a number of different road building settings. Consult manufacturer's specifications before using a fabric for drainage or other engineering applications.

Fish bearing - A stream known to support fish during some part of the year.

Flared inlet - A flared or widened culvert inlet to increase its capacity and reduce the chance of inlet plugging and damage. Attach flared inlets to the normal culvert inlet using a band or bolts. Mitered inlets, made by cutting a normal culvert at an angle, improve culvert efficiency and increase capacity.

Fluvial - Pertaining to the processes of, or related to streams or flowing water.

Ford (dry) - A rock, concrete or other hardened structure built on the bed of a swale, gully or usually dry stream, allowing vehicle passage during periods of low or no flow.

Ford (wet) - A rock, concrete or other hardened structure built on the bed of a live stream, allowing vehicle passage during low flow periods. A ford can also be a naturally stable section of stream that vehicles use in low flow periods.

Geomorphic - Pertaining to the form or shape of the earth's surface, and to those processes that affect and shape the land's surface. Geomorphic processes include all forms of soil erosion and mass soil movement, as well as other surface processes.

Grading - Involves the excavation and movement of soil along a road alignment to an established grade-line during road construction or reconstruction. Grading is one of the tasks of road construction, and is preceded by ripping and followed by surfacing. Grading also refers to the mechanical smoothing of the roadbed to maintain a free-draining, smooth traveling surface.

Gully (gullied) - An erosion channel formed by concentrated surface runoff, larger than one square foot in cross sectional area (1' deep by 1' wide). Gullies often form from road surface or ditch runoff directed onto unprotected slopes. Gullies are a symptom of a problem: too much water collected and discharged onto a hillslope.

Headwater swale - A swale or dip in the natural topography that is upslope from a stream, at its headwaters. There may or may not be any evidence of overland or surface flow of water in the headwater swale.

Humboldt log crossing - See *log crossing*.

Inboard ditch - A ditch located on the inside of the road, usually at the foot of the cutbank (see *ditch*).

Inner gorge - A geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream channel, having a side slope of generally over 65%, and being situated below the first break in slope above the stream channel.

Insloped road - A road surface sloped in toward the cutbank. Insloped roads usually have an inboard ditch that collects runoff from the road surface and cutbank.

Intermittent stream - A stream that flows only at certain times of the year, as when it receives water from springs or from a surface source; a stream that does not flow continuously, as when water losses from evaporation or seepage exceed the available stream flow.

Landing - Any place on or adjacent to a logging site (usually on a road) where logs are collected and assembled for further transport.

Landslide - The down slope movement of a mass of earth caused by gravity is termed a landslide. This includes, but is not limited to debris slides, torrents, rock falls, debris avalanches, and soil creep. It does not include; dry ravel, raindrop erosion or surface erosion caused by running water. Landslides may be the result of a natural erosion processes, such as earthquakes or fire events; or human disturbances such as, mining or road construction.

Log crossing (Humboldt log crossing) - A drainage structure made out of logs or woody debris, sometimes laid in parallel to a stream channel, covered with soil. Before the mid-1980's, log crossings were frequently used as permanent stream crossings instead of culverts or bridges. Log crossings are highly susceptible to plugging and washout during storm flows. Log crossings are used today only for temporary stream crossings that are to be removed prior to the winter period.

Lowboy transportation - Long, low trailers used to haul heavy equipment (tractors and excavators) to a work site.

Maintained road - A road whose cutslopes, road surface, drainage structures, and fillslopes are regularly inspected and repaired to prevent erosion and deterioration.

Mass soil movement - Down slope movement of a soil mass under the force of gravity. Often used synonymously with "landslide” common types of mass soil movement include rock falls, soil creep, slumps, earthflows, debris avalanches, debris slides and debris torrents (see *landslide*).

Mulch - Material placed or spread on the surface of the ground to protect it from raindrop, rill and gully erosion. Mulching is an erosion prevention treatment. Mulches include wood chips, rock, straw, wood fiber and a variety of other natural and synthetic materials.

Outsloped road - A road surface sloped away from the cutbank toward the road's fillslope. Outsloped roads may or may not have an inboard ditch.

Outsloping - To improve road drainage, by converting an insloped road to an outsloped road. Outsloped roads may or may not have an inside ditch to drain spring flow. Outsloping can also refer to the act of excavating the fill along the outside of the road and placing and grading it against the cutbank, thereby creating an outsloped road surface.

Peak flow (flood flow) - The highest amount of stream or river flow occurring in a year or from a single storm event. Design stream crossing culverts to pass the 100-year peak flood flow.

Permanent road - A road planned and constructed to be part of a permanent all-season transportation system. These roads have a surface suitable for travel and, where applicable, for hauling of forest and ranch products throughout the entire winter period. Permanent roads have drainage structures, at watercourse crossings designed to accommodate the 100-year flood flow. Permanent roads receive regular and storm-period inspection and maintenance.

Put-to-bed - See *decommission.*

Range finder - A hand-held field instrument used to measures distances less than 1,000 feet.

Rill - An erosion channel varying in size from a rivulet, to one-foot square in cross section, that typically forms where rainfall and surface runoff is concentrated on bare fillslopes, cutbanks and ditches. If the channel is larger than one square foot in size, it is a gully.

Riparian - The banks and other adjacent terrestrial environs of lakes, watercourses, estuaries and wet areas where transported surface and subsurface freshwater provides soil moisture to support mesic vegetation.

Ripping (of a road) - The process of breaking up or loosening compacted soil (e.g., skid trails, spur roads or landings) to better assure penetration of roots of young tree seedlings and to increase infiltration. Use a tractor with rear-mounted, hydraulically operated ripping chisels to rip roads. Also used are excavators, graders or other earth moving equipment. Three or four passes is usually sufficient to decompact a normal road surface.

Riprap - The rock placed on the ground, stream bank or gully to prevent or reduce erosion.

Road abandonment - Road abandonment involves a series of proactive activities which erosion-proof a road so that further maintenance will not be needed and significant erosion will not occur. In the past, road abandonment was synonymous with blocking the road and letting it grow over with vegetation, which led to significant erosion (see *road closure and decommission*).

Road closure (proactive road abandonment) - A method of closing a road so that regular maintenance is no longer needed and future erosion is largely prevented. The goal of road closure is to leave the road so that little or no maintenance is required for stability while the road is unused. Road closure usually involves storm-proofing techniques including removing stream crossing fills, removing unstable road and landing fills, installing cross road drains for permanent road surface drainage and other erosion prevention and erosion control measurers as needed. Proper road closure is not accomplished by blocking a road and walking away from it to let nature reclaim the road (decommission, road abandonment).

Road failure - Damage to the roadbed, usually caused by a roadbed slump, fill failure, stream crossing washout or major gully, which prevents vehicular passage; not minor cutbank or fill sloughing incidental to road settling.

Road grade - The slope of a road along its alignment is the road grade. Road grades typically run up to a maximum of 20%, but may exceed this slope for short pitches.

Road maintenance - Upkeep of a roads cutbanks, road surface, fillslopes, and all drainage structures, intending to prevent erosion and deterioration. Road maintenance activities include; grading, ditch cleaning, brushing and culvert cleaning.

Road runoff - Surface runoff drained from the road surface, usually as a direct response to rainfall.

Rock armor - Course rock placed to protect a soil surface, usually from erosion caused by flowing or falling water. Rock armor is one type of material used for energy dissipation at culvert outfalls.

Rock pit - A large outcrop of bedrock developed for aggregate uses, such as road surfacing material and/or larger rock armor. A borrow pit is an excavation from which material is removed for use in another location (see *borrow site*).

Rolling dip - Shallow, rounded dip in the road that reverses road grade for a short distance, and directs road surface runoff in the dip or trough to the outside or inside of the road. Construct rolling dips to allow vehicles to travel at normal or slightly reduced speeds.

Rotational slide - A failure plain landslide that is arcuate and concave-up. Its movement is predominantly rotational verses translational.

Runoff - Water from rainfall or snowmelt that drains from hillslopes, or bare areas along roads and trails becomes runoff.

Seasonal road - A road planned and constructed as part of a permanent transportation system whose use is restricted to periods when the surface is dry. Most seasonal roads are not surfaced for winter use, but have a surface adequate for hauling of forest and ranch products in the non-winter periods, and in the extended dry periods or hard frozen conditions occurring during the winter period. Seasonal roads have drainage structures at watercourse crossings designed to accommodate the 100-year flood flow.

Sediment delivery - The eroded material that is delivered to a stream channel. Sediment delivery refers to the percent of material eroded from a site and delivered to a stream channel, as opposed to that which is eroded but then stabilized on the hillslope and does not enter a stream. Sediment delivery is not the same as erosion.

Sediment yield - The quantity of soil, rock particles, organic matter, or other dissolved or suspended debris transported through a cross-section of stream in a given period. Technically, sediment yield consists of dissolved load, suspended load, and bed load.

Sidecast - Excess earthen material pushed or dumped over the side of roads or landings.

Skid trail or **tractor trail** - A tractor-constructed trail usually built while logging or in response to fire control or prevention activities.

Slope angle - The gradient of a slope, usually expressed as percent or degrees, but sometimes as a unit-less ratio (100% = 45E = 1:1; 50% = 26E = 2:1).

Slope stability - The resistance to failure, of a natural or artificial slope, or other inclined surface by landsliding (see *mass movement*).

Slump - An episodic, fast to very slow, mass movement process involving rotation of a block of hillslope or road along a broadly concave slip surface (see *rotational slide*).

Soil texture - The relative proportion of sand, silt and clay in a soil; grouped into standard classes and subclasses in the Soil Survey Manual of the U.S. Department of Agriculture.

Spoil (spoil materials) - Material (soil and organic debris) that is not used or needed as a functional part of the road or a landing. Spoil material is generated during road construction and maintenance activities and during restoration work when stream crossings are upgraded or removed and unstable material is excavated. Spoil may be stored locally (pushed) or it may be endhauled with dump trucks.

Spoil disposal site - The location to place spoil material (woody debris and excavated soils) without the threat of accelerated erosion and sediment delivery, or initiating slope instability. Stable spoil disposal sites may include the cut portion of closed roads, the inside portion of landings and turnouts, and flat or low gradient natural benches. Evaluate each spoil disposal site for its suitability before material is stored at the site.

Spur road - A side road off a main trunk road or a secondary road. Most spur roads are dead-end.

Storm-proof - Erosion control and erosion prevention activities which will protect a road, including its drainage structures and fills, from serious erosion and sediment delivery during a large storm and flood, as well as from chronic surface erosion and sediment delivery during normal runoff events.

Stream class (1, 2, 3): California stream classification methods are based on biological parameters, and not on flow conditions or the magnitude or frequency of stream flow. Class 1 streams are fish bearing, or provide a domestic water supply. Class 2 streams provide habitat to macroinvertebrates and/or amphibians at some time of the year, but are not fish bearing. Class 3 streams move sediment but do not provide habitat to macroinvertebrates or amphibians. Biological classification allows restorationists to prioritize problems and proposed treatments based on their potential to affect aquatic resources. Similarly, many in-channel treatments (e.g., the type of allowable culvert installation) are closely tied to the biological classifications. California stream classes do not correspond to generally accepted USGS classifications of perennial, intermittent and ephemeral streams. Thus, the biological classification has little relevance to the frequency of flow or the size of the stream channel. These factors are often necessary in designing effective in-channel and bank stabilization treatments.

Stream crossing - The location where a road crosses a stream channel is a stream crossing. Drainage structures used in stream crossings include bridges, fords, culverts and a variety of temporary crossings. If a stream diverts down a road to a ditch, it is a stream crossing.

Stream crossing excavation - The excavation of the fill material used to build (fill) a stream channel crossing during road construction. Specifically, this includes the removal of fill from culverted crossings, log crossings and fill (unculverted) crossings. A stable stream crossing excavation must be dug down to the level of the original stream bed, with side slopes graded (excavated) back to a stable angle (usually 50% or less, depending on soil and site characteristics).

Surface erosion - Soil particles detached and transported by wind, water or gravity. Surface erosion can occur as the loss of soil in a uniform layer (sheet erosion), in many rills, gullies, or by dry ravel. Surface erosion may deliver sediment to a stream channel.

Surfacing (surface course) - The top layer of the road surface, also called the wear course. Rock aggregate and paving are two types of surfacing used to weatherproof a road for year-round use.

Swale - A channel-like linear depression or low spot on a hillslope that rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface runoff under the present climatic conditions.

Tag line cross section survey - A surveying technique for monitoring channel and gully erosion, taking vertical measurements from a taught level line stretched between fixed endpoints on either side of the channel to the ground surface. Use tag line cross sections to monitor erosion of excavated stream crossings.

Temporary road - A road used temporarily. These roads have a surface adequate for seasonal hauling use and have drainage structures, adequate to carry the anticipated flow of water during the period of use. Remove all drainage structures prior to the beginning of the winter period (see *temporary stream crossing*).

Tension cracks - Cracks in the ground (usually in a road fill) that may indicate slope instability. Cracks that form as un-compacted fill material naturally settles, and may indicate the beginning of a potential fillslope failure.

Through-cut - A road cut through a hillslope or, more commonly, down a ridge, in which there is a cutbank on both sides of the road. Through-cuts more than two feet deep are very difficult to drain and prone to forming gullies.

Trash rack (debris barrier) - A barrier built just upstream from a culvert inlet to trap floating organic debris before it can plug the culvert. Design trash racks or barriers to filter organic debris from flood flows. All trash racks require periodic cleaning.

Treatment prescription - A suggested treatment for erosion prevention or erosion control is a treatment prescription.

Trough - A long depression between two ridges.

Upgrade - Road upgrading consists of storm-proofing treatments designed to reduce the risk of road failure and the volume of sediment delivery from roads. Treatments generally consist of upgrading stream crossings (to increase flow capacity and to prevent stream diversion), excavating unstable fillslopes (which would otherwise fail and deliver sediment to a stream channel), and disconnect road surface drainage from the natural stream network (thereby dispersing road surface runoff and preventing delivery of fine sediment to streams).

Unstable areas - Areas characterized by mass movement features or unstable soils. An example of an unstable area is hummocky topography consisting of rolling bumpy ground, with frequent benches, and depressions. Short irregular surface drainages which begin and end on the slope, visible tension cracks, and head wall scarps and irregular slopes which may be slightly concave in upper half and convex in lower half as a result of previous slope failure also indicate unstable areas. Evidence of impaired ground water movement resulting in local zones of saturation including sag ponds with standing water, springs, or patches of wet ground; hydrophilic (wet site) vegetation; leaning, jack-strawed or split trees; and pistol-butted trees with excessive sweep in areas of hummocky topography are generally unstable.

Unstable soils - Characteristics of unstable soils include unconsolidated, non-cohesive soils (coarser textured than loam) and colluvial debris including sands and gravels, rock fragments, or weathered granitics. Such soils are usually associated with a risk of shallow-seated landslides on slopes of 65% or more, having non-cohesive soils less than 5 feet deep in an area where precipitation exceeds 4 inches in 24 hours in a 5-year recurrence interval. Soils that increase and decrease in volume as moisture content changes are unstable. During dry weather, these materials become hard and rock-like exhibiting a network of polygonal shrinkage cracks and a blocky structure resulting from desiccation. Some cracks may be greater than 5 feet in depth. When wet, these materials are very sticky, dingy, shiny, and easily molded.

Washed-out stream crossing - A partially or completely eroded stream crossing fill washed downstream. When a culvert plugs and stream flow backs up and flows over the roadbed during flood events washouts occur. They are most common on abandoned roads, but may also occur on maintained roads in response to severe storm events.

Water bar (water break) - Shallow ditch excavated at an angle across a road or trail to drain surface runoff. Water bars are typically built on seasonal or temporary roads receiving little or no traffic during the winter period.

Watercourse - Any well defined channel with distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand or gravel. Watercourse also includes human-made watercourses (see *Class I, II, III and IV watercourse*).

Water quality - The chemical and biological characteristics of a stream and lake water defines water quality.

Watershed - The area or drainage basin contributing water, organic matter, dissolved nutrients and sediments to a stream or lake. An area bounded mostly by ridges and drained, at its outlet, by a single trunk stream.

APPENDIX X-A. INSTRUCTIONS FOR COMPLETING UPSLOPE INVENTORY DATA FORM

ASAP (Y, N): Enter "Y" if a site urgently needs treatment to prevent imminent damage to a stream, otherwise enter "N".

GENERAL INFORMATION

Site No: A unique systematic identification number assigned to a specific site. Also, record the site number on the aerial photo Mylar overlay. Use only numbers, not letters, for effective database searches.

Treat (Y, N): Enter "Y" if the final assessment recommendation is for site treatment; and "N" if not recommended for treatment.

Watershed: Write in the name of the watershed from the USGS 7.5 minute topographic map, (i.e. Bull Creek).

Quad: Write in the name of the USGS 7.5 minute quad.

GPS: Record the GPS coordinates for the specific site.

CALWAA: The California Watershed Analysis Area number assigned to the inventoried sub-watershed or land unit.

Photo: The flight line and frame number of the air photo used for mapping the location of this particular site. Original field mapping information is contained on acetate or Mylar overlay for each of the aerial photos covering the assessment area.

T/R/S: From the USGS quadrangle, enter the township, range, and section for the site.

Road Name/#: Enter the road name or number where the site is located. Many roads have posted names, such as the 500 Road. For unnamed road systems, adopt a logical road numbering system for the survey and include the names on the final site map.

Drivable (Y/N): If the road is drivable, even if abandoned, enter "Y"; if there are obstructions, washouts or vegetation that make it impassible, enter "N".

Mileage: For each drivable site, log a distance from start on the data sheet and a photo overlay map. Typically, start recording mileage at the beginning of the road to the site. Use an odometer or vehicle mileage computer to record mileage to the nearest 0.01 mile. If the road is not drivable, enter the word "WALK" instead of a mileage. The length of roads walked is determined later from digitizing maps or aerial photographs.

Inspector(s): Record the names or initials of the inventory crew. List the data recorder first.

Date: Record the date of the survey.

Year Built: Record the first year the road is visible on aerial photographs. This is likely not the year it was constructed, but provides a frame of reference for its construction.

Surface: Check one. Check “rock” for surfaced roads with pit-run or river-run rock, crushed or not crushed. Unsurfaced roads are “native” roads or dirt roads, even though they may contain some natural rock. Use “paved” for all roads surfaced with asphalt, concrete, or chip-seal.

Status: Check “maintained” for a maintained road or if there is evidence of maintenance activities having been performed recently. Check “abandoned” for an abandoned, blocked, or not maintained road. The road may still be drivable, but classify it as abandoned if there is no obvious maintenance at culvert sites, the ditches need cleaning, and vegetation has overgrown the roadbed. Spur roads are also considered abandoned if their access is completely and permanently blocked. A road is either “abandoned” or “maintained”. Check “decommissioned” for a decommissioned road. Check “decommissioned” if the stream crossings have been excavated and permanent surface drainage has been installed. A gated road, an overgrown road or a road with a tank trap at the beginning does not qualify as decommissioned.

Proposed: Check “upgrade” if recommending upgrading the road. Check “decommission” if recommending decommissioning the road. The site must be identified as either upgrade or decommission, but not both.

Sketch: Enter “Y” if a site sketch is included on the back of the data form (Figure X-3). Enter “N” if a site sketch is not included.

PROBLEM

Occasionally, more than one problem may occur at a single site.

Stream Crossing: Enter “Y” if the site is a stream crossing. Enter “N” if the site is not a stream crossing.

Landslide: Check “fill” if the site is a fillslope landslide involving the failure of sidecast materials along the outside edges of a road, especially those built on steep slopes, and around the outside edges of landings. Fillslope landslides usually cut into the roadbed and the slide material is deposited down slope from the road. Check “hill” if the site is a hillslope landslide above, across, and/or below the road, and involves more than just sidecast or cutbank material.
Check “cut” if the site is a cutbank landslide occurring on the inside, or cut side, of the road. Cutbank slides deposit material on the roadbed.

Roadbed: Check “bed” if the site involves erosion, rilling, or runoff from the roadbed. Check “ditch” if the site involves erosion from or runoff in the inboard ditch. Check “cut” if the site involves erosion from a cutbank.

Ditch Relief Culvert: Check if a ditch relief culvert (DRC) is delivering sediment to a stream channel. Erosion at the outlet of a ditch relief culvert does not warrant classification unless the eroded sediment reaches, or could reach, a stream. However, even a small gully or channel that extends from the outlet of a DRC down to a stream effectively connects the road and ditch to the stream, and merits classifying such a culvert as a site.

Gully: Check for a newly formed or actively eroding gully.

Bank Erosion: Check if the site involves eroding banks of a natural stream channel.

Road Related: Enter "Y" if the potential or existing erosion problem is directly related to the road. Enter "N" if the potential or existing erosion problem in not directly related to the road.

Other Non-road Related Site: If it is not road-related, check the location and land use associated with the on-going or potential erosion problem:

- □ home
- □ agricultural
- □ construction
- □ mining
- □ other site.

If "other site" included description.

LANDSLIDE

Road or Landing Fill: Check if the site involves failure of fill material on the outside edge of a road, landing, or pullout from loose material pushed over the road's edge during construction or maintenance.

Hillslope Debris Slide: Debris slides move fast and are typically relatively shallow compared to deep-seated, slow moving landslides. Debris slides may or may not turn into debris flows, depending on confinement, slope gradient and water content.

Cutbank Slide: Check for landslides confined to the cutbank on the inside of the road. Unless connected to an inboard ditch, these landslides just dump material on the roadbed and little or none of it gets into a stream channel. Some of the bigger cutbank slides cross over the road and continue down slope into a channel. Cutbank slides are usually just maintenance problems and do not often become sediment delivery problems.

Hillslope Landslide of Unknown Type and Depth: Check if the site is large with areas of multiple scarp systems running through natural slopes and/or across roads and skid trails. Large hillslope landslides often have the following characteristics: emerging groundwater; leaning trees; active and inactive scarp systems; and episodic, seasonal movement from several feet to several hundred feet annually. Some may not move annually. Most deep-seated hillslope landslides involve far more than just a road and are difficult and expensive to control.

Potential Failure: Check if the site has the potential to fail. The site may be currently inactive and show no signs of movement in the last several years, but the scarps and other indicators suggest that during an especially large storm the instability could become active and fail or move down slope. Potential failures may also be earth block remainders from a slide that previously failed. If an unstable mass is on-site, even if it shows developed scarps and has moved or dropped several feet, classify the site as a potential failure.

Past Failure: Check if the landslide has already failed and appears to be inactive and partially or largely revegetated. Gullies will often have armor lag deposits in the channel bed. Landslides may be inactive even though vegetation is still sparse and it still looks bad.

Slope (%): Enter the percent slope of the hillside below the site. This is the slope of the natural ground below the base of the fillslope, not the slope of the road fill looking from the outside edge of the road. Take the measurement from the foot of the fillslope with a clinometer. This is the steepness of the slope the slide mass would first have to travel over to reach a stream channel.

Distance to Stream (ft): Enter the distance in feet from a landslide site to the nearest stream. Measure the distance from the foot or base of the potential slide down to the channel. It is the minimum distance soil would have to travel to deliver sediment to a stream.

STREAM

Check the most appropriate type of stream crossing. It is possible to have more than one crossing type at a single location (e.g., Humboldt and culvert).

- culvert
- bridge
- Humboldt
- fill
- ford
- armored fill.

Excavated Crossing: Check for an excavated stream crossing on an abandoned or decommissioned road.

% Excavated: Estimate the percent of the fill excavated.

Ditch Road Length(ft): Left: and **Right:** Record in feet, the longest distance of the road and/or ditch which drains water to the stream crossing from each side. This is the length of ditch and/or road contributing surface runoff and fine road sediment to the stream crossing. Measure the distance along the ditch/road on both the left and right approaches. Right and left are determined when looking in the downstream direction.

Culvert Diameter (in): Enter the diameter of the culvert. Typical choices include 12, 18, 24, 30, 36, 42, 48, 52, 60, or 72 inches. Measure each culvert with a measuring tape or pocket-rod because it is easy to estimate incorrectly.

Pipe Condition (O, C, R , P) Inlet:, Bottom:, and **Outlet:** Record the condition of the three components of a culvert pipe crossing: the inlet, the bottom, and the outlet. Use the following codes: "O" for OK; "C" for Crushed (if any dents block 20% or more of the culvert, consider it crushed); "R" for Rusted (severe, to the point of having holes in the bottom); "P" for Plugged (any blockage of the culvert exceeding 20%, consider it plugged).

Separated: Check separated if a culvert joint has separated. Use a flashlight to determine if a separation exists. In a separated culvert, flow may enter the culvert but not come out the other end. Look for water flowing out from beneath the culvert outlet.

Headwall (in): Enter the headwall height on stream crossings with culverts. Measure the vertical height from the bottom of the culvert inlet to the lowest point in the stream crossing fill where the water would begin to flow out of the crossing and down an inboard ditch, or over the road and down its outboard fillslope. As long as water is ponding and backing up and not flowing down the road or over the crossing, the headwall height is not reached. Note: Make some headwall height measurements to the inboard edge of the road and make others to the ditch. The low point is merely the point where water would flow from the crossing inlet area if the culvert were to plug.

Culvert Slope (%): Enter the average slope of a culvert. Take this measurement by looking up the culvert from the outlet, or down the culvert from the inlet. Use a clinometer. If the culvert is straight, place the clipboard in the culvert inlet, put the clinometer on the clipboard and read out the slope gradient. If the crossing is on a fish bearing stream, see *Part IX*.

Stream Class (1, 2, 3): Enter the stream classification number. Class 1 streams are fish bearing, or provide a domestic water supply. Class 2 streams provide habitat to macroinvertebrates and/or amphibians at some time of the year, but are not fish bearing. Class 3 streams move sediment but do not provide habitat to macroinvertebrates or amphibians. California stream classification methods are based on biological parameters, and not on flow conditions or the magnitude or frequency of stream flow. Biological classification allows restorationists to prioritize problems and proposed treatments based on their potential affect aquatic resources. California stream classes do not correspond to generally accepted USGS classifications of perennial, intermittent and ephemeral streams.

Culvert Rust-line (in): Inlet: and **Outlet:** Enter the height of the rust-line at the inlet and outlet of the culvert. This is the vertical distance between the bottom of the culvert and the top of the rusted area in the pipe. The inlet rust-line is generally the best indicator of pipe capacity for accommodating the stream's flow and will have a higher rust-line than the outlet. Plastic, aluminum, and concrete pipes will not have rust-lines, but may show scour or moss lines.

Culvert Undersized (Y, M, N): Enter "Y" for yes if there is field evidence a culvert is undersized. Enter "N" for no if the field evidence indicates it will pass the design flow. Enter "M" for maybe if uncertain. Describe the evidence in the comment section.

Washed Out (%): Enter the percentage of the fill material at the crossing that has eroded and is already gone. If the entire fill washed out, enter 100. Culverted stream crossings can wash out by having stream flow over the fill, by having extreme culvert outlet erosion, or by having a Humboldt log crossing develop sinkholes and subsurface gully erosion.

Diversion Potential (Y/N): Enter "Y" for yes if diversion potential exists. If the culvert plugged and the water would flow down the road or inboard ditch there is diversion potential. A stream has a diversion potential if the flow would leave the fill crossing and divert down the road past the fill's hinge line, even if it would re-enter the natural stream channel at some distance down slope. Enter "N" for no if there is no diversion potential. If the culvert plugs and floodwaters would flow straight across the road and spill back into their stream channel downstream of the road, there is no diversion potential. If the crossing has no diversion potential, overflow might cause a washout of the road fill, but the stream flow would not divert out of its natural channel. All stream crossings have either diversion potential or no diversion potential. There are no other choices.

Currently Diverted: Check for a stream currently diverted down the road or ditch, or if there is evidence that even part of the peak stream flow currently diverts down the road or ditch.

Road Grade (%): Enter the road grade in percent. Measure the downhill slope of the road leading away from the crossing or the direction a diversion would flow.

Plug Potential (H, M, L): Estimate the potential for the crossing to plug with sediment or woody debris (High, Moderate or Low). The plugging potential is an estimate of how likely the culvert is to plug in the next big storm. Plugging potential typically is higher for streams that transport significant organic debris and sediment. Write "H" if the evidence for high plugging potential includes:

- Culvert is currently plugged or partially plugged
- Culvert is too small for the drainage
- Culvert has plugged in the past (note terraces, ponding evidence, etc.)
- Culvert has been cleaned once or more in the past as evidenced by scattered debris
- Culvert inlet is damaged
- Cutbank or slope failure threatens the inlet.

If the culvert is undersized, it still might not have a high plugging potential. An effective trash barrier may reduce plugging potential. Make note of a trash rack in the comments.

Plugged (%): Enter the percent of the culvert inlet or outlet that is currently plugged with sediment or organic debris.

Channel Gradient (%): Enter the slope of the natural channel upstream from the stream crossing. Do not measure channel gradient in the flat reach influenced by the stream crossing and culvert inlet.

Channel Width (ft): The estimated width of the 100-year flood event channel. Record the width of the expected flow dimensions in feet. Measure channel dimensions in the undisturbed, natural channel above the influence of the road crossing.

Channel Depth (ft): The estimated depth of the 100-year flood event channel. Record the depth of the expected flow dimensions in feet. Measure channel dimensions in the undisturbed, natural channel above the influence of the road crossing.

Sediment Transport (H, M, L): Estimate the relative capability of the stream to transport sediment and thereby move sediment and debris down to the culvert inlet. Enter "H" for high, ""M" for moderate, or "L" for low. This is a subjective evaluation of stream competence and capacity that is used to provide qualitative information on culvert plugging potential. If a lot of sediment is moving during annual high flow events, then sediment transport is high. If the streambed has moss-covered cobbles that are stable, then transport might be considered low. In performing an inventory, it is important to be consistent in classifying sediment transport so that sites can be ranked or compared against each other at the end of the assessment.

Drainage Area (acres): Enter drainage area of the sub-watershed draining to the stream crossing. The drainage area is calculated later from a scaled topographic map or GIS map using a planimeter or dot grid, or employing a digitizer and GIS software. Drainage area is necessary for calculating peak stream flow estimates and culvert sizes.

FISH PASSAGE

Fish passage data provides information to determine possible barriers to adult and juvenile fish migration on Class 1 streams (*Part IX*).

Culvert Outlet Drop (in): Measure the vertical height in inches from the bottom of the culvert to the water surface at the time of the survey.

Bankfull Drop (in): Estimate, based on channel bank scour lines, the bankfull outlet drop.

Pool Size Bankfull Width (ft): Measure the maximum width of the pool, in feet, below the culvert outfall, from the bank scour lines, at bankfull stage.

Pool Size Bankfull Depth (ft): Measure the maximum depth of the pool, in feet, below the culvert outfall, from the bank scour lines, at bankfull stage.

EROSION

Collect information about past erosion, future erosion, and erosion potential for each site. Give estimates of how much past erosion occurred at the site, how much was delivered to a stream channel, how much future erosion is to be expected, how much will be delivered to a stream channel and the likelihood of future erosion.

Erosion Potential (H, M, L): Estimate the potential for future erosion, based on observation. This is a qualitative evaluation of the likelihood of erosion, not a quantitative volume estimate. Enter "H" for High if erosion is very likely to occur. This does not quantify volume, or if the erosion will reach a stream channel. For potential landslides, base erosion potential on the likelihood that the slide will move or continue to move in response to a large magnitude rainfall and runoff event. For fluvial erosion, it is an evaluation of the likelihood of continued or future gullying in the event of a large magnitude rainfall and runoff event.

Potential for Extreme Erosion: Check if potential for extreme erosion and sediment delivery exists or if there is a potential for erosion of more than just the obvious road fill or stream crossing fill material. This usually implies erosion or landsliding of original ground and may be associated with deep fill failures, torrenting of road fills in steep swales and the diversion of large streams onto steep, erodible or unstable hillslopes.

Volume of Extreme Erosion (<500, 500-1,000, 1-2K, 2-5K, >5K): Estimate the expected volume of erosion or slope failure from an extreme erosion event. Enter one of the volume ranges of the potential extreme erosion.

Past Erosion (yd^3) (optional): Enter the volume of past erosion for the site, derived from field measurements. Enter width, depth and length measurements. If the feature is complex, take several different measurements to account for the entire feature. Show these measurements on the sketch. Often small gullies form below outlets to ditch relief culverts where there is diverted road and ditch runoff to a slope that previously did not carry such concentrated flow. These gully volumes are easily estimated using width, depth and length measurements. The largest road-related gullies form when a stream diverts out of its natural channel and then discharges into another channel or onto a hillslope area. These diversions can cause large gullies or even landslides and such erosion features are often down slope, out-of-sight of the road where the diversion originated.

Past Delivery (%) (optional): Estimate the percent of the past eroded material that was actually delivered to the stream channel system. The rest should still be in storage on the hillside.

Total Past Delivery (yds^3): Past erosion (yd^3) times past delivery (%). This is the estimated volume of erosion that has been delivered to a stream channel.

FUTURE EROSION

Future Erosion (ft):, **Width:,** **Depth:**, and **Length:** Measure the potential erosion feature, recorded as average width, depth, and length in feet. If the feature is complex, take several different measurements to account for the entire feature. These measurements describe the planimetric assumption used by field personnel to determine future erosion volumes and should be shown on the sketch map of the site. For existing gullies, potential and existing landslides and potential stream crossing washouts, it is possible to estimate the volume of future erosion that is likely to occur. Detailed descriptions on measuring and estimating future erosion volumes begin on page X-34.

Future Erosion (yd^3): Calculate the volume of future erosion from the Future erosion measurements by using the formula width x depth x length, or by geometric calculations (Figure X-5, Figure X-6, Figure X-7, and Figure X-8.

Future Delivery (%): Estimate the future eroded sediment that will enter a stream channel. If all the eroded sediment will be stored on the slope and never move into the stream system then there will be no delivery. Estimate how much sediment, as a percent of the volume of expected erosion, is likely to be delivered to the stream channel. For erosion at stream crossings, assume 100% delivery to the stream. Delivery from landslides is usually less, and often considerably less, than 100%, depending on distance to the stream, steepness of the slope and other factors. Delivery can be to any size stream. Once it is in the stream system it will eventually work its way downstream.

Total Future Delivery (yds^3): Future erosion (yd^3) times future delivery (%). This is the estimated volume of erosion delivered to a stream channel if the site is untreated and the erosion event triggers.

COMMENT(S) ON PROBLEM

The summary comments for each site generally describe the nature of the erosion problem as well as important site characteristics. It should also contain enough information to clearly depict this site and differentiate it from other nearby sites. It should describe the features contained in the sketch map on the back of the data form. Someone who has never been to the site should gain an immediate understanding of the nature and scope of the problem from reading the comment.

TREATMENT

Identify those sites that will require consultation with a licensed geotechnical specialist to develop treatment options, and prescribe treatments for all other inventoried sites of future erosion and sediment delivery for which there is an identifiable erosion control or prevention treatment that would reduce or prevent sediment delivery. In prescribing treatments, assume access for equipment to the site unless it is completely and obviously impossible to do so. In general, if there was ever a road or equipment trail to the site, there is a good chance access can be developed. After developing treatments, and evaluating costs for access and treatment, employ cost-effectiveness and other considerations to prioritize all the treatment sites.

There is a very real difference between the cause and the symptom of many erosion problems. For example, the gully below a ditch relief culvert is a symptom of the true cause; too much water flowing along the road and ditch to the culvert (i.e., too large a drainage area for the culvert). The treatment is not to stabilize the developing gully with grade control structures, or to release the water at another single location; rather, it is to disperse the water in the ditch (e.g., by using multiple ditch relief culverts) so gullying cannot continue here or elsewhere. Wherever feasible, it is important to treat the cause of the problem rather than the symptom.

Immediacy (H, M, L): Decide if the work needs to get done immediately. If the evidence suggests the feature is likely to change dramatically in the next storm event or winter season and the erosion at this site seriously threatens important downstream resources like salmonid spawning or rearing areas, enter "H" for High. Base this answer on the severity of the potential erosion, its volume, its predicted activity level and the sensitivity of the resources at risk. If mass movement, culvert failure or sediment delivery is imminent, even in an average winter, then treatment immediacy is high. Treatment immediacy is a summary assessment of a site's need for immediate treatment. Generally, rate sites likely to erode or fail in a normal winter that may deliver significant quantities of sediment to a stream channel, as having high treatment immediacy. The answers can also include combinations, such as "HM" or "ML" to cover sites where the answer is not clear-cut.

Complexity (H, M, L): Estimate the difficulty of performing the recommended treatment. For example, classify a 1,000 yd^3 excavation of a Humboldt log crossing that will require construction of a lower access road and dump truck endhauling as "H" for High complexity. Classify a simple stream crossing excavation or the excavation of a small unstable fill along the outboard edge of the road as "L" for Low complexity. Use the Comment(s) on Treatment for explanation.

Check Culvert Size (Y/N): Enter "Y" if the culvert may be undersized. This is not a treatment as such, but it requires a future action to determine proper culvert size for the drainage. It will alert staff to conduct further analysis to check for the correct culvert size. Make sure the site is accurately located on the photo (or map) so drainage areas can be correctly measured. Enter "N" if the culvert size does not need to be checked.

Bridge: Install a bridge. Check this recommendation for crossings of Class 1 streams, especially if culvert flow analysis calls for 72" or larger pipe.

No Treatment: Check if no treatment is required.

Mulch: Estimate the exposed area in ft^2 needing mulching, after heavy equipment operations, to prevent delivery of fine sediment to a stream. This is the area needing mulching and seeding to control erosion after operations are complete. Sites located away from stream channels may not need mulching if there is no sediment delivery potential to a stream.

TREATMENT OPTIONS

Excavate Soil: Check for permanent excavations of soil from the site. Replacing or installing a culvert is not marked excavate soil if all the dirt is returned to the site after the culvert is installed. However, check if removing any portion of the soil from the work site.

Critical Dip: Check for installation of a critical dip. A critical dip is a rolling dip constructed on or close to the down-road hinge-line of a stream crossing, displaying a diversion potential. Build a critical dip at all stream crossings in order to prevent stream diversions when a culvert plugs and water flows out onto the road (Figure X-13).

Ford: Check for installation of a ford. Install fords at sites prone to frequent culvert plugging due to high amounts of sediment and debris in transport. The treatment requires excavating the entire volume of fill placed in the stream crossing and leaving a very broad dip in the axis of the natural channel, with long and gently sloping ramps into and out of the stream crossing. Build fords along roads built on floodplains and terraces and where the natural streambed is not prone to downcutting. Also, install fords where roads cross steep gradient stream channels with relatively small depths of fill at the outboard edge of the road (Figure X-14).

Armored Fill: Check for installation of an armored fill. Install armored fills at small stream crossings where culverts are prone to plugging or where maintenance during the winter is unlikely. Use armored fills on crossings with fill depths of six feet or less, instead of a ford. Protect the outer fillslope from erosion with rock armor, with a rock sill set in a key way, and with rock surfacing on the fill face. Shape the rock in a broad swale across the road to contain flood flows and direct flow over the armored fillslope (Figure X-15).

> ***Armor Size:*** The rock used for armor protection must be larger than that which can be transported by the stream during the design flood flow. This is determined by calculating minimum stable rock or stone size (Racin, et al. 2000) for the site. A seven step process is used to quantitatively determine the most appropriate minimum rock size for channel armor (Racin, et al. 2000). This includes an analysis of the local site conditions and calculations that determine the minimum rock weight (W) that will resist the flowing water. The outside layer of rock must interlock and be stable in design flows. In a typical armored fill, the rock armor covers the outer half of the road, with rock sizes increasing in the downstream and downslope direction. The largest boulders are keyed into the base of the armored fill structure, at the base of the fillslope and where flow will re-enter the natural stream channel.

Sill Height (ft): If all the fill cannot be removed from the stream crossing while still providing for easy vehicular passage, then a sill wall and energy dissipation apron will need to be constructed down the outside edge of the road to prevent erosion of the underlying erodible fill in the crossing (Figure X-15). The sill is the armored outside slope of the stream crossing fill that must be protected with armor. Enter the sill height in feet at the centerline of the stream channel, adding two feet for embedding the lowest boulders below the level of the natural stream channel at the base of the structure (e.g., if three vertical feet of fill remain at the outboard edge of the road, enter 5 feet for the sill height). This will allow for a standard two-foot deep keyway into the natural streambed for the sill wall. The armored fill treatment is typically designed for small steam crossing fills, with outboard fill depths no more than about six vertical feet. Do not recommend using this treatment if a sill wall is greater than 6 feet high, excluding the keyway or footing.

Sill Width (ft): Enter the sill width, needed to span the 100-year return interval storm. Construct sills of concrete poured into plywood forms or, more commonly, they may be made of coarse riprap or quarry rock.

Trash Rack: Check to add a trash rack just upstream from the culvert inlet to catch organic debris and to prevent culvert plugging.

Add Downspout: Length (ft): and **Diameter (in):** Check if a downspout is needed, and enter length and width of downspout required. Add a downspout to the culvert outlet to carry stream flow beyond the fill and to prevent discharge of flow onto erodible road fill or sidecast. Record the length (in feet) and diameter (in inches) of the downspout. Downspouts longer than 20 feet require anchor posts. Downspouts on stream crossings should be full, round culverts. In some instances, rock armor can provide energy dissipation, and substitute for a short downspout.

Repair Culvert: Check for repairing a culvert damaged or significantly dented by a backhoe, grader or other equipment.

Clean Culvert: Check for cleaning a plugged or partially plugged culvert inlet, and for cutting vegetation, including trees, away from the inlet or outlet.

Install/Replace Culvert: Check to install or replace a culvert.

Culvert: Diameter (in): and **Length (ft):** Specify the recommended culvert diameter, in inches, and length, in feet. Base culvert diameter on 100-year storm discharge and determine diameter from one or more empirical equations or formulas. Guessing is not a very good way to determine the appropriate culvert size. Estimate culvert length by measurements taken in the field.

Install Flared Inlet: Check if prescribing a flared inlet to prevent culvert plugging. Specify the diameter of the flared inlet, in inches.

Reconstruct Fill: Check for a completely or partially failed road due to a landslide. This will probably involve a newly engineered fill that will likely require design by a qualified engineer. Do not use this space for reconstructing or filling in a washed-out stream crossing.

Armor Fill Face (U, D, B): Check for armoring fill face(s) of a stream crossing fill with coarse boulders that will protect the fill from stream erosion caused by stream flow and scouring at the culvert inlet or unavoidable culvert plugging or overtopping at the culvert outlet. Enter "U" for armoring the upstream crossing fill, "D" for downstream, or "B" for both.

Armor Area (ft^2): Specify the surface area of rock needed to armor the upstream (U) and/or downstream fill faces.

Clean or Cut Ditch (ft): Check if a plugged ditch needs cleaning or a new ditch built. Specify the length in feet.

Remove Ditch (ft): Check to remove (fill) a section of inboard ditch. Specify the length in feet.

Outslope Road (ft): Check for the conversion of a flat, crowned or insloped road to an outsloped road. Generally, this treatment is for road upgrading or decommissioning where road surface drainage needs to be improved. "Outslope Road" is the correct prescription to use to change the surface drainage pattern on the roadbed. Specify the length of outsloping required, in feet. Use "Excavate Soil" (instead of "Outslope Road") when decommissioning a road and there is need to excavate substantial material from the outside edge of the road in order to prevent fillslope landslides.

Outslope and Remove Ditch (ft): Check if the road is to be outsloped and the inboard ditch removed. Specify the length of road to be outsloped with the ditch removed.

Outslope and Retain Ditch (ft): Check for road reaches to be outsloped but the inboard ditch retained. Specify the length of road to be outsloped with the ditch retained.

Inslope Road (ft): Check for the conversion of a flat, crowned or outsloped road to an insloped road. Generally, this treatment is for areas where it is important to keep water off the outside fillslope. "Inslope road" is the correct prescription to use to change the surface drainage pattern on the roadbed. Typically, but not always, an inboard ditch is needed when the road is insloped. For a retained ditch, prescribe clean or cut ditch as well (see above). Specify the length of insloping required, in feet.

Rolling Dips (#): Check for installing rolling dips on the road surface. Typically, install rolling dips in road upgrade projects. Usually, but not always, the rolling dip connects to an inboard ditch if present. Also, use rolling dips on outsloped roads to drain the road surface (Figure X-21). Specify the number of rolling dips needed along the road reach. This is not the correct prescription to use for critical dips at stream crossings to prevent stream diversions.

Remove Berm (ft): Check to remove or grade a berm along the outside edge of the road. Specify the length of berm in feet.

Ditch Relief Culvert: Check for the installation of ditch relief culverts to drain the inside ditch. Specify the number and total length of the culvert needed. Unless otherwise specified, a ditch relief culvert will be 18 inches diameter (Figure X-20)

Rock Road Surface (ft^2): Check to rock the surface of a section of road. Use this treatment only for prescribing new rocking. Specify the total area needing rock in ft^2. To re-rock a site after installing a rolling dip or replacing a culvert on a rocked road, do not check this treatment.

Cross Road Drain (#): Check for installing cross road drains, or exaggerated waterbars, on decommissioned roads. Specify the number of cross road drains.

Other: Check if recommending another treatment. Fully describe in the Comment(s) on Treatment section.

HEAVY EQUIPMENT EXCAVATION DATA

Track and manage spoil according to the following equations:

- Total Volume Excavated = Volume Returned + Volume Removed
- Volume Removed = Volume Stockpiled + Volume Endhauled

Total Volume Excavated (yd^3): The total volume of material excavated from the unstable fillslope or stream crossing. Use this volume to help predict costs and equipment times needed to perform the excavation work. In addition, it is used to help determine whether endhauling will be necessary to dispose of spoil from the site.

Volume Put Back in (yd^3): This is the volume of material that is to be put back into the excavation hole, as in a culvert replacement.

Volume Removed (yd^3): This is the volume of excavated material removed from the excavation hole. For example in the excavation of unstable sidecast material, zero would be returned and all of it would be removed.

Volume Stockpiled (yd^3): Excavated spoil that can be locally stored without using dump trucks.

Volume Endhauled (yd^3): From measurements in the field, the available storage volume is calculated and compared to the total excavated volume to determine the need for endhauling equipment. If local storage is insufficient, identify additional storage sites in nearby areas along the road.

Distance Endhauled (ft): Record the distance materials will need to be endhauled for storage.

Excavation Production Rate (yd^3/hr): Estimate the excavation production rate for the site to determine the required equipment hours. Use the Comment(s) on Treatment section to itemize the hours needed for each piece of equipment, for every assigned task and sub-task. See Table X-5 for guidelines in estimating equipment production rates for various tasks. For equipment and labor time estimates do not include time for traveling or other miscellaneous tasks.

EQUIPMENT HOURS DATA

If a piece of equipment is to perform several different tasks or sub-tasks, then list the individual times that go together to add up to total equipment time for each piece of equipment.

Excavator: Estimate the hours of excavator time needed at the site.

Dozer (Crawler Tractor): Estimate the hours of tractor time needed for excavation and spoil management at the site.

Backhoe: Estimate the hours of backhoe time needed at the site.

Grader: Estimate the hours of grader time needed at the site.

Loader: Estimate the hours of loader time needed at the site.

Dump Truck: Estimate the hours of dump truck time needed for endhauling excess spoil to stable storage locations.

Labor: Estimate the hours of laborers needed to perform such tasks as culvert installation, culvert cleaning, etc.

Other: Any other tasks or equipment not listed above.

COMMENT(S) ON TREATMENT

Add details for equipment or labor treatments and logistics or any information useful for the project. Fill this comment section with descriptive information that will be useful for the equipment operators, and will make it clear what work has been prescribed for the site.

UPSLOPE INVENTORY DATA FORM

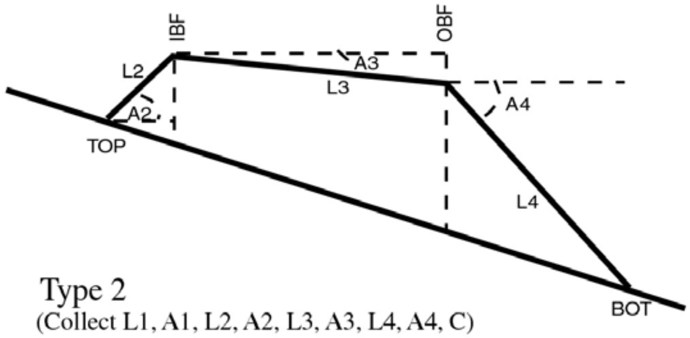
ASAP (Y, N)______

GENERAL	Site no:	Treat (Y/N):	Watershed:	Quad:	
	GPS:		CALWAA:	Photo:	
	T/R/S:		Road name/#:	Drivable (Y/N):	
	Mileage:		Inspector(s):	Date:	Year built:
	Surface: □ rock □ native □ paved		Status: □ maintained □ abandoned □ decommissioned		
	Proposed: □ upgrade □ decommission			Sketch (Y/N):	
PROBLEM	Stream crossing (Y/N):		Landslide: □ fill □ hill □ cut	Roadbed: □ bed, □ ditch, □ cut	
	□ ditch relief culvert		□ gully	□ bank erosion	Road related (Y/N):
	Other non-road related site: □ home □ agricultural □construction □ mining □ other site				
LANDSLIDE	□ road or landing fill		□ hillslope debris slide[1]	□ other hillslope landslide (depth unknown)[1]	
	□ cutbank slide		□ potential failure	□ past failure	Slope (%):
	Distance to stream (ft):				
STREAM	□ culvert	□ bridge	□ Humboldt	□ fill	□ ford □ armored fill
	□ excavated crossing		% excavated:		
	Ditch road length (ft): Left:		Right:	Culvert diameter (in):	
	Pipe condition (O, C, R, P): Inlet:		Bottom:	Outlet:	□ separated
	Headwall (in):		Culvert slope (%):		Stream class (1,2,3):
	Culvert rust-line (in): Inlet:		Outlet:	Culvert undersized (Y, M, N):	
	Washed out (%):		Diversion potential (Y/N):		□ currently diverted
	Road grade (%):		Plug potential (H, M, L):		Plugged (%):
	Channel gradient (%):		Channel width (ft):		Channel depth (ft):
	Sediment transport (H, M, L):		Drainage area (acres):		
FISH PASSAGE	Culvert outlet drop (in):		Bankfull drop (in):		
	Pool size bankfull width (ft):			Pool size bankfull depth (ft):	
EROSION	Erosion potential (H, M, L):		□ potential for extreme erosion		
	Volume extreme erosion (<500, 500-1,000, 1-2K, 2-5K, >5K):			Past erosion (yd^3) (optional):	
	Past delivery (%) (optional):		Total past delivery (yd^3):		
FUTURE EROSION	Future erosion (ft): Width:		Depth:	Length:	Future erosion(yd^3):
	Future delivery (%):		Total future delivery (yd^3):		
COMMENT(S) ON PROBLEM:					
TREATMENT	Immediacy (H, M, L):		Complexity (H, M, L):		
	check culvert size (Y/N):		□ bridge	□ no treatment	Mulch (ft^2):
TREATMENT OPTIONS	□ excavate soil	□ critical dip	□ ford	□ armored fill	Sill height (ft):
	Sill width (ft):	□ trash rack	□ Add downspout: Length (ft):		Diameter (in):
	□ repair culvert	□ clean culvert	□ install/replace culvert		
	Culvert: Diameter (in):		Length (ft):	□ flared inlet: Diameter(in):	
	□ reconstr. fill	□ armor fill face (U, D, B):		Armor area (ft^2): U: D:	
	□ clean or cut ditch, (ft):		□ remove ditch, (ft):		
	□ outslope road, (ft):		□ outslope & remove ditch, (ft):		
	□ outslope & retain ditch, (ft):			□ inslope road, (ft):	
	□ rolling dip, (#):		□ remove berm, (ft):		
	□ ditch relief culvert, (#):		Length (ft):	□ rock road surface, (ft^2):	
	□ cross road drain, (#):		□ other:		
HEAVY EQUIPMENT EXCAVATION DATA	Total vol. excavated (yds^3):		Volume put back in (yds^3):		
	Volume removed (yds^3):		Volume stockpiled (yds^3):		
	Volume endhauled (yds^3):		Distance endhauled (yds^3):		
	Excavation production rate: (yds^3/hr):				
EQUIPMENT HOURS	Excavator:	Dozer:	Backhoe:	Grader:	Loader:
	Dump truck:		Labor:	Other:	
COMMENT(S) ON TREATMENT:					

[1] *Consultation with a licensed geotechnical specialist is required to estimate slide volumes and to evaluate or develop treatment options. The location of these features should be noted on the field form and on maps, but the inventory crew should not estimate the sediment volumes for calculation of cost-effectiveness.*

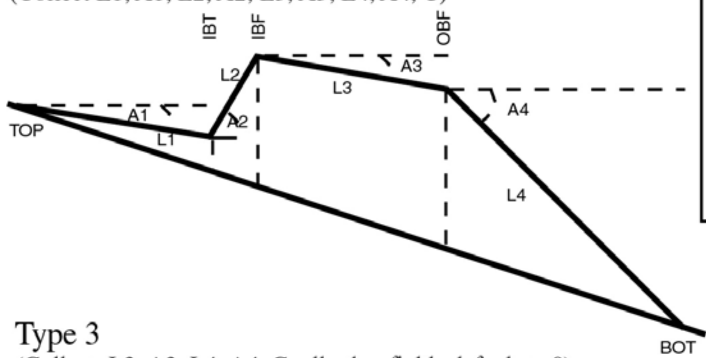
Type 1

(Collect L2, A2, L3, A3, L4, A4, C, all other fields default to 0)



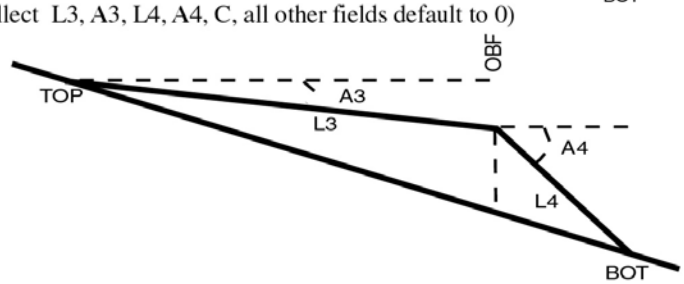
Type 2

(Collect L1, A1, L2, A2, L3, A3, L4, A4, C)



Type 3

(Collect L3, A3, L4, A4, C, all other fields default to 0)



Field data

Length of sediment fan (L1): _____ ft

Angle of sediment fan (A1): _____ degrees

Length of inboard fillslope (L2): _____ ft

Angle of inboard fillslope (A2): _____ degrees

Length of road bed (L3): _____ ft

Angle of road bed (A3): _____ degrees

Length of outboard fillslope (L4): _____ ft

Angle of outboard fillslope (A4): _____ degrees

Channel width (C): _____ ft

Sketch

APPENDIX X-B. INSTRUCTIONS FOR STREAM BANK INVENTORY DATA FORM

Use the *Stream Bank Inventory Data Form* in the assessment of past and potential erosion problems along stream channels, including determining their nature, cause, magnitude and treatment. Also, use it to identify and classify erosion problems along stream channels, to prioritize potential work sites, and to prescribe specific treatments aimed at protecting stream channels and fish habitat. *Part III* describes methodologies for stream channel classification, stream habitat inventories, and large woody debris and riparian inventories.

The *Stream Bank Inventory Data Form* provides a standardized protocol for evaluating stream-related erosion and identifying erosion control options. Also, use it to evaluate all types of riparian sediment sources. Where roads are in close proximity to a stream channel, there may be individual sites described by both the *Upslope Inventory Data Form* and the *Stream Bank Inventory Data Form*. If the proposed treatments are sufficiently different, retain both forms to describe the same location. However, do not duplicate recommended treatments and treatment times. Using the *Stream Bank Inventory Data Form*, field personnel can measure, describe and interpret landforms and erosion problems in a consistent and uniform manner. Enter the data collected into a database for analysis, leading to the preparation of a work plan for implementation.

General Information

Site Number: The identification number assigned to each site. This is a unique ID number for future reference. Also, write the Site Number on an aerial photo Mylar overlay. This number identifies each site in database searches. Use only numbers, not letters, for effective database searches.

Distance (ft.): Enter the stream channel distance, in feet, to the beginning of the site, from a known beginning point, usually a confluence, road, bridge, etc.

Date: Date of the survey.

Inspector(s): Record the names or initials of the inventory crew. List the data recorder first.

Watershed: Major drainage as described on the USGS 7.5 minute topographic map, for example Bull Creek.

Stream: As described on the USGS 7.5 minute topographic map.

Air Photo: List the flight line and frame number of the air photo used for mapping. Original field mapping information is contained on acetate or Mylar overlay for each of the aerial photos covering the assessment area.

Location (LB, RB, B): Enter the location of the site along the stream channel (“LB” = left bank, “RB” = right bank or “B” = both banks). Location is always determined when facing downstream.

Road Related: Check for erosion related to a road. If it is road-related, identify the corresponding road site number, if one exists, in the Comment(s) on Problem section.

Treat: Enter "Y" if recommended for treatment and "N" if not recommended for treatment.

Problem

Type: Check the appropriate type of problem at each locality. More than one problem may occur at a single site.

- debris slide: These slides may involve a substantial percentage of original bedrock and soil materials, or they may be composed of un-compacted spoil or road sidecast material. Debris slides move relatively fast and are typically shallow compared to larger deep-seated hillslope landslides. Stream side debris slides can range from small slope failures less than 10 yd^3 in volume, that are not visible on aerial photos and are only identifiable from a field inventory, to large landslides that can be easily identified from small scale aerial photos.
- debris torrent: Debris slides may or may not turn into fluid debris flows or torrents. Confinement, slope gradient and water content determine if a debris slide becomes a debris torrent. Torrents typically originate somewhere upslope or upstream and carry soil materials and organic debris to a hillslope or lower gradient stream channel where it is deposited.
- hillslope landslides of unknown depth: Usually cover relatively large areas with multiple scarp systems running through natural slopes and/or across roads and skid trails. Slow, deep-seated landslides characterized by emerging groundwater; leaning trees; active and inactive scarp systems; and episodic, seasonal movement from several feet to several hundred feet annually. Along a stream channel, a slow, deep-seated landslide may express itself as continuous length of raw, eroding stream bank, or as one or more shallow debris slides that are forming along the leading edge of the deeper slide mass. Some slides may not move annually. Most deep-seated landslides are difficult and expensive to control, if at all.
- torrent channel: The channel left after a debris torrent or mudflow has passed.
- bank erosion: The most common channel erosion problem encountered during a stream bank inventory. Bank erosion occurs wherever stream flow impinges against a soft stream bank. The erosion may occur in previously deposited alluvial materials (e.g., a terrace or flood plain surface) or along the base of the confining hillslope. Bank erosion may result in the development of debris slides where the hillslope erodes and undercuts. Bank erosion often occurs along the outside bend of a stream or river where stream flow diverts or deflects against a stream bank from woody debris (logs), boulders, a sediment deposit or other channel obstructions.
- LDA: Stream bank erosion related to a log debris accumulation.
- other: A problem other than those listed above. Describe in the Comment(s) on Problem Section.

Delivery: Check "past" for stream bank erosion that is unlikely to deliver additional sediment to the stream. Check "future" for a site currently delivering sediment to a stream channel. Check "both" for a site that contributed sediment in the past, and is likely to deliver sediment in the future.

Activity (A, IA, W): Enter “A” for an active feature such as a stream bank that is bare and erodes during each high flow period. Enter “IA” for a feature that appears inactive such as an older failure area that looks like it may no longer have the potential for further movement. Enter “W” for waiting if the feature is not currently active but shows substantial potential for future activity. An example of a waiting feature might include an unstable slope exhibiting scarps and leaning trees, but no indication of recent slope movement.

Age (Decade): Enter the estimated age, by decade, of the site. Age is typically determined using historical accounts, photos or other information to date the feature. Oftentimes use vegetation (leaning trees, recent sprouts, or vegetation size) to date features to within 10 years. A typical answer might be “1980’s”. For a continuously active feature, answer “1980 – 2000”.

Stream Bank Slope (%): The slope of the bank at the site. This is the slope of the natural ground. Stand at the base of the erosion feature and take a clinometer reading looking upslope.

Land Use: Check if there is direct evidence for some type of land use contributing to the occurrence or activity of the erosion site. Describe the land use associated with the erosion site in the Comment(s) on Problem section.

Undercut by Stream: Check for a bank undercut by the stream. It is important to identify an existing or potential debris slide that is threatening to develop because of stream bank erosion.

Past Erosion

Estimates of past erosion and sediment delivery volumes provide an indication of erosion activity along the stream channel. Calculate the volume of past bank erosion and debris slides, the two most common erosion features, by multiplying average linear dimensions of width, depth and length.

Width (ft): Estimate the average width of past erosion in feet. Width is the average thickness of bank cutting.

Depth (ft): Estimate the average depth of past erosion in feet. Depth is the bank height.

Length (ft): Estimate the length of past erosion in feet. For stream banks, measure length along the stream channel.

Volume (yd^3): Estimate the volume of past erosion (yd^3) at the site. Sketch the site on the back of the form, including the measurements, recorded on the data form. Volume (yd^3) = (width x depth x length)/27. Assume that stream bank erosion is 100% delivered to the stream.

Future Erosion

Estimate future erosion by applying reasonable rates or by calculating debris slide volume and delivery (page X-41).

Future Erosion Potential (H, M, L): Estimate the potential for future significant erosion at this site, based on observations. This is a probability estimate, not an estimate of how much erosion is likely to occur. Enter “H” or high, “M” for moderate or “L” for low. High means that erosion is very likely to occur at this site.

Width (ft): Estimate the width of future erosion in feet. Width is the average thickness of bank cutting.

Depth (ft): Estimate the depth of future erosion in feet. Depth is the bank height.

Length (ft): Estimate the length of future erosion in feet. For stream banks, measure length along the stream channel.

Volume (yd^3): Estimate the volume of future erosion. Volume (yd^3) = (width x depth x length)/27. For stream bank erosion, delivery is 100%.

Comment(s) on Problem

The comments for each site generally describe the nature of the erosion problem as well as important site characteristics. Include enough information to clearly depict the site and differentiate it from other nearby sites. Describe the features contained in the sketch map on the data form.

Treatment

Immediacy (H, M, L): Enter “H” for high if the work needs to get done immediately. Base this prioritization on the severity of the potential erosion, its volume, its predicted activity level and the sensitivity of the resources at risk.

Complexity (H, M, L): Estimate the difficulty of performing the recommended treatment. For example, simply moving a small boulder to prevent flow deflection enter “L” for low, whereas performing heavy equipment treatments in remote locations requiring road construction, endhauling or riprap enter “H” for high. Explain in the Comment(s) on Treatment section.

Equipment or Labor (E, L, B): Enter one of these treatment types. Treat the site using heavy equipment (E), manual labor (L) or both (B).

Equipment Access (E, M, D): Estimate the degree of difficulty of getting appropriate heavy equipment to the work site. Use “E” for easy, “M” for moderate, or “D” for difficult.

Local Materials: Check if material is available and sufficient for treating the site.

Import Materials: Check if material (e.g., boulder riprap) needs to be imported to treat the site. If needing local and imported materials, check both answers.

Treatment Options

Check each of the recommended treatments prescribed for a work site (*Part VII*). The treatments include:

Excavate Soil: Check if the treatment option is to excavate soil and remove it from the site. Landslide excavations would fall under this category of treatment. Enter width, depth and length of excavated material, in feet. Calculate excavated volume, in cubic yards.

Rock Armor / Buttress: Check for sites where armoring the stream bank with boulders will eliminate or reduce erosion of a stream bank or toe of a landslide. Specify both the size (diameter or ton) and surface area of rock armor (ft^2) needed.

Log Protection: Check for use of logs and other organic debris to protect stream banks from erosion. Identify the size (length and diameter) of the woody debris, the length of the bank protected, and the bank area to be covered (ft^2). In the Comment(s) on Treatment section identify the anchoring method (if any), the source of the woody materials (local or imported) and describe the placement method.

Remove Logs / Debris: Check if logs, boulders or other debris in the channel are deflecting flow and aggravating bank erosion and sediment delivery, identify this as a possible treatment. Include treatment details in the Comments on Treatment section.

Boulder Deflectors: Check for use of boulder deflectors to protect stream banks from erosion. Identify the number of boulder deflectors. Identify the yds^3 of boulder to necessary for each deflector.

Bio-engineering: Check for bio-engineering. Describe the bio-engineering methods to be used in the Comment(s) on Treatment section.

Plant Erosion Control: Check if recommending planting for erosion control. Revegetation with grasses is a short-term (1 to 2 years) treatment to control surface erosion. Plant woody species, such as willow and coyote brush, for intermediate term revegetation. Planting conifer or hardwood trees will provide for long-term erosion control and stability. Planting conifers reestablishes a large woody debris source. Describe the planting recommendations in the Comment(s) on Treatment section.

Riparian Restoration: Check if recommending manipulation of the riparian zone. An example of vegetation manipulation is thinning red alders and planting of conifers for long-term restoration of streamside vegetation (*Part XI*).

Area Planted: Measure or estimate the size of the area to plant or treat, in square feet. Identify the spacing, species composition, and number of trees to be planted in the Comment(s) on Treatment section.

Exclusionary Fencing: Check if the erosion control treatment is to exclude grazing animals from the stream or riparian zone. Identify the length of fencing needed, in feet.

Other: Check if recommending some other treatment. Fully describe in the Comment(s) on Treatment section.

Equipment Hours

If heavy equipment is needed to perform one or more different tasks, then list the individual times that go together to add up to total equipment time for each piece of equipment. In the Comment(s) on Treatment section, itemize equipment times by task for all equipment, which includes:

Excavator: Estimate the hours of excavator time needed for direct excavation, log and rock placement, and for other tasks at the work site. Include time needed for developing access for all equipment.

Dozer: Estimate the hours of tractor time needed for direct excavation work, winching or other work tasks.

Dump Truck: Estimate the hours of dump truck time needed for endhauling excess spoil to stable storage locations, or for importing rock armor other materials to the project.

Backhoe: Estimate the hours of backhoe time needed for direct excavation at the work site. Estimate time for travel or other miscellaneous tasks.

Labor: Estimate the hours of laborers needed to perform such tasks as rock placement, planting, seeding, mulching, winching, cabling, and providing assistance to heavy equipment.

Other: Describe other tasks or equipment not listed above, such as a front-end loader or lowboy.

Comment(s) on Treatment

Include details for equipment or manual labor treatments and logistics. Be as specific as is possible, and relate the comments to the sketch map.

STREAM BANK INVENTORY DATA FORM

GENERAL	Site no:	Distance (ft):	Date:	Inspector(s):
	Watershed:		Stream:	
	Air photo:	Location (LB, RB, B):	☐ road related	Treat (Y/N):
PROBLEM	Type:	☐ debris slide ☐ debris torrent ☐ hillslope failure of unknown depth and activity[2]		
		☐ torrent / debris flow channel[1] ☐ bank erosion ☐ LDA[3] ☐ other		
	Delivery:	☐ past ☐ future ☐ both		Apparent activity (A, IA, W):
	Age (decade):	Stream bank slope (%):		
	☐ land use	☐ undercut by stream		
PAST EROSION	Width (ft):	Depth (ft):	Length (ft):	Volume (yd^3):
FUTURE EROSION	Future erosion potential (H, M, L):	Width (ft):		Depth (ft):
	Length (ft):		Volume (yd^3):	

COMMENT(S) ON PROBLEM:

TREATMENT	Immediacy (H, M, L):	Complexity (H, M, L):		Equipment or labor (E, L, B):	
	Equipment access (E, M, D):	☐ local materials		☐ import materials	
TREATMENT OPTIONS	☐ excavate soil	Width (ft): Depth (ft):	Length (ft):	Volume (yds^3):	
	☐ rock armor/buttress	rock armor size (ft or ton):		rock armor area (ft^2):	
	☐ log protection	Log size: Length (ft): Bank length protected (ft):		Diameter (ft): Bank area to cover (ft^2):	
	☐ remove logs/debris			☐ boulder deflectors	
	Deflectors (#):	Deflector (yd^3):		☐ bio-engineering	
	☐ plant erosion control	☐ riparian restoration		Area planted (ft^2):	
	☐ exclusionary fencing	Length of fence (ft):		☐ other	
EQUIPMENT HOURS	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor: Other:

COMMENT(S) ON TREATMENT:

[1] A debris torrent is a mudflow that originates as a debris slide and then fluidizes (through the addition of water) and flows down a stream channel. It typically ends as a deposit or dam of poorly sorted sediment and woody debris in a lower gradient section of channel. The process is the mudflow; the evidence of that process is the scoured channel through which the flow passed, and the sediment and debris that is deposited at the end of the flow path. The activity level is typically that of the potential debris slide that would form the source of the mudflow. Note: if you have identified a potential hillslope debris slide, treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.

[2] If a failure of unknown type and depth is identified, treatment prescriptions must be developed in consultation with a licensed geotechnical specialist.

[3] LDA is a log jam or accumulation of logs and woody debris in the channel that is causing bank erosion or other erosion and sediment delivery problems.

SKETCH

APPENDIX X-C. CASE STUDY #1

1999 S.B. 271 WATERSHED ASSESSMENT FOR PARSONS CREEK, MENDOCINO COUNTY, CALIFORNIA

prepared by
Pacific Watershed Associates

for
The U.C. Hopland Research and Extension Center and the California Department of Fish and Game

Background

Parsons Creek is a fourth or fifth order, steelhead producing tributary to the Russian River located approximately five miles east of Hopland, California. The majority of the watershed is located within the boundaries of the U.C. Hopland Research and Extension Center (HREC). The watershed is approximately 6 mi^2 in area upstream from the western HREC boundary on the mainstem of Parsons Creek (Figure X-C-1). Parsons Creek watershed is primarily composed of oak woodlands, chaparral, and converted and natural grasslands, which are managed for sheep and cattle grazing and various academic research projects.

Parsons Creek has recently been recognized as a viable steelhead producing tributary to the Russian River region of Northern California. Since the early 1900's, much of the forested and chaparral portions of the watershed have been converted to pasture.

By 1952 roads had been pioneered to the upper reaches of the watershed and more intensive livestock management practices had been implemented. These initial roads essentially circled the entire watershed and provided access to the upper reaches of the watershed.

By 1963 the road network had expanded to access most of the mid-slope portions of the watershed and many of the roads built prior to 1952 had been partially rerouted or abandoned due to their deteriorating condition. This time frame exhibits the most extensive, post 1952 new road construction, in the Parsons Creek watershed and provided access to the more remote areas of the watershed.

Over the next 33 years the road network of the Parsons Creek watershed expanded by only a fraction of the existing network. Most of these new roads were built as connecters to the main roads which already provided access to the majority of the watershed.

Currently there are over 40 miles of dirt road managed by six separate landowners on the Parsons Creek watershed with the majority of the roads (36 miles) managed by HREC. Of the 36 miles of road most are currently maintained with only a small portion abandoned or permanently gated to restrict vehicle use. These roads are currently used predominantly for ranching and research and receive light traffic and minimal heavy vehicle use.

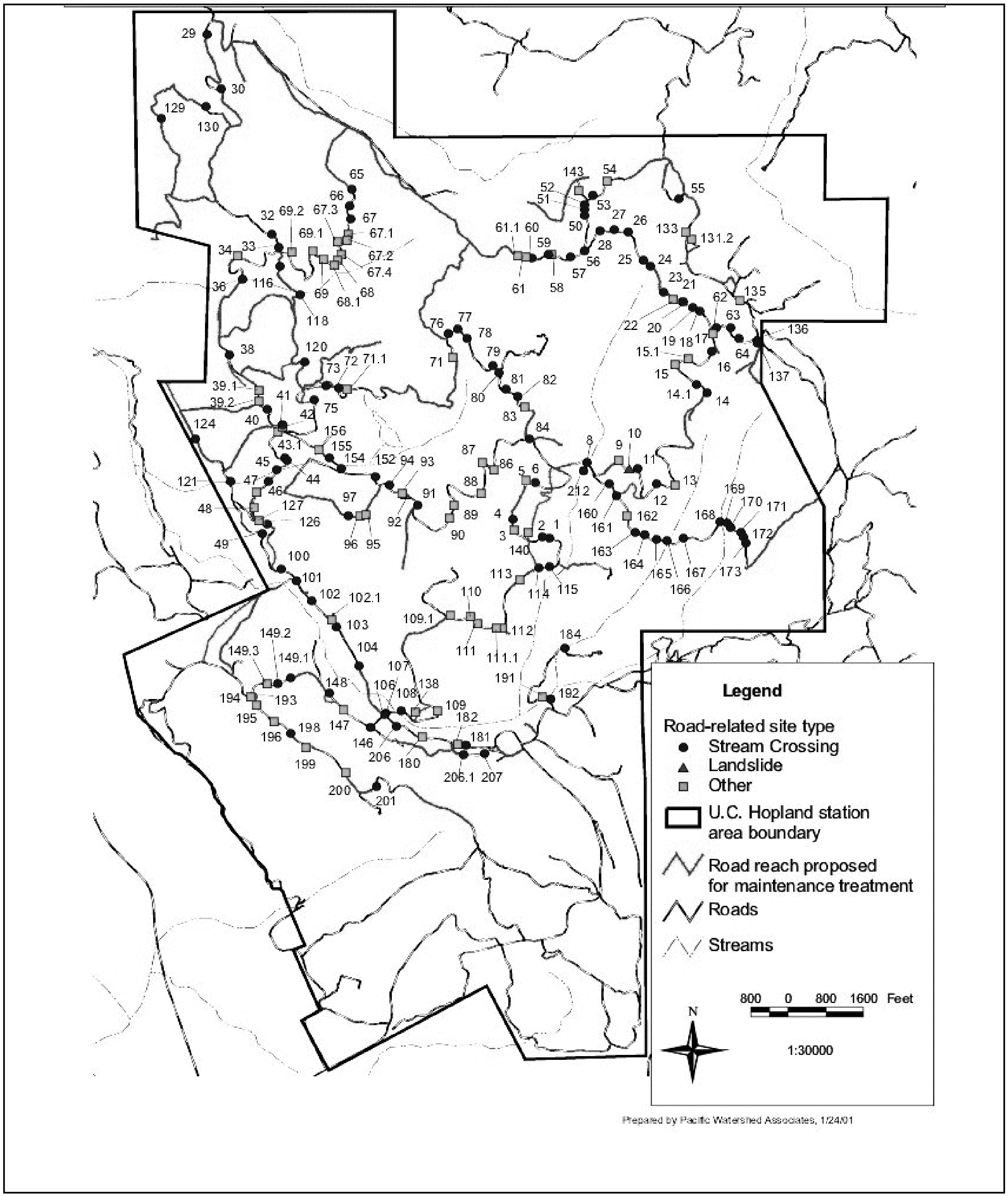


Figure X-C-1. Road-related sites with future sediment delivery, UC Hopland Experimental Station, Parsons Creek, Mendocino County, California.

Geologic setting of the Parsons Creek watershed
Sediments and rocks within the Parsons Creek watershed consist almost entirely of undifferentiated sedimentary and metamorphic rocks of the Franciscan formation. Most of the rocks found within the watershed have undergone severe post depositional deformation. This deformation ranges from pervasive fracturing to intense recrystallization. The most common rocks found in the watershed are Mesozoic marine sandstones, cherts and mudstones. These rocks tend to outcrop at higher elevations in the study area and where major tributary channels have cut through the overlying thick mantle of colluvium in the lower portions of the watershed. These rocks are extensively sheared and tend to erode into small fragments in all but the largest outcrops. Other rocks present in lesser amounts in the watershed include highly metamorphosed fragments of the oceanic lithosphere. These rocks vary in their degree of metamorphism and include greenschist and blueschist facies rocks. Metamorphic rocks rarely outcrop in the study area but tend to litter the tributary channels because of their resistence to erosion. The geology in the lower watershed is dominated by Quaternary alluvium and thick colluvial deposits, on the hillslopes. These deposits are interstratified where the hillsides are adjacent to the active and historic fluvial terraces.

The southern 60% of the Parsons Creek watershed is mantled by multiple, coalescing, mountain scale landslides. These landslides tend to dominate the topography resulting in large amphitheater shaped cavities in the upper headwall areas of the watershed and thick unconsolidated deposits in the lower sections. The slides are presently inactive, probably thousands of years old and are clearly unrelated to present land use activities and historic climatic fluctuations. Although the slides are inactive and old they do significantly influence the watershed drainage patterns and sediment sources for Parsons Creek. The toes of these large landslides appear to have merged and formed the southern margin of the lower Parsons Creek drainage, possibly dividing a historically more extensive drainage basin. Further up the hillside the deposits of the landslides mantle a high percentage of the southwest portion of the watershed. They vary in thickness but are typically less than 80 feet thick. These deposits consist of broken rock fragments, of various sizes and lithologies, jumbled within a matrix of heterogeneous sand and mud. This type of deposit is highly erodible and significantly affects the distribution of erosion within the watershed.

Parsons Creek watershed assessment and implementation
Perhaps the most important element needed for long term restoration of steelhead habitat, and the eventual recovery of salmonid populations in Parsons Creek, is the reduction of accelerated erosion and sediment delivery to the channel system. This summary report describes the watershed assessment and inventory process that was employed in the Parsons Creek Assessment.

It also serves as a prioritized plan-of-action for cost-effective erosion control and erosion prevention treatments for the Parsons Creek watershed. When implemented and employed in combination with protective land use practices, the proposed projects are expected to significantly contribute to the long term protection and improvement of salmonid habitat in the basin. The implementation of erosion control and erosion prevention work is an important step towards protecting and restoring watersheds and their anadromous fisheries (especially where sediment input is a limiting or potentially limiting factor to fisheries production, as is thought to be the case for Parsons Creek).

Project Description

The watershed assessment process consisted of two distinct project elements. These included: 1) a completed inventory of all future road-related sediment sources in the watershed, and 2) an inventory of sediment sources along the mainstem of Parsons Creek, totaling approximately 3.3 miles of stream channel in both the upper and lower watershed.

In the first phase of the Parsons Creek inventory project all roads within the study area were identified and age dated from historic aerial photography. Aerial photographs were analyzed to identify the location and approximate date of road construction. A composite map of the road systems in both lower and upper Parsons Creek was developed from GIS base maps produced by HREC. The base maps, updated through analysis of aerial photos, depict the primary road network in the watershed and show the location of sites with future erosion and sediment delivery to the stream system.

The second phase of the project involved a complete inventory of the road systems, selected hillslope areas and major stream channels. Technically, this assessment is neither an erosion inventory nor a road maintenance inventory. Rather, it is an inventory of sites where there is a potential for future sediment delivery to the stream system that could impact fish bearing streams in the watershed. All roads, including both maintained and abandoned routes, were walked and inspected by trained personnel and all existing and potential erosion sites were identified. Sites, as defined in this assessment, include locations where there is direct evidence that future erosion or mass wasting could be expected to deliver sediment to a stream channel. Sites of past erosion were not inventoried unless there was a potential for additional future sediment delivery. Similarly, sites of future erosion that were not expected to deliver sediment to a stream channel were identified but, were not included in the assessment.

In the final phase of the watershed assessment project, the mainstem of Parsons Creek was inventoried for bank erosion sites and stream side landslides. Data was collected on the location and volume of sediment sources along approximately 3.3 miles of the mainstem and the largest major tributary of Parsons Creek. Data collected included the type of erosional process, the current activity level, the volume of sediment delivery, and applicable treatment prescriptions at sites where work has been recommended. In addition, erosion sites were mapped on mylar overlays to the 1:14,000 scale aerial photos. Derivative site maps of the channel system were then produced (see channel maps in back of report).

Inventory Results

Approximately 36 miles of roads were inventoried for future sediment sources within the Parsons Creek watershed. Inventoried road-related erosion sites on HREC lands fell into one of two treatment categories: 1) upgrade sites – defined as sites on maintained open roads that are to be retained for access and management and 2) decommission sites – defined as sites exhibiting the potential for future sediment delivery that have been recommended for either temporary or permanent closure. Virtually all future road-related erosion and sediment delivery in the Parsons Creek watershed is expected to come from three sources: 1) the failure of road fills (landsliding), 2) erosion at or associated with stream crossings (from several possible causes), and 3) road surface and ditch erosion.

A total of 214 sites were identified with the potential to deliver sediment to streams. Of these, 180 sites were recommended for erosion control and erosion prevention treatment. Approximately 62% (n=131) of the sites are classified as stream crossings and 2% (n=6) as potential landslides (Figure X-C-1, Table X-C-1). The remaining 36% (n=77) of the inventoried sites consist of other sites which include ditch relief culverts and gullies.

Site Type	Number of sites or road miles	Number of sites or road miles to treat	Future delivery (yds^3)	Stream crossings w/a diversion potential (#)	Streams currently diverted (#)	Stream culverts likely to plug (plug potential rating = high or moderate)
Landslides	6	2	61	NA	NA	NA
Stream crossings	131	111	8,853	75	6	41
Other	77	67	1,356	NA	NA	NA
Total (all sites)	214	180	10,270	75	5	41
Persistent surface erosion[1]	14.94	14.94	14,608	NA	NA	NA
Totals	214	180	24,878	75	6	41

[1] Assumes 25' wide road prism and outbank contributing area, and 0.2' of road/cutbank surface lowering per decade.

Table X-C-1. Site classification and sediment delivery from all inventoried sites with future sediment delivery in the Hopland field station assessment area, Mendocino County, California.

Landslides Only those landslide sites with a potential for sediment delivery to a stream channel were inventoried. Potential landslides account for approximately 2% of the inventoried sites in the Parsons Creek assessment area (Figure X-C-1, Table X-C-1). Most of the potential landslide sites were found along roads where material had been sidecast during earlier construction and now show signs of instability. Potential landslides are expected to deliver nearly 61 yds^3 of sediment to Parsons Creek and its tributaries in the future. Correcting or preventing potential landslides associated with the road is relatively straightforward, and involves the physical excavation of potentially unstable road fill and sidecast materials.

There are a number of potential landslide sites located in the Parsons Creek assessment area that did not, or will not deliver sediment to streams. These sites were not inventoried using data sheets due to the lack of expected sediment delivery to a stream channel. They are generally shallow and of small volume, or located far enough away from an active stream such that sediment delivery is unlikely. For reference, all landslide sites were mapped on the mylar overlays of the aerial photographs, but only those with the potential for future sediment delivery were inventoried using a data sheet (Figure X-C-2).

ASAP____	**R O A D I N V E N T O R Y D A T A F O R M**						*Check_____*
GENERAL	**Site No:** ________	GPS:	Watershed:		CALWAA:		
Treat (Y,N):	Photo: ______	T/R/S:	Road #:		Mileage: ___________		
	Inspectors:_______	Date: ________	Year built:______	Sketch (Y):			
	Maintained	Abandoned	Driveable	Upgrade	Decommission	Maintenance	
PROBLEM	Stream xing	Landslide (fill, cut, hill)	Roadbed (bed, ditch, cut)	DR-CMP	Gully	Other	
	Location of problem (U, M, L, S)	Road related? (Y)	Harvest history: (1=<15 yrs old; 2=>15 yrs old) TC1, TC2, CC1, CC2, PT1, PT2, ASG, No		Geomorphic association: Streamside, I.G., Stream Channel, Swale, Headwall, B.I.S.		
LANDSLIDE	Road fill	Landing fill	Hillslope failure; depth unk	Cutbank	Already failed	Pot. Failure	
	Slope shape: (convergent, divergent, planar, hummocky)			Slope (%) ______	Distance to stream (ft) __________		
STREAM	CMP	Bridge	Humboldt	Fill	Ford	Armored fill	
	Pulled xing: (Y)	% pulled ______	Left ditch length (ft) ___________		Right ditch length (ft) ___________		
	cmp dia (in) ______	inlet (O, C, P, R)	outlet (O, C, P, R)	bottom (O, C,P, R)	Separated?		
	Headwall (in) ____	CMP slope (%) _____	Stream class (1, 2, 3)	Rustline (in)			
	% washed out ____	D.P.? (Y)	Currently dvted? (Y)	Past dvted? (Y)	Rd grade (%) ________		
	Plug pot: (H, M, L)	Ch grade (%) _____	Ch width (ft) _____	Ch depth (ft) ____			
	Sed trans (H, M, L)	Drainage area (mi^2) _________					
EROSION	E.P. (H, M, L)	Potential for extreme erosion? (Y, N)		Volume of extreme erosion (yds^3): 100-500, 500-1000, 1K-2K, >2K			
Past erosion…	Rd&ditch vol (yds^3) (yds^3)___________	Gully fillslope/hillslope (yds^3)__________	Fill failure volume (yds^3) _________	Cutbank erosion (yds^3)__________	Hillslope slide vol. (yds^3)	Stream bank erosion (yds^3)	xing failure vol (yds^3)
	Total past erosion (yds) __________	Past delivery (%) __________	Total past delivery (yds) _________	Age of past erosion (decade)_______	________________	__________	_________
Future erosion…	Total future erosion (yds) __________	Future delivery (%) __________	Total future delivery (yds) _________	Future width (ft) _________	Future depth (ft) ________	Future length (ft) _______	
TREATMENT	Immed (H,M,L)	Complex (H,M,L)	Mulch (ft^2)				
	Excavate soil	Critical dip	Wet crossing (ford or armored fill) (circle)		sill hgt (ft) ___	sill width (ft) _______	
	Trash Rack	Downspout	D.S. length (ft) ________	Repair CMP	Clean CMP		
	Install culvert	Replace culvert	CMP diameter (in) _____	CMP length (ft) _______			
	Reconstruct fill	Armor fill face (up, dn)	Armor area (ft^2) _______	*Clean or cut ditch*	*Ditch length (ft)* _________		
	Outslope road (Y)	*OS and Retain ditch (Y)*	*O.S. (ft)* ____________	*Inslope road*	*I.S. (ft)* _____	*Rolling dip*	*R.D. (#)* __
	Remove berm	*Remove berm (ft)* _____	*Remove ditch*	*Remove ditch (ft)* __________		*Rock road - ft^2* ________	
	Install DR-CMP	*DR-CMP (#)* ________	Check CMP size? (Y)	Other tmt? (Y)	No tmt. (Y)		
COMMENT ON PROBLEM:							
EXCAVATION VOLUME Total excavated (yds^3) _______ Vol put back in (yds^3) _______ Volume removed (yds^3) ________ Vol stockpiled (yds^3) _______ Vol endhauled (yds^3) _______ Dist endhauled (ft) ______ Excav prod rate (yds^3/hr) _______ **EQUIPMENT HOURS** Excavator (hrs) ________ Dozer (hrs) ________ Dump truck (hrs) ______ Grader (hrs) ________ Loader (hrs) ________ Backhoe (hrs) ________ Labor (hrs) _______ Other (hrs) ________ COMMENT(S) ON TREATMENT: Note: no excavation volume should be estimated for failure areas of unknown type and depth. Treatments must be prescribed in consultation with a licensed geotechnical specialist.							
	Vol stockpiled (yds^3)	Vol endhauled (yds^3) __	Dist endhauled (ft) ____	Excav prod rate (yds^3/hr) ________			
EQUIPMENT HOURS	Excavator (hrs) ________________	Dozer (hrs) ________	Dump truck (hrs) ______	Grader (hrs) _____ ________			
	Loader (hrs) _____	Backhoe (hrs) ______	Labor (hrs) _______	Other (hrs) ______			
COMMENT(S) ON TREATMENT:							

Figure X-C-2.Road Inventory Data Form.

Stream crossings One hundred thirty one (131) stream crossings were inventoried in the Parsons Creek assessment area including 96 culverted crossings, 9 unculverted fill crossings, 1 bridge, 1 armored fill, 2 washed out crossings, and 22 fords crossings. An unculverted fill crossing refers to a stream crossing with no formal drainage structure to carry the flow through the road prism. Flow is either carried beneath or through the fill, or it flows over the road surface, or it is diverted down the road to the inboard ditch. Most unculverted fill crossings are located at small Class III streams that exhibit flow only in the larger runoff events. If the crossing has been made temporary or decommissioned by removing the majority of the crossing fill, then these crossings are commonly known as “pulled” crossings.

Approximately 8,853 yds^3 of future road-related sediment delivery in the Parsons Creek assessment area could originate from erosion at stream crossings (Table X-C-1). This amounts to nearly 36% of the total expected future sediment delivery from the road system. The most common problems which lead to erosion at stream crossings include: 1) crossings with undersized culverts, 2) crossings with culverts that are likely to plug, 3) stream crossings with a diversion potential and 4) crossings with gully erosion at the culvert outlet. The sediment delivery from stream crossing sites is always classified as 100% because any sediment eroded at the crossing site is then delivered to the channel. Even sediment which is delivered to small ephemeral streams will eventually be delivered to downstream fish-bearing stream channels.

At stream crossings, the largest volumes of future erosion can occur when culverts plug or when potential storm flow exceeds the culvert capacity (i.e., the culvert is undersized or prone to plugging) and flood runoff spills onto or across the road. When stream flow goes over the fill, part or all of the stream crossing fill may be eroded. Alternately, when flow is diverted down the road, either on the road bed or in the ditch (instead of spilling over the fill and back into the same stream channel), the crossing is said to have a “diversion potential” and the road bed, hillslope and/or stream channel that receives the diverted flow can become deeply gullied or destabilized. These hillslope gullies can be quite large and can deliver significant quantities of sediment to stream channels. Alternately, diverted stream flow which is discharged onto steep, potentially unstable slopes can also trigger large hillslope landslides. Of the 131 stream crossings inventoried in the Parsons Creek watershed, 75 have the potential to divert in the future and 6 streams are currently diverted at stream crossing sites (Table X-C-1).

Three road design conditions indicate a high potential for future erosion at stream crossings. These include 1) undersized culverts (the culvert is too small for the 100 year design storm flow), 2) culverts that are prone to plugging with sediment or organic debris and 3) stream crossings with a diversion potential. The worst scenario is for the culvert to plug and the stream crossing to wash out or the stream to divert down the road in a major storm. These road and stream crossing conditions are easily recognizable in the field and have been inventoried in the Parsons Creek watershed.

Approximately 85% (n=111) of the stream crossings inventoried in the Parsons Creek assessment area will need to be upgraded for the roads to be considered “storm-proofed”. For example, 31% (n=41) of the existing culverts have a “moderate” to “high” plugging potential and nearly 57% of the stream crossings exhibit a diversion potential (Table X-C-1). Because most of the roads were constructed many years ago, culverted stream crossings are typically under-designed for the100 year storm flow. At stream crossings with undersized culverts or where there is a diversion potential, corrective prescriptions have been outlined on the data sheets and in the following tables. Preventative treatments include such measures as constructing critical dips (rolling dips) at stream crossings to prevent stream diversions, installing larger culverts wherever current pipes are under-designed for the 100 year storm flow (or where they are prone to plugging), installing culverts at the natural channel gradient to maximize the sediment transport efficiency of the pipe and ensure that the culvert outlet will discharge on the natural channel bed below the base of the road fill, installing debris barriers and/or downspouts to prevent culvert plugging and outlet erosion, respectively, and armoring the downstream fill face of the crossing to minimize or prevent future erosion.

***"Other"sites* –** A total of 77 other sites were also identified in the Parsons Creek assessment area. The main cause of existing or future erosion at these sites is surface runoff and uncontrolled flow from long sections of undrained road surface and/or inboard ditch. Uncontrolled flow along the road or ditch may affect the road bed integrity as well as cause gully erosion on the hillslopes below the outlet to ditch relief culverts. Road runoff is also a major source of fine sediment input to nearby stream channels. In the Parsons Creek assessment area, we measured approximately 14.94 miles of road surface and/or road ditch (representing 42% of the total inventoried road mileage) which currently drains directly to stream channels and delivers ditch and road runoff and sediment to stream channels. These roads are said to be hydrologically connected to the stream channel network. When these roads are being maintained and used for ranch access, they may represent a potentially important source of chronic fine sediment delivery to the stream system.

We estimate 1,356 yds^3 of sediment will be delivered to streams from the 77 other specific sites inventoried (Table X-C-1). From the 14.94 miles of connected road segments, we calculated over 14,608 yds^3 of sediment will be delivered to stream channels in the Parsons Creek watershed over the next 10 years if no efforts are made to change road drainage patterns. This will occur through a combination of 1) cutbank erosion delivering sediment to the ditch triggered by dry ravel, rainfall, freeze-thaw processes, cutbank landslides and brushing/grading practices, 2) inboard ditch erosion and sediment transport, 3) mechanical pulverizing and wearing down of the road surface, and 4) erosion of the road surface during wet weather periods.

Treatment Priority

An inventory of future or potential erosion and sediment delivery sites is intended to provide information which can guide long range transportation planning, as well as identify and prioritize erosion prevention, erosion control and road decommissioning activities in the watershed. Not all of the sites that have been recommended for treatment have the same priority, and some can be treated more cost-effectively than others. Treatment priorities are evaluated on the basis of several factors and conditions associated with each potential erosion site:

- the expected volume of sediment to be delivered to streams (yds^3),
- the potential or likelihood for future erosion (high, moderate, low),
- the urgency of treating the site (treatment immediacy – high, moderate, low),
- the ease and cost of accessing the site for treatments, and
- recommended treatments, logistics and costs.

Treatments

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of both potential sources of road-related sediment delivery and road maintenance sites with no potential sediment delivery. Table X-C-2 and Figure X-C-3 outline the treatment priorities for all 173 inventoried sites with future sediment delivery that have been recommended for treatment in the Parsons Creek watershed assessment area. Of the 173 sites with future sediment delivery, 26 sites were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 4,520 yds^3. Eighty two (82) sites were listed with a moderate or moderate-low treatment immediacy and account for nearly 4,206 yds^3 of future sediment delivery. Finally, 65 sites were listed as having a low treatment immediacy with approximately 1,544 yds^3 of future sediment delivery.

Treatment Priority	**Upgrade sites (# and site #)**	**Decommission sites (# and site #)**	**Problem**	**Future sediment delivery (yds^3)**
High	**7** (site #: 41, 86, 104, 118, 148, 166, 172)	**0**	6 stream crossings, 1 other	747
High Moderate	**19** (site #: 4, 13, 14, 24, 25, 36, 40, 43, 44, 47, 64, 72, 75, 91, 94, 102, 110, 113, 163)	**0**	14 stream crossings, 5 other	3,773
Moderate	**29** (site #: 8, 10, 15, 19, 20, 22, 33, 34, 43.1, 48, 65, 68, 69, 80, 82, 88, 92, 97, 111, 116, 124, 131.2, 149.1, 160, 168, 170, 171, 181, 199)	**1** (site #: 127)	17 stream crossings, 2 landslides, 11 other	2,055
Moderate Low	**53** (site #: 1, 2, 5, 6, 9, 11, 12, 17, 21, 23, 26, 28, 29, 30, 38, 42, 45, 46, 49, 52, 54, 56, 57, 59, 62, 63, 68.1, 71.1, 76, 77, 79, 81, 83, 84, 93, 101, 106, 109, 109.1, 114, 121, 129, 149.2, 149.3, 152, 154, 155, 161, 164, 165, 167, 195, 206)	**4** (site #: 126, 133, 138, 212)	42 stream crossings, 15 other	2,151
Low	**65** (site #: 3, 14.1, 15.1, 16, 18, 27, 32, 39.1, 39.2, 42.1, 50, 51, 53, 55, 58, 60, 61, 61.1, 66, 67, 67.1, 67.2, 67.3, 67.4, 69.1, 69.2, 71, 73, 78, 87, 89, 90, 95, 96, 100, 102.1, 103, 107, 108, 111.1, 112, 115, 120, 130, 135, 136, 137, 143, 146, 147, 156, 162, 169, 173, 180, 182, 184, 191, 192, 193, 194, 196, 198, 200, 201,)	**2** (site #: 140, 207)	32 stream crossings, 35 other	1,544
Total	**173**	**7**	**180**	**10,270**

Table X-C-2. Treatment priorities for all inventoried sediment sources in the Hopland field station assessment area, Mendocino County, California.

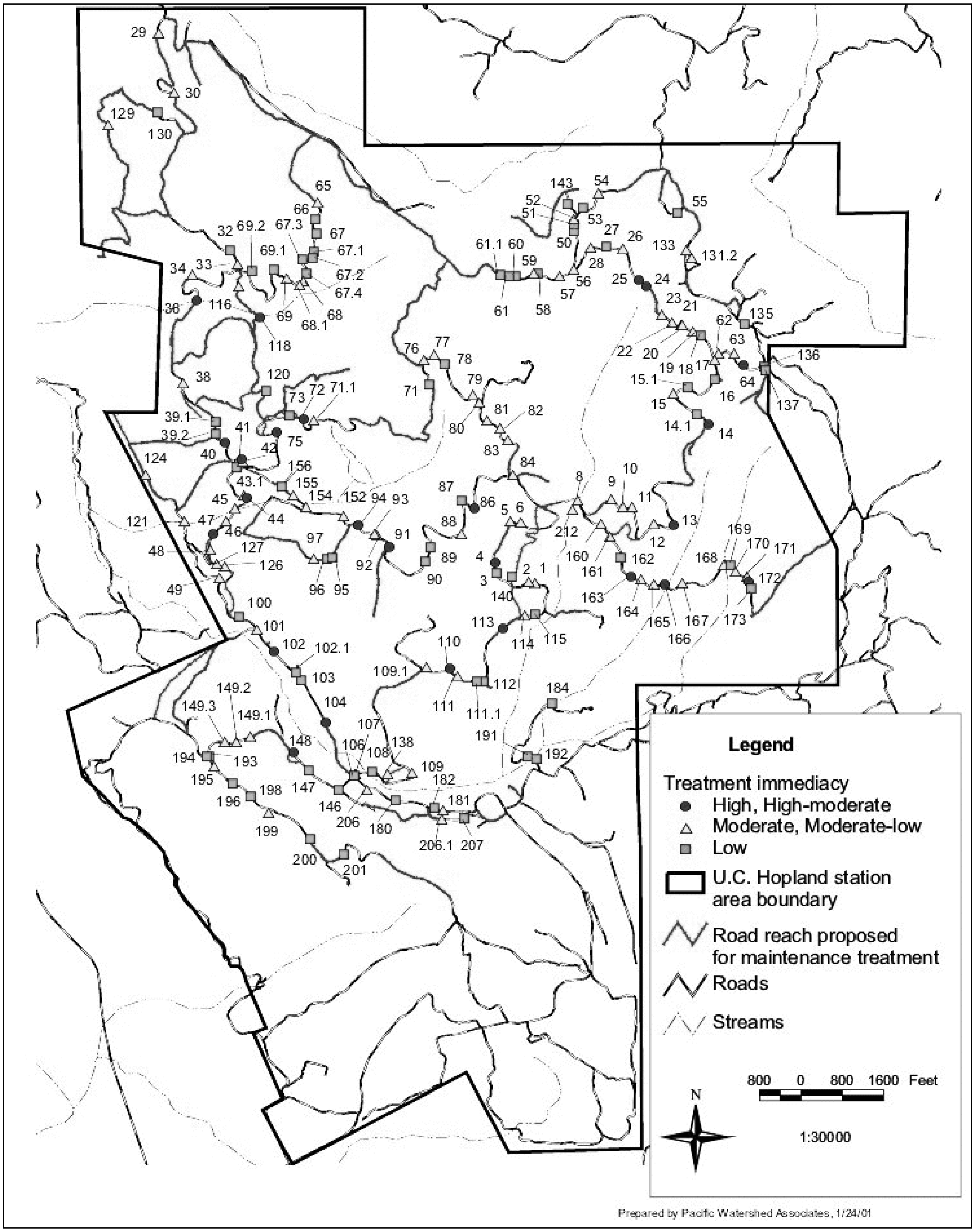


Figure X-C-3. Treatment Immediacy (priority) for inventoried road-related sites, UC Hopland Experimental Station, Parsons Creek, Mendocino County, California.

Table X-C-3 summarizes the proposed treatments for sites inventoried on all roads in the Parsons Creek assessment area, including both the upper and lower watershed areas. These prescriptions include all upgrading measures. The database, as well as the field inventory sheets, provide details of the treatment prescriptions for each site. Most treatments require the use of heavy equipment, including an excavator, tractor, dump truck, grader and/or backhoe. Some hand labor is required at sites needing new culverts, downspouts, flared inlets or culvert repairs, trash racks or for applying seed, plants and mulch following ground disturbance activities. A total of 71 critical rolling dips have been recommended to prevent future stream diversions at road crossings (Table X-C-3). A total of 89 culverts are recommended for installation at stream crossings. Eighty-five will replace existing undersized or rotten stream crossing culverts with culverts sized for the 100 year storm, and 4 culverts are recommended for installation at currently unculverted small streams.

It is estimated that erosion prevention work will require the excavation and disposal of approximately 6,171 yds^3 at 22 sites. Approximately 98% of the volume excavated is associated with upgrading or properly excavating stream crossings and nearly 2% of the volume is proposed for excavating potentially unstable road fills (landslides). Most of the stream crossing volume is associated with removal of channel stored sediment above the current culvert inlet. A total of 45 yds^3 of 0.5 to 1.5 foot diameter, mixed and clean rip-rap sized rock will be needed to construct eight proposed armored wet crossings (Table X-C-3). We have recommended 232 rolling dips be constructed at selected locations along the road, at spacings dictated by the steepness of the road. A minimum of twenty five (25) new ditch relief culverts are recommended to be installed along the road routes inventoried. Some proposed rolling dips can be replaced with additional ditch relief culverts, but the total cost for additional ditch relief culverts are not included here.

Equipment Needs and Costs

Treatments for the 180 sites identified with future sediment delivery in the Parsons Creek assessment area will require approximately 312 hours of excavator time and 454 hours of tractor time to complete all prescribed upgrading, road closure, erosion control and erosion prevention work (Table X-C-4). Excavator and tractor work is not needed at all the sites that have been recommended for treatment and, likewise, not all the sites will require both a tractor and an excavator. Approximately 8 hours of dump truck time has been listed for work in the basin for endhauling excavated spoil from stream crossings and at unstable road and landing fills where local disposal sites are not available. Approximately 358 hours of labor time is needed for a variety of tasks such as installation or replacement of culverts, installation of debris barriers and downspouts.

<u>Estimated costs for erosion prevention treatments</u> – Prescribed treatments are divided into two components: a) site specific erosion prevention work identified during the watershed inventories, and b) control of persistent sources of road surface, ditch and cutbank erosion and associated sediment delivery to streams. The total costs for road-related erosion control at sites with future sediment delivery is estimated at approximately $331,345 for an average cost-effectiveness value of approximately $13.31 per cubic yard of sediment prevented from entering Parsons Creek and its tributaries (Table X-C-5).

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	71	To prevent stream diversions	Outslope road and remove ditch	97	Outslope and remove ditch for 37,342 feet of road to improve road surface drainage
Install CMP	4	Install a CMP at an unculverted fill	Outslope road and retain ditch	8	Outslope and retain ditch for 1,840 feet of road to improve road surface drainage
Replace CMP	85	Upgrade an undersized CMP	Install rolling dips	232	Install rolling dips to improve road drainage
Excavate soil	23	Typically fillslope & crossing excavations; excavate a total of 7,019 yds^3	Cross road drain	2	Install cross road drains to improve road drainage
Down spouts	5	Installed to protect the outlet fillslope from erosion	Remove berm	13	Remove 2,815 feet of berm to improve road surface drainage
Wet crossing	8	Install rocked ford and armored fill crossing using 45 yds^3 rip-rap	Install ditch relief CMP	25	Install ditch relief culverts to improve road surface drainage
Install flared inlet	2	Install flared inlet to increase intake capacity	Clean/cut ditch	4	Clean/cut 618 feet of ditch
Clean CMP	1	Remove debris and/or sediment from CMP inlet	Rock road surface	323	Rock road surface using 3,654 yds^3 road rock (includes road rock for 14 site specific locations, and post installation for 214 rolling dips, 75 stream crossings and 20 ditch relief culverts
Inslope road	1	Inslope 210 feet of road to improve road drainage	Other	10	Miscellaneous treatments
Remove ditch	1	Remove 130 feet ditch to improve road drainage	No treatment recommended	34	

Table X-C-3. Recommended treatments along all inventoried roads in the Hopland field station assessment area, Mendocino County, California.

Overall site specific erosion prevention work*:* Equipment needs for site specific erosion prevention work at sites with future sediment delivery are expressed in the database, and summarized in Table X-C-4 and Table X-C-5, as direct excavation times, in hours, to treat all sites. These hourly estimates include only the time needed to treat each of the sites, and do not include travel time between work sites, times for basic road surface treatments that are not associated with a specific site, or the time needed for work conferences at each site. These additional times are accumulated as logistics and must be added to the work times shown in Table X-C-4 to determine total equipment costs as shown in Table X-C-5.

Treatment Immediacy	No. of Sites	Excavated Volume (yds^3)	Excavator (hrs)	Tractor (hrs)	Dump Trucks (hrs)	Backhoe (hrs)	Labor (hrs)
High, High/Moderate	26	4,920	151	173	0	23	81
Moderate, Moderate.Low	87	946	124	201	8	154	194
Low	67	305	37	80	0	69	83
Total	**180**	**6,171**	**312**	**454**	**8**	**246**	**358**

Table X-C-4. Estimated heavy equipment and labor requirements for treatment of all inventoried sites with future sediment delivery, Hopland field station assessment area, Mendocino County, California.

The costs in Table X-C-5 are based on a number of assumptions and estimates, and many of these are included as footnotes to the table. The costs provided are assumed reasonable if work is performed by outside contractors, with no added overhead for contract administration and pre- and post-project surveying. Movement of equipment to and from the site will require the use of low-boy trucks. The majority of treatments listed in this plan are not complex or difficult for equipment operators experienced in road upgrading and road decommissioning operations on forest lands. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended treatments conform to guidelines described in *The Handbook for Forest and Ranch Roads* (PWA 1994) for the California Department of Forestry, Natural Resources Conservation Service and the Mendocino County Resource Conservation District.

Table X-C-5 lists a total of 225 hours for supervision time for detailed pre-work layout, project planning (coordinating and securing equipment and obtaining plant and mulch materials), on-site equipment operator instruction and supervision, establishing effectiveness monitoring measures, and post-project cost-effectiveness analysis and reporting. It is expected that the project coordinator will be on-site full time at the beginning of the project and intermittently after equipment operations have begun.

Stream channel surveys

Approximately 3.3 miles of stream channel, extending from the private property boundary in the lower basin to the upper reaches in grasslands and oak forests of the upper watershed, was inventoried to identify past and current sediment sources (Figure X-C-1). The goals of the channel assessment were three fold: 1) to evaluate the general condition of stream banks throughout the reach, 2) to document the dominant processes and extent of sediment production along stream side slopes, 3) to determine locations where effective stream bank protection or re-vegetation efforts could be employed to reduce erosion and promote long term recruitment of large organic debris to the main channel of Parsons Creek.

Cost Category[1]		**Cost Rate[2] ($/hr)**	**Estimated Project Times**			**Total Estimated Costs[5] ($)**
			Treatment[3] (hours)	**Logistics[4] (hours)**	**Total (hours)**	
Move-in; move-out[6] (Lowboy expenses)	Excavator	95	4	—	4	380
	D-5 tractor	70	4	—	4	280
Heavy Equipment requirements for site specific treatments	Excavator	115	312	94	406	46,690
	D-5 tractor	85	454	136	590	50,150
	Dump Truck	60	8	2	10	600
	Backhoe	65	246	74	320	20,800
Heavy Equipment requirements for road drainage treatments	Excavator	115	60	18	78	8,970
	D-5 tractor	85	101	30	131	11,135
	Backhoe	65	50	15	65	4,225
	Grader	85	65	20	85	7,225
Laborers[7]		20	487	146	633	12,660
Rock Costs: (includes trucking for 3,654 yds^3 of road rock and 45 yds^3 of rip-rap sized rock)						62,883
Culvert materials costs (750' of 18', 2,110' of 24", 820' of 30", 400' of 36", 280' of 42", 200' of 48", 130' of 54", 60' of 60", 190' of 72". Costs included for couplers and flared inlets)						91,735
Mulch, seed and planting materials for 4.3 acres of disturbed ground[8]						2,358
Layout, Coordination, Supervision, and Reporting[9]						11,254
Total Estimated Costs						**$ 331,345**
Overall project cost-effectiveness: $ 13.31 spent per cubic yard saved						

[1]Costs for tools and miscellaneous materials have not been included in this table. Costs for administration and contracting are variable and have not been included. Costs and dump truck time (if needed) for re-rocking the road surface at sites where upgraded roads are outsloped are not included.
[2] Costs listed for heavy equipment include operator and fuel. Costs listed are estimates for favorable local private sector equipment rental and labor rates.
[3] Treatment times include all equipment hours expended on excavations and work directly associated with erosion prevention and erosion control at all the sites.
[4] Logistic times for heavy equipment (30%) include all equipment hours expended for opening access to sites on maintained and abandoned roads, travel time for equipment to move from site-to-site, and conference times with equipment operators at each site to convey treatment prescriptions and strategies. Logistic times for laborers (30%) includes estimated daily travel time to project area.
[5] Total estimated project costs listed are averages based on private sector equipment rental and labor rates.
[6] Lowboy hauling for tractor and excavator, 4 hours round trip for the following areas within Parsons Creek. Costs assume 2 hauls for two pieces of equipment (one to move in and one to move out).
[7] Additional labor hours are included for the following: 1) 54 hours for seeding and mulching activities and 2) 75 hours for ditch relief culvert installation.
[8] Seed costs equal $6/pound for erosion control seed. Seed costs based on 50# of erosion control seed per acre. Straw costs include 50 bales required per acre at $5 per bale. Sixteen hours of labor are required per acre of straw mulching.
[9] Supervision time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, supervision of labor work and post-project documentation and reporting). Supervision times based on 30% of the total excavator time plus 1 week prior and 1 week post project implementation.

Table X-C-5. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on all inventoried sites with future sediment delivery in the Hopland field station, Parsons Creek, Mendocino County, California.

Aerial photos (1:14,000) were used as a base map to record stream channel observations. The channel survey started at the downstream boundary of the HREC ownership and extended upstream through HREC properties (Figure X-C-1). The details of the channel mapping data is shown in three separate maps covering the lower to upper basin and three additional maps covering the same area but with the erosional sites sorted by treatment priority. The individual channel maps depict the location of debris landslides, deep-seated landslides, and sites of bank erosion. Bank erosion sites exceeding 10 yds^3 and debris landslides exceeding 50 yds^3 were quantified and described using the stream channel inventory data forms (Figure X-C-4). The location of bank erosion sites less than 10 yds^3 and debris landslides less than 50 yds^3 are shown on the strip maps, but have not been further described.

STREAM CHANNEL INVENTORY DATA FORM						
General	Site #:	Date:	Mappers:	Air Photo:	Watershed:	Stream:
	Bank (L/R):	Treat?(Y)				
Problem	Debris Slide	Hillslope failure of unknown depth and activity	Torrent channel	Bank erosion	Log jam:	Other:
	Past, future, both	Activity (A, W, IA):	Age (decade):	Hillslope (%)	Land use:	Undercut (Y)
Erosion	Past width:	Past depth:	Past length:	Past vol:	Past del (%)	Past yld (yds):
E.P.:	Future Width	Future depth:	Future length:	Future vol:	Fut del (%)	Fut yld (yds):
Treatment	Immed: (H, M, L)	Complexity: (H, M, L)	Eqpt or labor (E, L, B):		Access: (Easy, Moderate, Hard)	
	Excavate soil	Rock armor/buttress	Log protection	Remove logs/debris	Plant	Other
Hours:	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor:	Other:
Problem:						
Treatment:						

Figure X-C-4. Stream Channel Inventory Data Form.

Besides documenting locations of past and current erosion and landsliding along the channel, efforts were made to document other important channel features. These included:

- the location of fish habitat structures and concentrations of large woody debris;
- the location of log jams;
- stream gradients, and
- the location of tributary stream junctions

All information collected in the field was compiled into a catalog of channel features by station number to assist in future channel surveys. The six channel strip maps summarize the data that was collected for the 3.3 miles of inventoried stream channel.

Channel survey results

A total of 117 sites of significant erosion were identified during the stream channel surveys. A total of 60 sites of past and active bank erosion were mapped along the lower reaches and main tributary to Parsons Creek (Table X-C-6). Bank erosion sites averaged 342 yds^3 in volume.

Stream side debris slides have generated over twice as much sediment delivery to the channel system than did bank erosion in the Parsons Creek watershed. Fifty seven debris slides in the >50 yds^3 class averaged nearly 1218 yds^3 in volume and accounted for 39,631 yds^3 of sediment delivery (Table X-C-6). Some of these debris slides were associated with roads near the inner gorge of Parsons Creek.

Reach	Reach Length (feet)	Bank Erosion site >10 yds^3			Debris slides >50 yds^3		%
		No.	Length (ft)	Delivery (yds^3)	No.	Delivery (yds^3)	BE/DS
Mainstem[1]	7,628	26	5,236	4,278	4	2,749	87/13
Largest Tributary of Parsons Creek	9,708	34	3,267	12,164	53	37,382	39/61
Total	17,336	60	8,503	16,442	57	40,131	----

[1] Sites 182.1 and 183 were quantified on the road erosion inventory but contributed an additional 19,925 yds^3 to the stream channel which could be added to the total Mainstem past erosion volume.

Table X-C-6. Bank erosion and small stream side debris slides along inventoried stream reaches, Parsons Creek, Mendocino County, California.

When evaluating erosion sites on Parsons Creek it is clear that the dominant erosion processes change from the mainstem to the main tributary. On the mainstem, where stream gradients are low, the channel is unconfined and meandering, and fluvial terraces are the dominant sediment source, bank erosion is the most common type of erosional process. On the main tributary where gradients are high, the channel is confined, and thick heterogeneous, low strength colluvial sediments are the dominant sideslope material, debris landsliding is the most common erosional process (Table X-C-6). Thirty seven sites have been identified as treatable along the mainstem and main tributary to Parsons Creek. These sites have been sorted by treatment priority and are summarized in (Table X-C-7).

Of the treatable sites, 2 are high priority, 4 are high moderate priority, 14 are moderate priority, 6 are moderate low priority, and 11 are low priority. Treating erosional sites along Parsons Creek is not as straight forward as treating erosion related to roads. Most of the sites of future erosion along Parsons Creek are in remote locations with little to no access by road. In most cases pioneering a road to allow heavy equipment access may generate more sediment and long term maintenance costs than is justifiable by either a sediment savings cost analysis or sediment production standpoint. The two high treatment priority sites are along the mainstem of Parsons Creek and have been deemed high priority due to their proximity to, and possible effect on, main access roads managed by HREC. These two sites do not have high future sediment delivery and are therefore not very cost-effective to treat but they are easily accessible and should be monitored for increased activity.

Treatment Priority	Upgrade sites (# and site #)	Problem	Future sediment delivery (yds^3)
High	**2** (site #: 312, 314)	2 bank erosion	94
High Moderate	**4** (site #: 305, 316, 320, 416)	3 bank erosion, 1 other	1,715
Moderate	**14** (site #:300, 302, 306, 308, 309, 313, 326, 327, 333, 344, 360, 361, 364, 381)	12 bank erosion, 2 debris landslides	2,076
Moderate Low	**6** (site #: 301, 304, 307, 311, 315, 362)	5 bank erosion, 1 debris landslide	77
Low	**11** (site #: 310, 321, 323, 339, 343, 348, 351, 351.1, 354, 369, 386)	4 bank erosion, 7 debris landslides	114
Total	**37**	**26 bank erosion 10 debris landslides 1 other**	**5,786**

Table X-C-7. Treatment priorities for treatable sediment sources along inventoried stream reaches in the Hopland field station assessment area, Mendocino County, California.

Sediment source summary

We extrapolated the data collected in the stream channel inventory to the other main tributaries of Parsons Creek to try to come up with an estimate of total past streamside erosion within the HREC management boundary. This was done by determining the ratio of air photo identified sites to sites actually documented during the stream inventory along the main tributary. Using this data and the known ratio of bank erosion sites to debris slides on the main tributary an estimate of the number of unidentified erosional sites for the other 4 tributaries was determined. These estimated erosional sites were then multiplied by the average erosion volume of non-air photo identified bank erosion (221 yds^3) and debris landslides (421 yds^3) respectively on the surveyed main tributary. The total estimated erosional volume of unidentified slides for the four un-inventoried tributaries was then quantified (Table X-C-8). Based on our field observations, this probably represents a maximum erosion volume. Reconnaissance of the un-surveyed tributaries suggests that the density of sites is lower for the four un-surveyed tributaries than the main tributary. Furthermore the thickness of the colluvial deposits, which are the main source of sediment along the main tributary, is thinner to the north especially in the upper portions of tributaries three and four. Other factors including stream size, road influence, conversion from chaparral to pasture, grazing practices, and other management activities most likely influence the number and size of erosion sites along the four un-surveyed tributaries.

Reach	Reach length	Air photo sites	Estimated volume of air photo identified sites (yds^3)	Estimated volume of non-visible sites (yds^3)	Total estimated erosional volume (yds^3)
Mainstem	7,628	2	460	6,567[1]	7,027
Largest Tributary of Parsons Creek	9,708	29	37,981	11,565	49,546
Tributary 1	9,700	7	4,181	5,565	9,746
Tributary 2	6,934	6	7,144	4,452	11,596
Tributary 3	8,321	5	2,679	3,760	6,439
Tributary 4	8,321	6	6,027	4,452	10,479
Total	**50,612**	**57**	**58,472**	**36,361**	**94,833**

[1]Mainstem Parsons Creek is alluvial and has abundant bank erosion sites that are not identifiable on air photos

Table X-C-8. Estimated past sediment delivery from air photo interpretation and data extrapolation for the mainstem and five largest tributaries of Parsons Creek, Mendocino County, California.

Table X-C-9 summarizes the estimated past sediment delivery to the Parsons Creek Watershed from road and streamside erosion for the last 30 years. Of a total of 201,771 yds^3 of estimated past erosion 43% is road related and 57% is streamside sediment delivery. The fact that most of the streamside sediment delivery occurred along reaches of stream bounded by thick, highly erodible, colluvial deposits suggests that the erosion is natural, although some channel incision from road related runoff and channel bed aggradation is possible. Surface erosion from converting chaparral to pasture is evident from our field observations but is difficult to quantify and has not been considered in this study.

Conclusion

The expected benefit of completing the erosion control and prevention planning work lies in the reduction of long term sediment delivery to Parsons Creek, an important steelhead stream. A critical first-step in the overall risk-reduction process is the development of a watershed transportation analysis and plan. In developing this plan, all roads in an ownership or sub-watershed are considered for either decommissioning or upgrading, depending upon the risk of erosion and sediment delivery to streams, and the future use levels. Not all roads are high risk roads and those that pose a low risk of degrading aquatic habitat in the watershed may not need immediate attention. It is therefore important to rank and prioritize roads in each sub-watershed, and within each ownership, based on their potential to impact downstream resources, as well as their importance to the overall transportation system and to management needs.

Good land stewardship requires that roads either be upgraded and maintained, or intentionally closed (put-to-bed). The old practice of abandoning roads, by either installing barriers to traffic (logs, tank traps or gates) or simply letting them naturally revegetate, is no longer considered acceptable. These roads typically continue to fail and erode for decades following abandonment.

Site Type	Number of sites or road miles	Past erosion (yds^3)	% Total
Total road inventory sites (all sites)[1]	214	43,189	21
Estimated Persistent past surface erosion[2]	14.94	43,824	22
Quantified stream past erosion sites[3]	117	76,498	38
Estimated stream past erosion sites	59	38,260	19
Totals	**390**	**201,771**	**100**

[1] The road inventory documented 63,114 yds^3 of past erosion. At sites 182.1 and 183 the past erosion volume totaled 19,925 yds^3 but both features are non-road related debris slides (i.e. the road had little to no influence on the slides). Subtracting the 19,925 yds^3 of past erosion equals 43,189 yds^3 of past road related sediment delivery.
[2] Assumes 25' wide road prism and cutbank contributing area, and 0.2' of road/cutbank surface lowering per decade for all existing roads for 3 decades. This is the current road connectivity, we have no way of estimating past connectivity.
[3] The channel surveys documented 56,573 yds^3 of past sediment delivery (Table X-C-6). We have added the volume of sediment delivery from sites 182.1 and 183 of the road survey (19,925) to the channel survey to total 75,498 yds^3

Table X-C-9. Estimated total past sediment delivery for Parsons Creek Watershed over the last 30 years, Hopland field station assessment area, Mendocino County, California.

Currently unused, unmaintained and/or abandoned roads in Parsons Creek were evaluated for either upgrading or permanent or temporary decommissioning. Road upgrading consists of a variety of techniques employed to erosion-proof and to storm-proof a road and prevent unnecessary future erosion and sedimentation. Erosion-proofing and storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff, as well as a large storm event without failing or delivering excessive sediment to the stream system. All roads in Parsons Creek have been prescribed for upgrading. The goal of road upgrading is to strictly minimize the contributions of fine sediment from roads and ditches to stream channels, as well as to minimize the risk of serious erosion and sediment delivery when large magnitude, infrequent storms and floods occur.

A plan was submitted in May to the California Department of Fish and Game to implement suggested sediment reduction upgrades for the high, high moderate, and moderate treatment priority sites within the HREC property boundary. As of February 1, 2001 it is our understanding that the proposal has been funded and implementation work will be begin as soon as the funding becomes available and CEQA is completed.

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APPENDIX X-D. CASE STUDY #2

2002 – 2003 REDWOOD CREEK SB 271

ROAD DECOMMISSIONING PROJECT FOR 1300 ROADS
Contract # P0110305

for

The Redwood Creek Watershed,
Humboldt County, California

prepared for

PCFWWRA,
California Department of Fish and Game,
and Simpson Resource Company

by

Pacific Watershed Associates
Arcata, California
(707) 839-5130
January 2004

PROJECT OVERVIEW
SB 271 Road Decommissioning Project
Redwood Creek, Humboldt County, California

INTRODUCTION

Redwood Creek, with its mouth located near Orick, California, has long been recognized as one of the more important salmon and steelhead producing watersheds in the region. Approximately 59 miles of the mainstem and 50 miles of tributary streams are utilized by anadromous salmonids in this 285 square mile watershed. The purpose of this watershed implementation project was to assist in protecting and restoring a quality habitat for fisheries, by reducing the amount of anthropogenic sediment that contributes to the stream system. This project was made possible by funding from the California Department of Fish and Game (through SB 271 funding). Simpson Resource Company provided partial matching funds. More than 4.4 miles of inner gorge and stream-side road, including fifty-six sites that threatened to deliver sediment into the Redwood Creek system, were decommissioned. This report documents the erosion prevention project that was completed in 2003.

BACKGROUND

In 1999 field work began on a SB 271 funded watershed assessment project that included 33,000 acres of the Redwood Creek watershed immediately upstream from Redwood National Park boundaries (Figure X-D-1). This area was identified in the federal legislation expanding Redwood National Park as the Park Protection Zone (PPZ). Approximately 225 miles of road were inventoried for sediment sources within this assessment area.

The PPZ assessment area is typical of the region, where land is privately managed for timber harvest and agricultural production, with the exception of several areas. The BLM manages over 920 acres in the upper Lacks Creek area and several rural residential land holdings also exist within the assessment area. Three major landowners (Simpson Resource Company, Barnum Timber Company, and Stover Ranch) control in excess of 95% of the watershed area in the PPZ.

Roads constructed to support timber harvesting activities were built as areas were entered for first and second cycle logging activities. Some major routes (Old K & K Road, K & K Road, and Dolly Varden Road) were constructed for off-highway log hauling prior to 1958. These routes were aligned across steep inner gorge slopes using Humboldt stream crossings and sidecast construction techniques.

Road systems are now widely recognized throughout the region as one of the most significant, and perhaps the most easily controlled, sources of sediment production and delivery to stream channels. Redwood Creek is underlain by erodible and potentially unstable geologic substrate, and both field observations and aerial photo analysis suggests that roads have been a significant source of accelerated sediment production in the watershed (E.P.A. 1998). In Redwood Creek, as elsewhere, excess sediment input to stream channels triggered by large rainfall events is one of the most significant factors affecting or threatening salmonid populations.

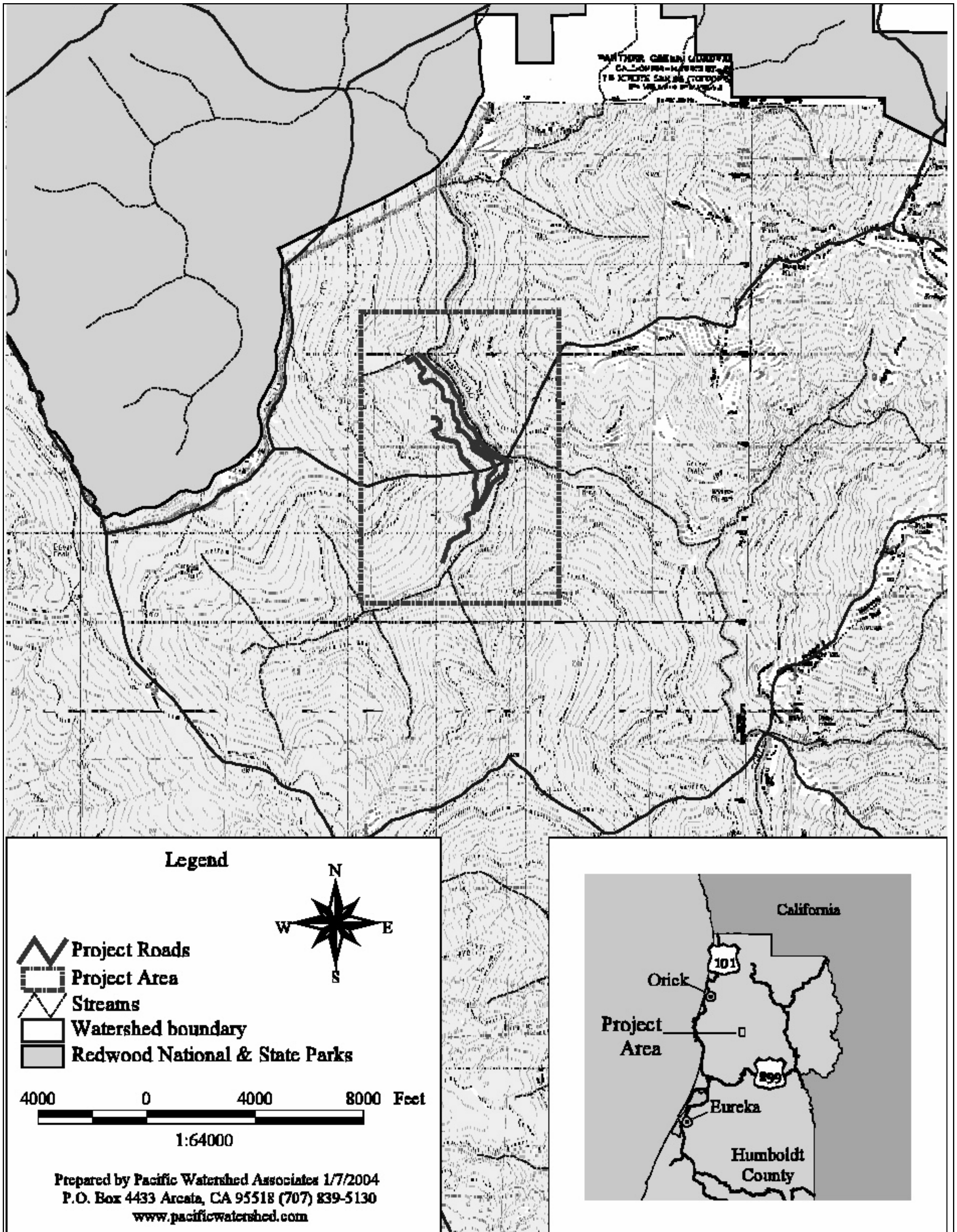

Figure X-D-1. Project Location Map Redwood Creek Road Decommissioning and Erosion Prevention Project Panther Creek USGS Quadrangle, Humboldt County, California.

Field inventories and data base analyses for the Redwood Creek watershed identified several high priority, high yield abandoned roads and road segments that threaten to deliver large quantities of sediment to the stream system if they are left untreated. Seven of these high priority road segments, totaling 4.4 miles, were decommissioned as a part of this project (Figure X-D-2). These included abandoned logging roads that had been constructed along the steep inner gorges of Redwood Creek and Panther Creek (tributary to Redwood Creek).

PROJECT OBJECTIVES

This road decommissioning project was designed to protect and improve salmonid habitat through controlling and preventing road-related erosion on several inner gorge slopes in the Redwood Creek watershed. The primary objective of the project was to implement cost-effective erosion control and erosion prevention work on high priority roads that were identified as a part of the comprehensive watershed assessment and inventory project for the basin.

The implementation of erosion control and erosion prevention work is perhaps the most important step to protecting and restoring watersheds and their anadromous fisheries, especially where sediment input is a limiting or potentially limiting factor to fisheries production, as is thought to be the case for the Redwood Creek watershed. Unlike many watershed improvement and restoration activities, erosion prevention and “storm-proofing” has an immediate benefit to the streams and aquatic habitat of the basin. It helps ensure that the biological productivity of the watershed’s streams is not impacted by future human-caused erosion, and that future storm runoff can cleanse the streams of accumulated coarse and fine sediment, rather than depositing additional sediment from managed areas. Roads treated for this implementation project have been identified as high priority for immediate implementation so that fill failures, stream crossing washouts and stream diversions do not degrade the stream system. The decommissioning work completed on this project is a significant step toward realization of long term salmon habitat protection and improvement in the Redwood Creek watershed.

LOCATION

This erosion control and erosion prevention project was focused on the area of Redwood Creek watershed downstream from the mouth of Panther Creek. It includes seven road segments (4.4 miles) in the lower watershed on Simpson Resource Company lands (Figure X-D-2). The attached maps (Figure X-D-2 and Figure X-D-3) depict the locations of the implementation projects as well as the specific sites that were treated for erosion prevention along each of the road segments.

PROJECT DESCRIPTION

The primary emphasis of the Redwood Creek watershed erosion prevention project was to treat existing and potential sediment sources identified along abandoned stream-side and inner gorge roads (Figure X-D-2 and Figure X-D-3). All roads that were treated were high priority road reaches that threatened to deliver substantial volumes of sediment to Redwood Creek or to Panther Creek if they were left untreated. A number of sites had already failed and many others showed signs of pending and potential failure and sediment delivery.

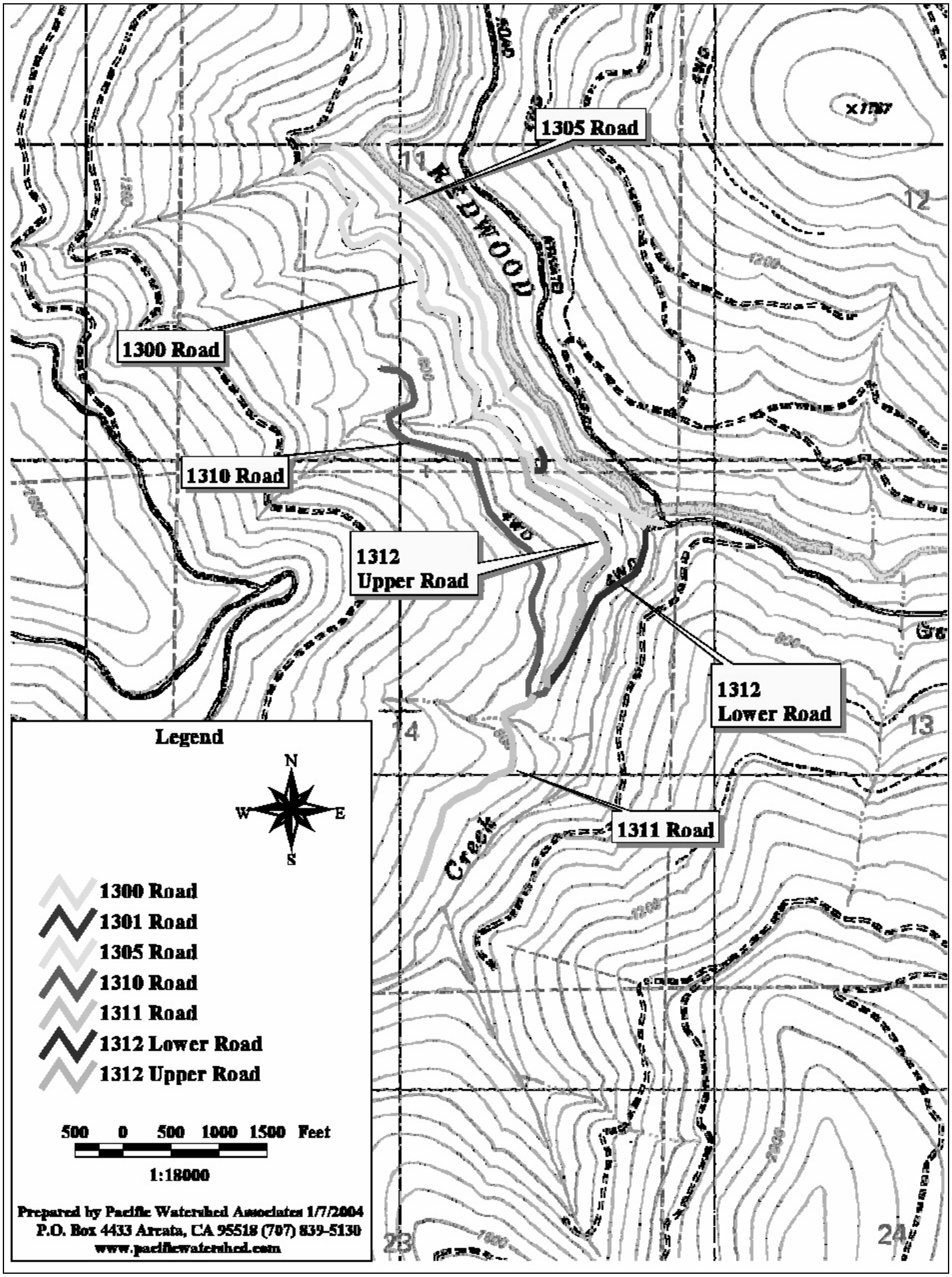

Figure X-D-2. Road location map Redwood Creek Road Decommissioning and Erosion Prevention Project Humboldt County, California.

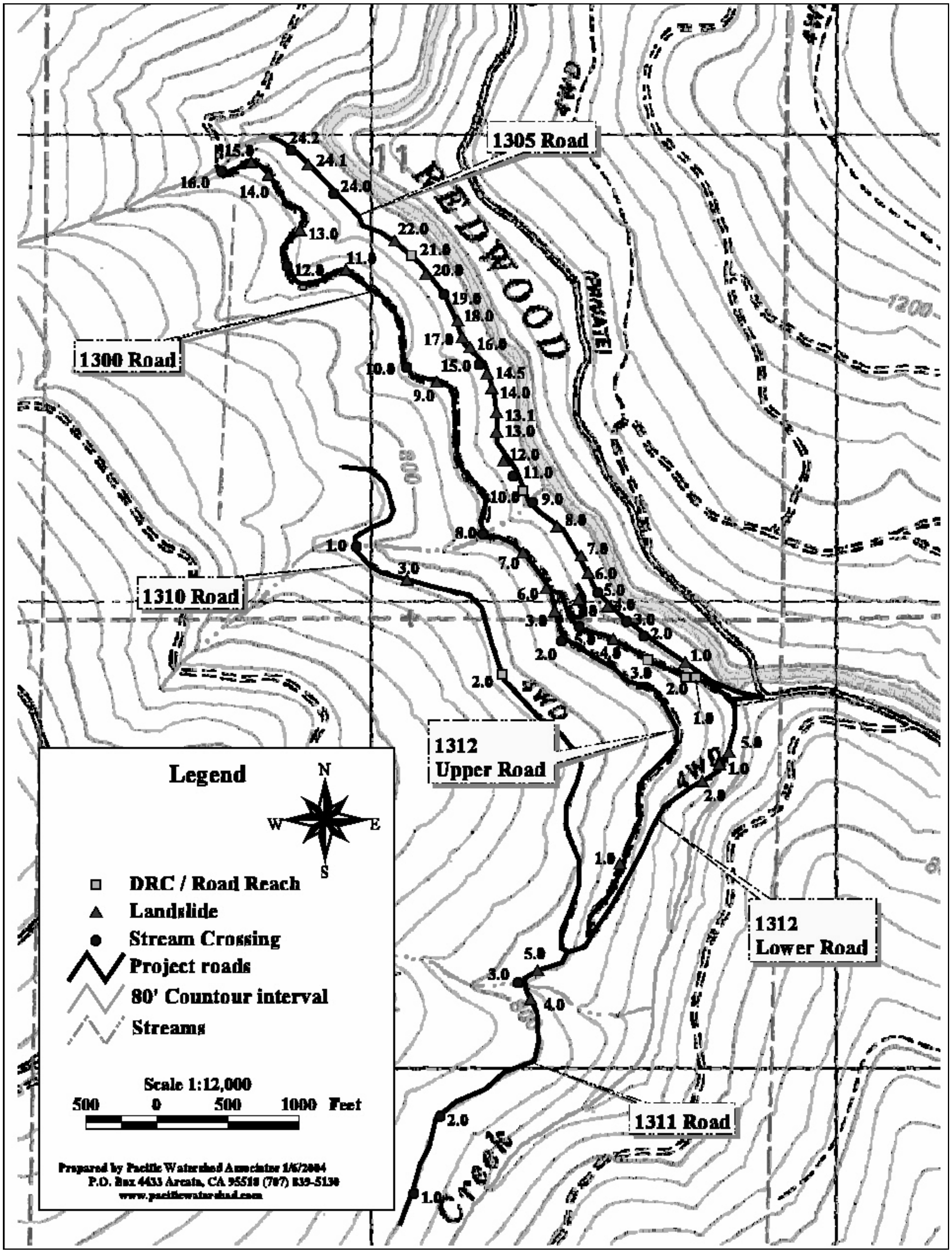

Figure X-D-3. Site location map, Redwood Creek Road Decommissioning and Erosion Prevention Project, Humboldt County, California.

This road decommissioning (closure) plan was aimed at old, abandoned high risk roads located within stream-side and inner gorge areas. Overall recommendations for the road reaches, as well as site-specific treatment prescriptions, were prepared for each road proposed for decommissioning. Only sites which would likely deliver sediment to a stream channel if left untreated were targeted for implementation.

General heavy equipment treatments for *road decommissioning* have been tested, described and evaluated elsewhere (Harr and Nichols 1993; Weaver and others 1987; Weaver and Sonnevil 1984; Weaver and Hagans 1994). Decommissioning essentially involves reverse road construction, except that full topographic obliteration of the road bed is not normally required to accomplish cost-effective sediment prevention goals. In order to protect the aquatic ecosystem, our goal was to hydrologically decommission the roads; that is, to minimize the adverse effect of the road on natural hillslope stability and watershed hydrology. From least intensive to most intensive, decommissioning included many of the following tasks[4]:

1. Road ripping or decompaction, in which the surface of the road or landing is "decompacted" or disaggregated using mechanical rippers. This action reduces surface runoff and often dramatically improves revegetation.

2. Cross-road drains, (deep waterbars) are installed at 50, 75, 100 or 200-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff, especially on roads that are to be permanently or temporarily decommissioned. Cross-road drains are large ditches or trenches excavated across a road or landing surface to provide drainage and to prevent the collection of concentrated runoff on the former road bed. In some locations, such as stream-side zones, mild outsloping may be used instead of cross road drain construction.

3. In-place stream crossing excavation (IPRX) is a decommissioning treatment that is employed at locations where roads or landings were built across stream channels. The fill (including the culvert or Humboldt log crossing) is completely excavated and the original stream bed and side slopes are exhumed. Excavated spoil is stored at nearby stable locations where it will not erode, sometimes being pushed several hundred feet from the crossing by bulldozer tractor(s). A stream crossing excavation typically involves more than simply removing the culvert, as the underlying and adjacent fill material must also be removed and stabilized. Side slopes are excavated to about a 2:1 slope so that they can be mulched and seeded with minimal post-project erosion.

4. Exported stream crossing excavation (ERX) is a decommissioning treatment where stream crossing fill material is excavated and spoil is hauled off-site for storage. Spoil is moved farther up- or down-road from the crossing, due to the limited amount of stable storage locations at the excavation site. This treatment frequently requires dump trucks to endhaul spoil material to the off-site location.

5. In-place outsloping (IPOS) ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and

[4] Many of these and other erosion prevention and erosion control techniques are describe in the ᐅHandbook for Forest and Ranch Roads (PWA, 1994)

placement of the spoil on the roadbed against the corresponding, adjacent cutbank, or within several hundred feet of the site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road.

6. Exported outsloping (EOS) is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is endhauled to a spoil disposal site. This treatment frequently requires dump trucks to endhaul spoil material. This is typically a decommissioning treatment as part or all of the roadbed is removed.

Only in relatively few instances does hydrologic decommissioning have to include full recontouring of the original road bed. Typically, potential problem areas along a road are isolated to a few locations (perhaps 10% to 20% of the full road network to be decommissioned) where stream crossings need to be excavated, unstable landing and road sidecast needs to be removed before it fails, or roads cross potentially unstable terrain and the entire prism needs to be removed. Most of the remaining road surface simply needs permanently improved surface drainage, using decompaction, road drains and/or partial outsloping.

Certain road segments included in this proposal contained a high density of treatment sites and subsequent decommissioning work involved relatively large portions of the road bed. Successfully decommissioning most roads typically costs a fraction of complete or total topographic road obliteration. Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment. Specific hours and costs for the Redwood Creek decommissioning project are included on the attached data tables.

We have included profiles and cross sectional diagrams of selected sites. For the sake of simplicity, specific details and drawings for each sediment treatment site are not included with this report, but are available for review and evaluation. For each treatment site, there is a detailed field data form describing site conditions, risk of future erosion, and details of the proposed treatment. For all stream crossing sites, we have prepared sketch maps, as well as cross sections and profile surveys, and design drawings for the proposed excavation.

The specific erosion prevention plan for these routes includes (for each site recommended for treatment) the recommended treatment prescription, treatment specifications, needed materials and equipment (including heavy equipment), estimated equipment times (hours), needed labor, and estimated costs to complete the project. This implementation information was included in the data forms and actual heavy equipment hours have been detailed in the attached treatment tables. All treatments for specific sites, whether roads, road segments, or other specific sites, were discussed with the landowner and land manager to ensure they were in conformance with existing or future management plans for the watershed areas.

SCHEDULE OF WORK

This road decommissioning project was administered by the Pacific Coast Fish, Wildlife and Wetlands Restoration Association. Actual project design, layout, implementation and reporting was conducted under the supervision of Pacific Watershed Associates of McKinleyville, California. On-the-ground implementation (road decommissioning) work was performed in the summer of 2002 and 2003 (Table X-D-1). All heavy equipment work was completed during summer low flow periods when impacts to water quality could be minimized or avoided.

In July, August, September, October and November 2002, the 1300, 1301, 1305, 1310, 1312 Upper and the 1312 Lower Roads were treated for permanent closure. In June and July 2003, the 1311 Road was treated for permanent closure. These roads were located along, or crossed, the steep inner gorge slopes of Class 1 and Class 2 stream channels. Each road that was treated showed evidence of substantial past erosion, as well as considerable future potential for erosion and sediment delivery.

Road Number	**Length (ft.)**	**Number of Sites Treated**	**Dates of Operation**	**Heavy Equipment Hours[1]**		
				Excavator	**Dozer**	**Dump Truck**
1300 Road	6,178	16	July 24 – October 13 ,2002	298.5	308.5	349.5
1301 Road	475	1	October 8,2002	6.5	6.5	0
1305 Road	4,716	25	August 9 – September 18,2002	162	174.5	163
1310 Road	4,488	3	July 28 – July 30,2002	24	24	38
1311 Road	2,270	5	June 25 – July 21,2003	192	109.25	115.25
1312 Upper Road	3,010	3	October 10 – November 5,2002	122	121.5	163.75
1312 Lower Road	1,742	3	September 18 – October 15,2002	31.5	33	2
Total	**22,879**	**56**	**July 23 – November 5,2002and June 25 – July 21,2003**	**836.5**	**777.25**	**831.5**

[1] Equipment hours do not include road opening and development of off-site spoil disposal areas.

Table X-D-1. Equipment work schedule and hours, Redwood Creek Decommissioning 2002-2003.

IMPLEMENTATION

Mike McDonald Construction of Trinity Center, CA was the primary equipment operator for the project area and McCullough Construction of Salyer, CA was the secondary equipment operator for the project area. Mike McDonald Construction carried out treatments using a CAT 325C hydraulic excavator, CAT D-6 high track bulldozer, 10 yd^3 dump trucks, and a CAT 22 yd^3 off-highway dump truck. McCullough Construction carried out treatments using a Komatsu hydraulic excavator, Komatsu (D-7 equivalent) bulldozer and several 10 yd^3 dump trucks (Table X-D-1). The excavators were used to: 1) open access to each site (brushing and filling of gullies), 2) excavate soil and organic debris (logs and chunks) from the stream crossings, 3) place small volumes of excavated spoil on stable slopes near the decommissioned stream crossings, 4) decompact (rip) the road roadbed between stream crossing locations (especially if fill was to be stored on the old road surface), 5) outslope the old road bed between sites, 6) "mulch" the treated road with logs, limbs and brush and 7) construct cross-road drains on the decommissioned roads.

The bulldozer was used to help reconstruct the roads and stream crossings for access by the dump trucks, to push excavated material to nearby disposal sites, to work off-site spoil disposal sites where excavated material was dumped and to rip (decompact) old road surfaces. Up to three 10 yd^3 dump trucks were used to haul excavated spoil from the inner gorge stream crossing sites to stable storage areas.

Two separate equipment crews treated sections of seven roads in Redwood Creek (Figure X-D-2 and Figure X-D-3). Because the roads had not been used for some time, it was estimated that 91 hours of excavator and dozer time would be required to open the seven road reaches treated in this project. A total of fifty-six (56) sites were treated along 4.4 miles of road surface (Table X-D-1).

The original inventory identified 20 stream crossings, 31 landslides and 8 other sites that were all in need of treatment. By the time the project was undertaken in 2002, three sites were removed (one road fill landslide and two washed out stream crossings on the 1305 Road) from the proposed work area. The three sites (24.1, 24.2 and 25) occurred along the last 300' of the 1305 Road. It was determined that the risk of sediment production caused by road opening and backfilling the washed out stream crossings would be greater than maintaining abandonment of the road segment. The predicted heavy equipment hours, actual heavy equipment hours and predicted excavation volumes for each treatment site are detailed at the end of this report.

It was estimated that 44,287 yds^3 of sediment would have to be excavated from the original 59 work sites identified in the initial road inventory, and that treatment of these sites would prevent the delivery of 26,425 yds^3 of sediment to Redwood Creek. Actual excavation volumes differ due to the removal of work sites by the time implementation was conducted in 2002 and due to an enlarged excavation on one stream crossing (see deviations from the original work plan). Because much of the excavated sediment was stored locally, it was not possible to determine the exact volume of material that was moved during the project.

Table X-D-2 describes the types and number of sites that were originally proposed for treatment on each road segment, as well as a general description of each decommissioned road. Landslide sites included road fill failures and instabilities, cutbank slides, hillslope slumping and large rotational slides. Stream crossings included culverted and unculverted crossings as well as Humboldt log crossings.

The 1300 Road contours along the left bank/inner gorge hillslope of Redwood Creek (Figure X-D-2). This abandoned road varies from approximately 150' – 750' above mainstem Redwood Creek and crosses five class 2 and class 3 streams that drain directly to Redwood Creek. The initial inventory identified five stream crossings, eight potential road fill landslides and three other sites. The five stream crossings that were decommissioned empty directly into Redwood

Creek. All sites on this road were straight forward, were treated as originally prescribed and equipment hours were relatively close to the original estimates.

A total of 6,178 feet of road length with 16 sites were treated on the 1300 Road. This took the equipment crew 32 working days and approximately 299 hours for the excavator, 309 hours for the dozer and 350 hours for dump trucks, not including all time necessary for road opening and clearing of spoil sites. All decommissioned stream crossings were seeded and straw mulched to help inhibit surface erosion.

The 1301 Road is located just off the 1300 Road near site # 5 (Figure X-D-2). This abandoned road is a 475 feet spur with a terminal landing. Only one potential road fill landslide site was identified during the initial road inventory. This site exhibited active scarps with up to 3 feet of vertical displacement and up to12 feet back from the outboard fill, perched on 70% slopes 20 feet above a Class 2 stream channel. The site was treated as originally prescribed and equipment hours were relatively close to the original estimates.

The 1305 Road contours directly above the left stream bank of Redwood Creek (Figure X-D-2). This abandoned road varies from approximately 30 to 75 feet above mainstem Redwood Creek and crosses ten Class 2 and Class 3 streams that drain directly to Redwood Creek. The initial inventory identified ten stream crossings, fourteen potential road fill landslides and four other sites. This road exhibited nearly continuous fillslope instabilities along most of the road length with the exception of the northern-most 500 feet. Most sites on this road were straight forward, were treated as originally prescribed and equipment hours were relatively close to the original estimates. One noted exception to the initial treatment plan was the elimination of three sites from the proposed work. As previously mentioned, it was determined that the risk of sediment production caused by road opening and backfilling of the washed out stream crossings would be greater than simply leaving the sites untreated.

A total of 4,716 feet of road length with 25 sites were treated on the 1305 Road. This took the equipment crew 28 working days and approximately 162 hours for the excavator, 175 hours for the dozer and 163 hours for dump trucks. All decommissioned stream crossings were seeded and straw mulched to help inhibit surface erosion.

Road Number (site list)	Location	Road Description	Number of sites of future sediment delivery (#)		
			Stream Crossing	Landslides	Other
1300 (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)	Redwood Creek	Abandoned road contours along left side of Redwood Creek and parallels above 1305 Road. Multiple medium size culverted and Humboldt stream crossings actively eroding and delivering sediment to Redwood Creek. Road exhibited multiple fillslope instabilities with potential sediment delivery.	5	8	
1301 (1)	Redwood Creek	Short 475 foot spur road with terminal landing. One Potential road fill failure perched directly above left approach of site # 5 on 1300 Road.	0	1	0
1305 (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 13.1, 14, 14.5, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 24.1, 24.2)	Redwood Creek	Abandoned stream-side road contours directly above the left bank of Redwood Creek. Road averages 30' – 75' above Redwood Creek at bankfull level. Multiple small, poorly culverted, actively eroding Humboldt crossings and nearly continuous road fill failure problems.	10	14	4
1310 (1, 2, 3)	Redwood Creek	Abandoned road contours along left hillslope of Redwood Creek and parallels above 1312 and 1300 Roads. Relatively low gradient (30-45%) hillslope setting. One washed out stream crossing, one potential road fill failure in a headwater swale setting and one road reach / DRC delivery location on this road.	1	1	1
1311 (1, 2, 3, 4, 5)	Panther Creek	Abandoned inner gorge road contours along left hillslope 600' – 800' above Panther Creek. Several medium sized culverted stream crossings, one enormous eroding Humboldt stream crossing and several potential road fill failures perched above site # 3 on this road.	3	2	0
1312 Upper (1, 2, 3)	Panther and Redwood Creeks	Short abandoned tie road contours along left hillslope of Redwood and Panther Creeks. Road parallels above 1312 Lower and 1300 Roads. One very large potential road fill failure, one medium sized eroding stream crossing and one smaller potential road fill failure on this road.	1	2	0
1312 Lower (1, 2, 5)	Panther Creek	Abandoned inner gorge road contours uphill along left hillslope 200' – 500' above Panther Creek. Road exhibited nearly continuous fillslope instabilities and one very large past debris slide taking out 250' road prism width.	0	3	0
Total			**20**	**31**	**8**

Table X-D-2. 2002-2003 Decommissioned sites for Redwood Creek – 1300 roads.

The 1310 Road is located along the left hillslope of Redwood Creek (Figure X-D-2). This abandoned road parallels above the 1300 Road and is located along a gentler hillslope setting.

The initial inventory identified one washed-out stream crossing, one potential road fill failure and one road reach / DRC delivery location. This road segment was less critical and exhibited lower potential for future sediment delivery. The sites on this road were straight forward, were treated as originally prescribed and equipment hours were relatively close to the original estimates.

A total of 4,488 feet of road length with 3 sites were treated on the 1310 Road. This took the equipment crew 3 working days and approximately 24 hours for the excavator, 24 hours for the dozer and 38 hours for dump trucks.

The 1311 Road contours along the left bank / inner gorge hillslope of Panther Creek (Figure X-D-2). This abandoned road varies from approximately 500 to 700 feet above mainstem Panther Creek and crosses three Class 2 and Class 3 streams that drain directly to Panther Creek. The initial inventory identified three stream crossings and two potential road fill landslide sites. Four out of five sites on this road were straight forward, were treated as originally prescribed and equipment hours were relatively close to the original estimates.

Site # 3 on the 1311 Road turned out to be the noted exceptional site in the project area. This site was a large Class 2 Humboldt stream crossing with active collapsing fill and decomposing logs backed up by large sediment deposits and flanked on the left and right approaches by future road fill failures (sites 4 & 5). This site was a chronic sediment producer and had a very large future potential yield. The initial inventory estimated this site to have a future delivery of 1,868 yds^3 and an excavation volume of 3,481 yds^3. Upon further field review and volumetric analysis it was determined that the actual volumes were much larger. The estimated excavation volume for this site was 9,413 yds^3 and the revised potential future delivery prior to excavation was 4,750 yds^3. These volumes are reflected in Table X-D-3.

A total of 2,270 feet of road length with 5 sites were treated on the 1311 Road. This took the equipment crew 23 working days and approximately 192 hours for the excavator, 109 hours for the dozer and 115 hours for the 22 yd^3 dump truck. All decommissioned stream crossings were seeded and straw mulched to help inhibit surface erosion.

The 1312 Upper & Lower Roads are located along the left bank / inner gorge hillslope of Panther and Redwood Creeks (Figure X-D-2). The initial inventory identified one stream crossing and five potential road fill landslide sites. The 1312 Lower Road exhibited nearly continuous fillslope instabilities as well as one large past debris slide that removed the entire road prism for 250 feet. The 1312 Upper Road had one medium sized stream crossing, one minor potential road fill failure and one very large potential road fill failure. The sites on these roads were straight forward, were treated as originally prescribed and equipment hours were relatively close to the original estimates.

Treatment Category	Sites to Treat[1] (#)	Cross Road Drains (#)	Total Volume Excavated[2] (yds^3)	Volume Sediment Saved[3] (yds^3)	Cost Effectiveness[4] ($\$/yds^3$ saved)	Total Project Costs[5] ($)
Proposed	59	26	44,287	26,425	11.91	314,809
As Built	56	67	49,488	28,954	11.90	344,520

[1] Three sites were eliminated from the project. Reasons specified in the report.
[2] Total volume excavated increased from the proposed estimate. Site # 3, 1311 Road, stream crossing excavation volume was significantly larger than the original estimate. Excavation volumes from sites 24, 24.1 and 24.2 on the 1305 Road were removed from the "As Built" figure.
[3] Total volume of sediment saved increased from the proposed estimate due to a post inventory volume revision of site # 3, 1311 Road. Future erosion volumes from sites 24, 24.1 and 24.2 on the 1305 Road were removed from the "As Built" figure.
[4] Cost effectiveness increased slightly from the proposed estimate due to the volume of sediment saved and total project costs changing.
[5] Total project costs includes all equipment and labor time, materials, subcontractor costs, project management and overhead (all costs included). Simpson Resource Company provided a $129,836 cost share. National Park Service provided a $20,000 cost share. CDF&G grant monies provided $184,809 + $9,875.

Table X-D-3. Deviations from the original proposed treatment plan, Redwood Creek Road Decommissioning Project – 1300 roads.

A total of 4,752 feet of road length with 6 sites were treated on the 1312 Upper & Lower Roads. This took the equipment crew 25 working days and approximately 154 hours for the excavator, 155 hours for the dozer and 166 hours for dump trucks. The decommissioned stream crossing was seeded and straw mulched to help inhibit surface erosion.

COSTS

Total costs were broken down for the entire project area, based on cost categories listed (Table X-D-4). Rates for equipment were as follows: excavator $125/hr and $110/hr, dozer $95/hr and $90/hr, 10 yd^3 dump trucks $65/hr and $60/hr, 22 yd^3 dump truck $130/hr and labor $21/hr. Costs in Table X-D-4 include all road opening and equipment mobilization time. It also reflect costs for straw, seed, administrative overhead and technical oversight, which includes general layout, heavy equipment oversight and monitoring, plot documentation, resurveying and reporting. Total inclusive costs for decommissioning these seven roads in the Redwood Creek watershed was approximately $344,520.

DEVIATIONS FROM THE ORIGINAL WORK PLAN

Table X-D-3 shows specific deviations from the original proposed treatment plan. These deviations were caused by a variety of factors but generally because it was determined that the project would benefit if these changes were made (i.e.; reduced future erosion at stream crossing sites where excavation volumes enlarged and decreased surface runoff on road reaches due to construction of additional cross road drains). It should be expected that as work is being implemented some variation from the original work plan is necessary to accommodate unforeseen complications. The variations that were made to the original work plan were motivated by improving the overall effectiveness of the project and to reduce the likelihood of future erosion and sediment delivery.

Cost Category	Total Hours	Cost Rate[1] (average $/hr)	Total Costs ($)
Personnel Costs			
Project Manager	250	30	7,500.00
Heavy Equipment Costs			
Excavator	1,134.25	119	134,581.25
Dozer	1,078.75	93	100,068.75
10 yd^3 Dump Truck	916	61	55,688.00
22 yd^3 Dump Truck	115.5	130	15,047.50
Water Truck	28.5	55	1,567.50
Low-Boy Transport	17	82	1,401.50
Truck and Trailer	8	30	240.00
Subcontractor Costs			
Sub Labor	182	21	3,831.00
Sub Technical Oversight, Layout and Reporting	355	50	17,750.00
Mulch, Seed and Erosion Control Materials			3,356.79
Administrative Overhead @ 1.023%			3,487.71
Total Project Costs			**344,520**
Estimated Sediment Savings: 28,954 yds^3			
Overall Project Cost-Effectiveness: $ 11.90 / yd^3 saved			
[1] Cost rates listed are averages. Within several equipment categories different rates were billed for different pieces of equipment.			

Table X-D-4. Total costs for road-related erosion control and erosion prevention work on all sites in the Redwood Creek Road Decommissioning Project – 1300 roads.

MONITORING

Before the project commenced, photo point stations were established for many of the project work sites. These photo points were used to document the work sites before, during and following the excavation. Examples of before and after photo point shots have been included in the report to depict excavated stream crossings, landslides and outsloped roads in the Redwood Creek Road Decommissioning Project.

Each decommissioned stream crossing was surveyed prior to treatment and re-evaluated after equipment had completed excavation work. A select number of representative decommissioned stream crossings were re-surveyed following equipment operations.   depicts surveyed profiles and cross sections of three stream crossings. Also, a typical pre- and post-excavation road profile of a landslide excavation was surveyed at site # 7 on the 1300 Road. The plotted surveys show the original ground profile, the design profile and the as built profile that was surveyed following heavy equipment excavation work at the three sites. Each of the stream crossings have been excavated to a stable longitudinal and cross sectional profile.

CONCLUSION

The expected benefit of completing the erosion control and prevention work lies in the reduction of long term sediment delivery to Redwood Creek and Panther Creek, important salmonid streams. The purpose of this project was to permanently reduce the amount of sediment that could have eroded and been delivered to Redwood Creek and its tributaries. It is estimated that over 49,000 cubic yards of material was excavated in this project. This volume includes the volume that was endhauled to spoil disposal sites as well as excavated material that was stored locally on-site. In the initial inventory, it was estimated that approximately 26,425 yds^3 of sediment had a high potential to deliver to Redwood Creek and Panther Creek.

With the extensive restoration of these 56 specific sites a significant amount of sediment that once threatened these salmon bearing streams no longer poses a threat. Although it is difficult to assess the immediate benefits of the decommissioning project to fish habitat, the lasting benefit of removing over 49,000 cubic yards of material, and preventing the delivery of over 28,954 yds^3 to the Redwood Creek system should help promote habitat recovery over the next several decades.

PROJECT LOCATION DIRECTIONS AND LANDOWNER ADDRESS
The project area can be reached by the following directions. From Arcata, California travel east on highway 299 for 5 miles and take the “Blue Lake” exit. Continue east for 3 miles to “Korbel” lumber mill. Take a left at the first guard station and continue through the lumber mill to the K & K Road. On the K & K Road travel northwesterly for 14 miles to the mouth of Panther Creek. Park here and cross the foot bridge over Panther Creek. At this location is the intersection of the 1312 Lower Road and 1300 Road in the project area.

Landowner address:
Simpson Resource Company
PO Box 68
Korbel, CA 95550

REFERENCES

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Erosion Prevention Implementation Results, 2002-2003 Road Decommissioning Project, Redwood Creek Watershed

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds^3)	Dump truck loads removed[3]
1	DRC	4	4	4	4	0	0	431	0
2	DRC	4	7	4	7.5	0	0	100	0
3	DRC	6	13	6	12.5	0	0	150	0
4	Landslide	3	8	3	8	6	0	256	0
5	Crossing	8	51	8	55	8	2	390	
6	Landslide	23	29.5	23	29.5	46	59	2599	182
7	Landslide	4	29.5	4	29.5	8	49	311	152
8	Crossing	6	14	6	14	12	28	279	84
9	Landslide	8	14	8	14	8	17	833	54
10	Crossing	75	44.5	75	44.5	75	85.5	2538	262
11	Landslide	12	10	12	10	12	20	1426	30
12	Crossing	14	17	14	17	28	32	698	
13	Landslide	3	6	3	6	0	12	291	
14	Landslide	16	20.5	16	20.5	32	41	1574	
15	Landslide	10	10.5	10	10.5	20	0	925	0
16	Crossing	61	20	61	26	122	4	2438	
Subtotal – 1300 Rd		257	298.5	257	308.5	377	349.5	15239	764

[1] Hours included only for site specific treatment and not for road reaches between sites, road opening or clearing and grubbing.
[2] Predicted equipment hours listed do not include "logistics" hours.
[3] Fields left blank indicate no operator record was kept for the number of dump truck loads removed. On the 1311 Road a 20 yd^3 off-highway dump truck was used instead of standard 10 yd^3 dump trucks.

Table X-D-5. Decommissioning data for the 1300 Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds^3)	Dump truck loads removed[3]
1	Landslide	5	6.5	5	6.5	0	0	324	0
Subtotal – 1301 Rd.		5	6.5	5	6.5	0	0	324	0

Table X-D-6. Decommissioning data for the 1301 Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds^3)	Dump truck loads removed[3]
1	Landslide	11	4	11	4	0	0	1460	0
2	Crossing	5	20.5	5	34.5	0	0	366	0
3	Crossing	4	2.5	4	1	0	0	207	0
4	Landslide	8	8.5	8	8.5	16	0	900	0
5	Crossing	2	3.5	2	3.5	0	0	54	0
6	Landslide	3	4	3	4	0	0	277	0
7	Landslide	4	3	4	3	0	0	388	0
8	Landslide	6	11.5	6	11.5	12	0	574	0
9	Crossing	7	11	7	11	14	11	359	25
10	Road Reach	5	5	5	5	10	5	527	20
11	Crossing	6	18	6	18	0	16	379	65
12	Landslide	2	5	2	5	0	8	111	28
13	Landslide	6	4	6	4	0	8	711	32
13.1	Landslide	2	4	2	4	0	8	138	16
14	Landslide	4	6	4	6	0	9	438	40
14.5	Landslide	4	4	4	4	8	8	402	16
15	Crossing	4	10	4	10	8	20	157	40
16	Landslide	3	7	3	7	6	14	277	30
17	Landslide	4	4	4	4	8	8	324	19
18	Landslide	8	3	8	3	16	6	850	21
19	Crossing	2	7	2	7	4	14	74	43
20	Landslide	9	6	9	6	0	12	1283	30
21	DRC	4	2.5	4	2.5	0	0	381	0
22	Landslide	3	4.5	3	4.5	0	9	267	20
23	Road Reach	2	3.5	2	3.5	0	7	100	30
24	Crossing	8	0	8	0	0	0	429	0
24.1	Landslide	2	0	2	0	0	0	111	0
24.2	Crossing	3	0	3	0	0	0	191	0
Subtotal – 1305 Rd.		131	162	131	174.5	102	163	11,735	475

Table X-D-7. Decommissioning data for the 1305 Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds^3)	Dump truck loads removed[3]
1	Crossing	13	10	13	10	26	20	648	
2	DRC	8	8	8	8	0	6	200	
3	Landslide	5	6	5	6	10	12	407	
Subtotal – 1310 Rd		26	24	26	24	36	38	1255	

Table X-D-8. Decommissioning data for the 1310 Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds³)	Dump truck loads removed[3]
1	Crossing	10	24.5	10	0	0	3	962	18
2	Crossing	4	5.5	4	0	0	0	248	0
3	Crossing	78	148	78	103.25	0	102.25	4981	529
4	Landslide	4	8	4	0	8	4	941	20
5	Landslide	3	6	3	6	0	6	419	37
Subtotal – 1311 Rd		99	192	99	109.25	8	115.25	7551	604

Table X-D-9. Decommissioning data for the 1311 Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds³)	Dump truck loads removed[3]
1	Landslide	51	113.5	51	113.5	102	163.75	3824	410
2	Crossing	6	5.5	6	5	6	0	271	0
3	Landslide	3	3	3	3	3	0	292	0
Subtotal – 1312U Rd		60	122	60	121.5	111	163.75	4387	410

Table X-D-10. Decommissioning data for the 1312 Upper Road Redwood Creek Watershed, Humboldt County, California.

Site #	Site type[1]	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds³)	Dump truck loads removed[3]
1	Landslide	5	2.5	5	2.5	15	0	620	0
2	Landslide	9	14.5	9	16	9	2	1083	8
5	Landslide	14	14.5	14	14.5	28	0	2093	0
Subtotal – 1312L Rd		28	31.5	28	33	52	2	3796	8

Table X-D-11. Decommissioning data for the 1312 Lower Road Redwood Creek Watershed, Humboldt County, California.

Heavy Equipment Work	Predicted Excavator Hrs[2]	Actual Excavator Hrs	Predicted Dozer Hrs[2]	Actual Dozer Hrs	Predicted Dump truck Hrs[2]	Actual Dump Truck Hrs	Predicted Excavated Volume (yds³)	Dump truck loads removed[3]
Totals	606	836.5	606	777.25	686	831.5	44,287	2,261

Table X-D-12. Decommissioning data for the Redwood Creek Watershed, Humboldt County, California.

Selected Photo-point Photos of the 2002-2003 Redwood Creek Road Decommissioning Project

Figure X-D-4. Site #8, 1300 Road, before excavation.
This picture was taken just above the top of the stream crossing, looking downstream. This Humboldt crossing has been brushed out and is ready to be excavated

Figure X-D-5. Site #8, 1300 Road, after excavation. This picture was taken from the same viewpoint as above. The stream crossing has been excavated, mulched and seeded. See same view below after heavy rainfall (Figure X-D-6).

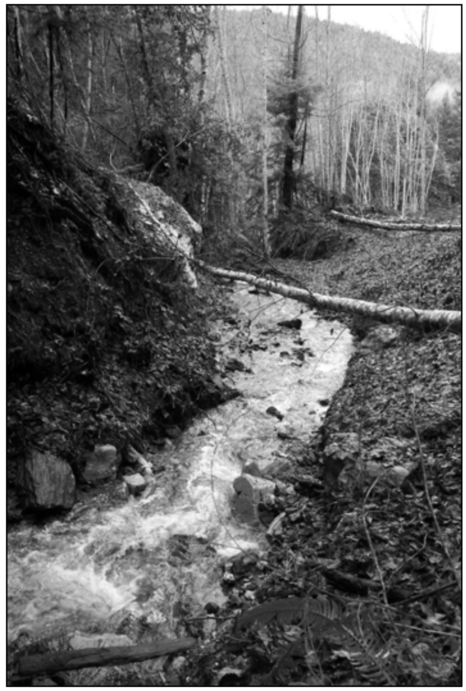


Figure X-D-6. Site # 8, 1300 Road, after excavation. Same viewpoint as Figure X-D-4 during heavy rainfall event.

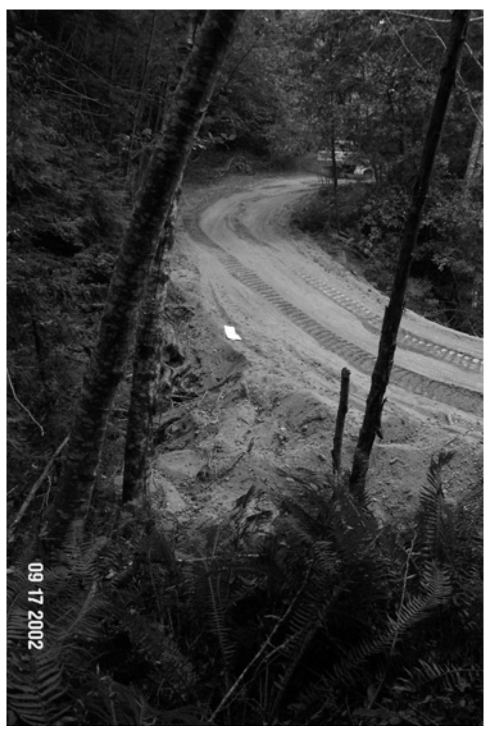


Figure X-D-7. Site #8, 1300 Road, before excavation. Picture taken 30 feet up the right bank, near the right hinge line of this stream crossing. The stream crossing has been excavated, mulched, and seeded. Note location of the two trees for reference.

Figure X-D-8. Site # 8, 1300 Road, after excavation. This picture (and Figure X-D-7) was taken 30 feet up the right bank, near the right hinge line of this stream crossing. The stream crossing has been excavated, mulched and seeded. Note location of the two trees for reference.

Figure X-D-9. Site # 12, 1300 Road, before excavation. This picture was taken 20 feet above the top of the stream crossing and along the left bank, looking downstream. The stream crossing has been brushed out and is ready to be excavated.

Figure X-D-10. Site #12, 1300 Road, after excavation. This picture was taken from the same viewpoint as Figure X-D-9. The stream crossing has been excavated, mulched and seeded. Upon excavation it was determined that the original watercourse meandered to the right prior to entering the Bot. Armor was placed along the left bank to prevent stream bank erosion (see arrow).

Figure X-D-11. Site #10, 1305 Road, during excavation. A potential road fill landslide was excavated at this site. Unstable outboard road fill was excavated and endhauled to a stable storage location, creating an outsloped road surface (see Figure X-D-12).

Figure X-D-12. Site #10, 1305 Road, after excavation. This picture was taken from the same viewpoint as Figure X-D-11. The unstable road fill has been completely excavated, mulched and seeded, leaving an outsloped road surface. Because this road exhibited nearly continuous road fill instabilities, a similar nature of treatments were applied to the remaining road, along with stream crossing excavations.

Figure X-D-13. Site # 11, 1305 Road, before excavation. This picture was taken 30 feet above the top of the stream crossing and along the left bank, looking downstream. The stream crossing has been brushed out and is ready to be excavated. A large "Humboldt" log is visible just left of the mossy alder tree in the right-center portion of the picture (see arrow).

Figure X-D-14. Site #11, 1305 Road, after excavation. This picture was taken from the same viewpoint asX-D-13. The stream crossing has been excavated, mulched and seeded. See same view below after heavy rainfall (Figure X-D-15).

Figure X-D-15. Site # 11, 1305 Road, after excavation. This picture was taken from the same viewpoint as above (Figure X-D-13 and Figure X-D-14) during a heavy rainfall event. Note the stream channel bed has developed a self armoring “lag” deposit during the first season’s rainfall. Redwood Creek is in the background.

Figure X-D-16. Site # 13, 1305 Road, before excavation. A potential road fill landslide was excavated at this site. Unstable outboard fill was excavated and endhauled to a stable storage location, creating an outsloped road surface (see Figure X-D-17).

Figure X-D-17. Site #13, 1305 Road, after excavation. This picture was taken from the same viewpoint as Figure X-D-16. The unstable road fill has been completely excavated, mulched and seeded, leaving an outsloped road surface. In the background is one of the main spoil sites for this road. The sloped surface can be seen extending up above the old road bench (see arrows).

Figure X-D-18. Site #3, 1311 Road, before excavation. This is a 3 shot panoramic compilation photo taken from the cutbank on the right approach to this Humboldt stream crossing. The site has been brushed out and a temporary flex pipe has been installed along the right hinge line to divert active flow around the work area.

Figure X-D-19. Site # 3, 1311 Road, after excavation. This is a 2 shot panoramic compilation photo taken from near the same location as the previous picture. The site has been completely excavated, large woody debris removed from the fill during the excavation has been redistributed along the stream crossing slopes and seed & mulch has been applied to the bare slope areas.

Figure X-D-20. Site # 3, 1311 Road, during excavation. This picture was taken near the Bot of the stream crossing. The picture view is looking upstream with the outboard edge of the road in the upper center portion of the photo. Some fill has been excavated from the outboard edge of the road downslope towards the Bot and a swath of brush as been cleared to the Bot, in preparation for continued excavation.

Figure X-D-21. Site # 3, 1311 Road, after excavation. This picture was taken near the same location as the previous photo. The stream crossing has been excavated and an abundance of woody debris has been redistributed along the banks and the channel.

Figure X-D-22. Site #3, 1311 Road, after excavation. This picture was taken from near the Top looking downstream.

Figure X-D-23. Site #3, 1311 Road, after excavation. This picture was taken from near the right bank looking upstream.

Figure X-D-24. Site # 2, 1312 Lower Road, before excavation. A potential road fill landslide was excavated at this site. Unstable outboard road fill was excavated and stockpiled locally along the cutbank behind the site, creating an outsloped road surface (see below).

Figure X-D-25. Site # 2, 1312 Lower Road, after excavation. This picture was taken from the same viewpoint as above. The unstable road fill has been completely excavated, mulched and seeded, leaving an outsloped road surface. Note trees and brush removed during excavation have been used a ground surface mulch. Panther Creek (not visible in photo) is located to the right.

Figure X-D-26. Site # 5, 1312 Lower Road, before excavation. A potential road fill landslide was excavated at this site. Unstable outboard road fill was excavated and stockpiled locally along the cutbank behind the site, creating an outsloped road surface (see below).

Figure X-D-27. Site # 2, 1312 Lower Road, after excavation. This picture was taken from the same viewpoint as above. The unstable road fill has been completely excavated. Straw mulch and seed had not yet been spread in this picture (note straw bales near former cutbank).

Selected Pre- & Post-excavation Profiles and Cross Sections of the 2002-2003 Redwood Creek Road Decommissioning Project

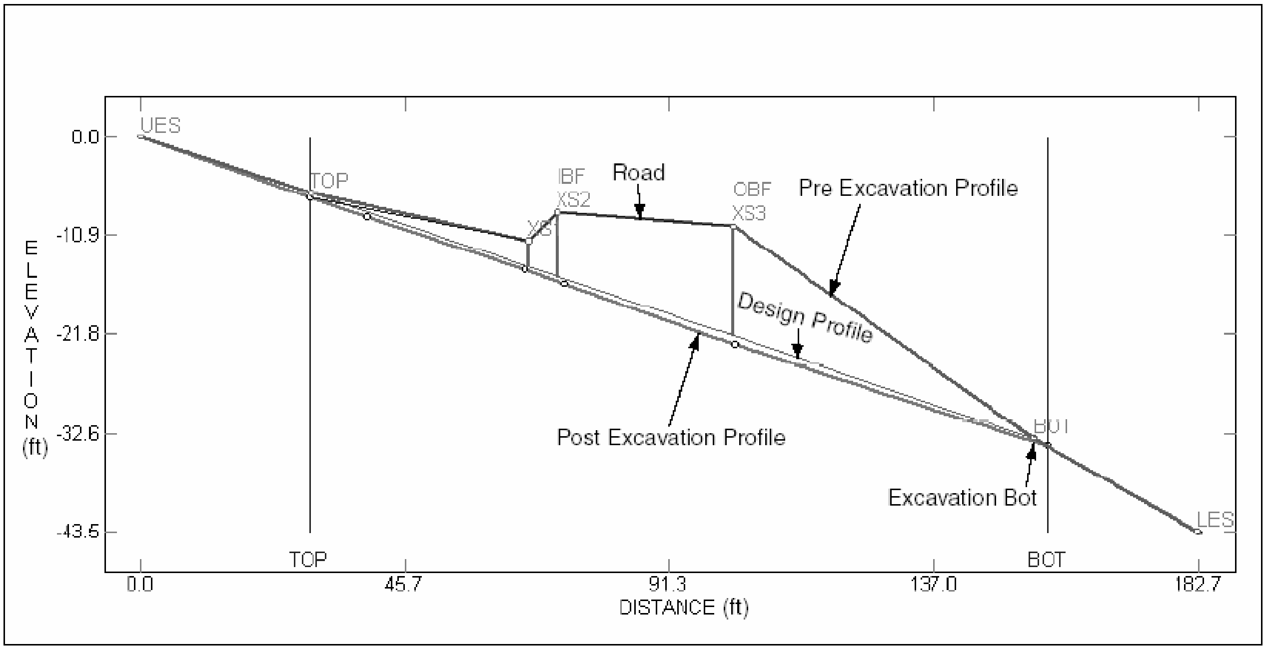


Figure X-D-28. Redwood Creek 1300 Road Site #12 – Stream Crossing Pre & Post Excavation Profiles.

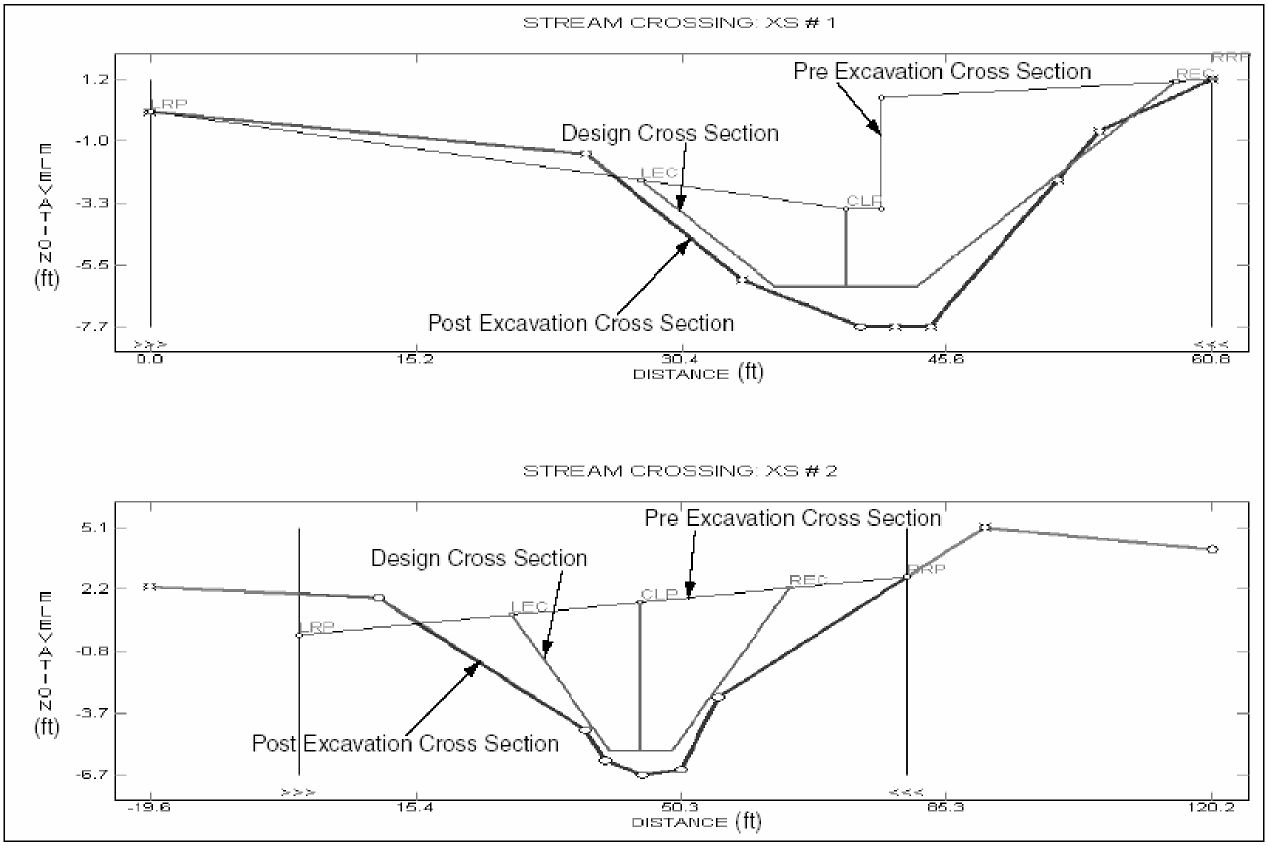


Figure X-D-29. Redwood Creek 1300 Road Site #12 – Stream Crossing Pre & Post Excavation Cross Sections.

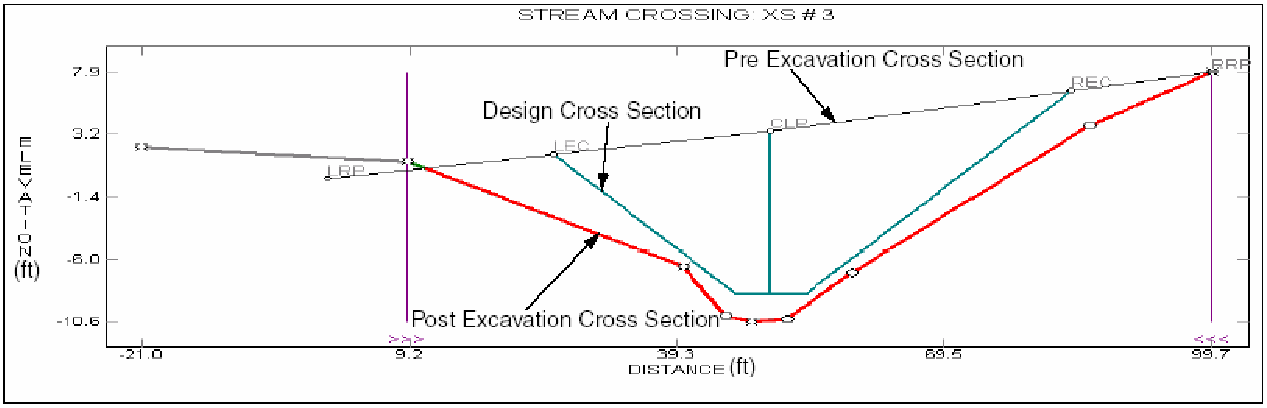


Figure X-D-30. Redwood Creek 1300 Road Site #12 – Stream Crossing Pre & Post Excavation Cross Sections.

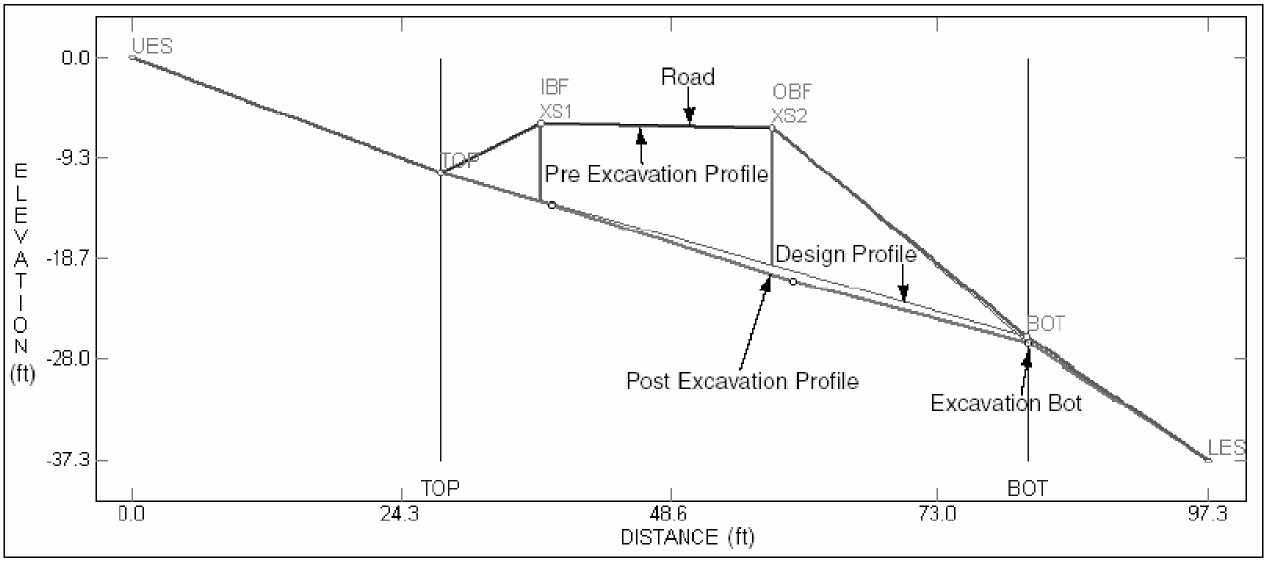


Figure X-D-31. **Redwood Creek 1305 Road Site #11 – Stream Crossing Pre & Post Excavation Profiles.**

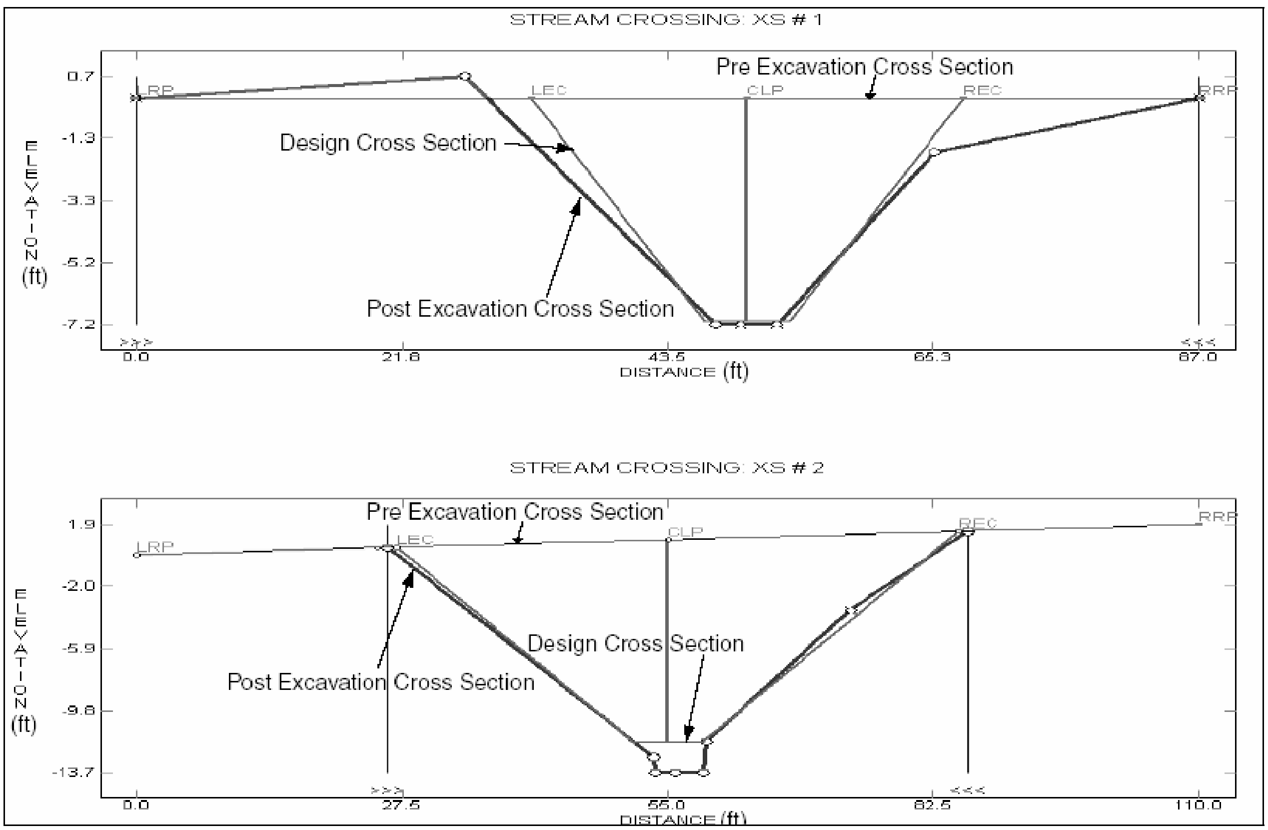


Figure X-D-32. **Redwood Creek 1305 Road Site #11 – Stream Crossing Pre & Post Excavation Cross Sections.**

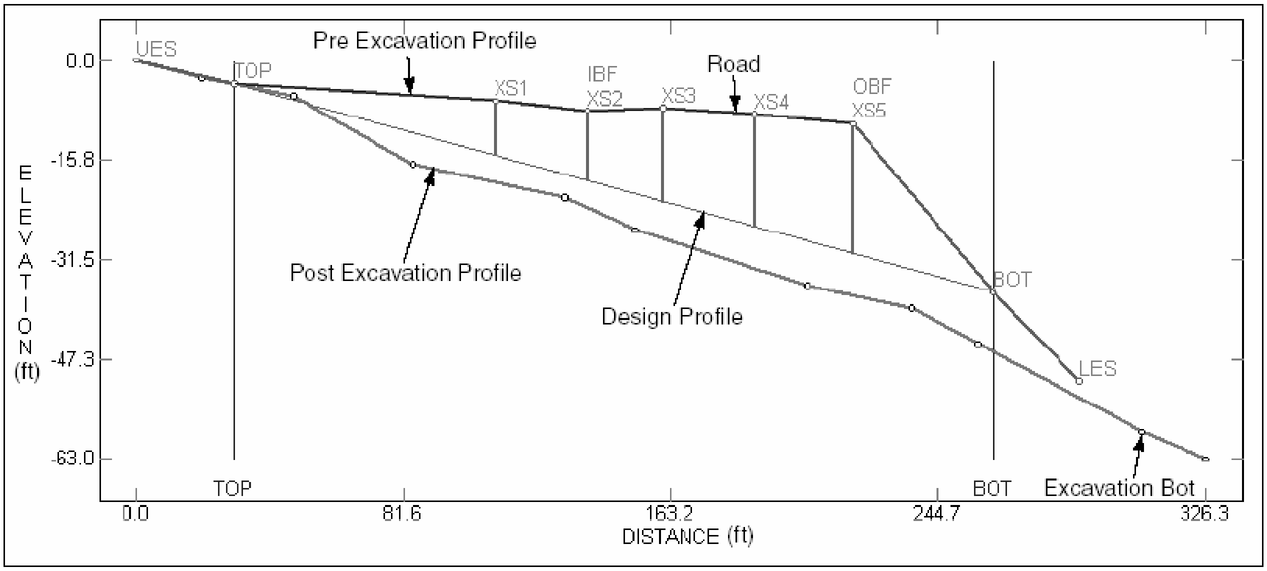


Figure X-D-33. Redwood Creek 1311 Road Site #3 – Stream Crossing Pre & Post Excavation Profiles.

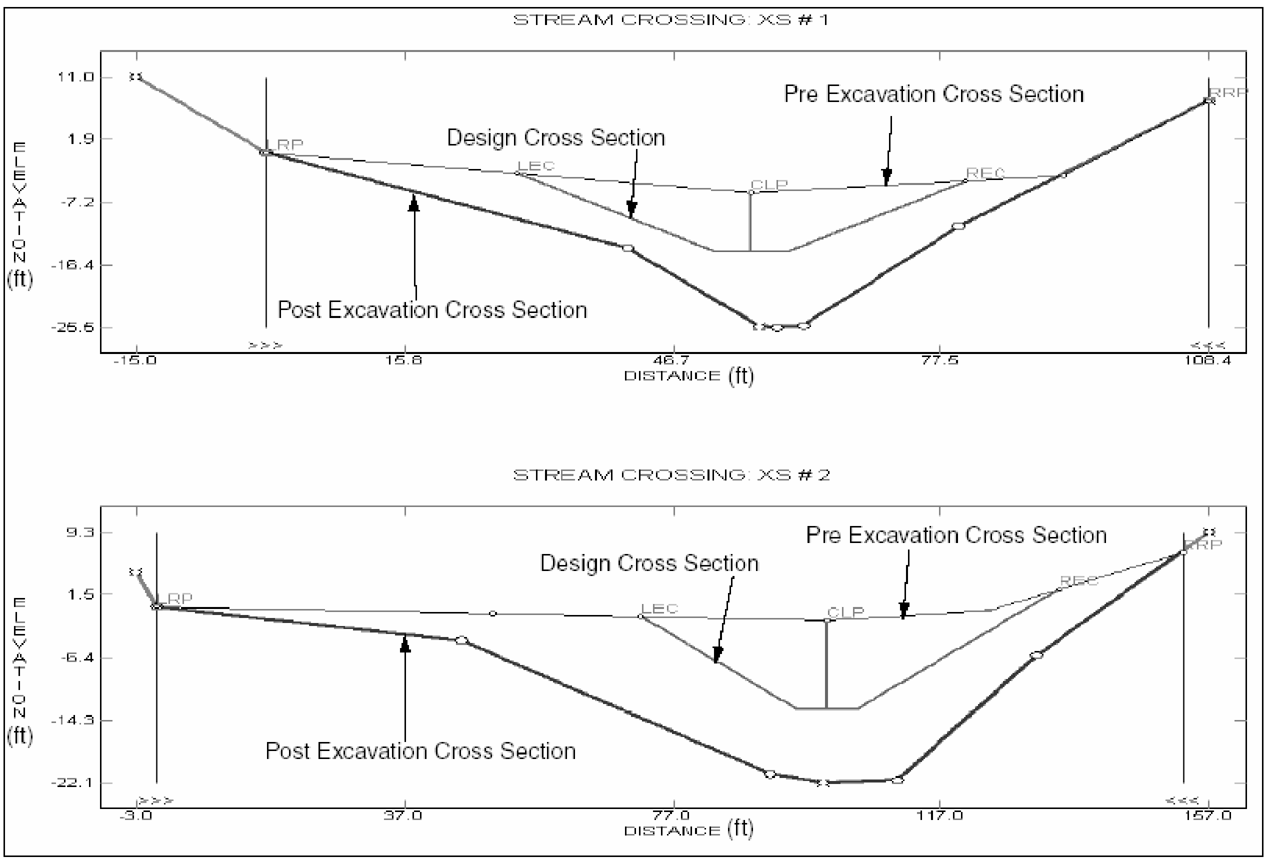


Figure X-D-34. Redwood Creek 1311 Road Site #3 – Stream Crossing Pre & Post Excavation Cross Sections.

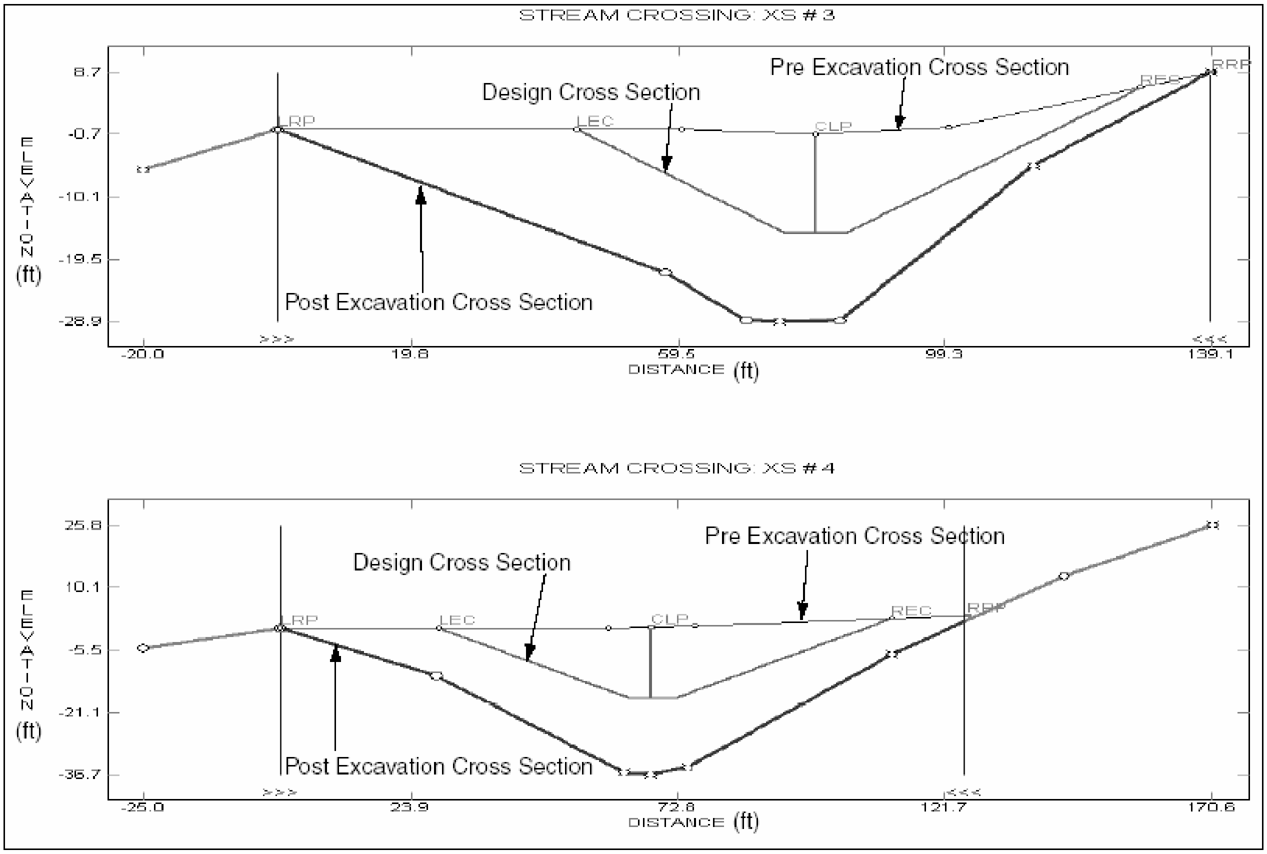


Figure X-D-35. **Redwood Creek 1311 Road Site #3 – Stream Crossing Pre & Post Excavation Cross Sections.**

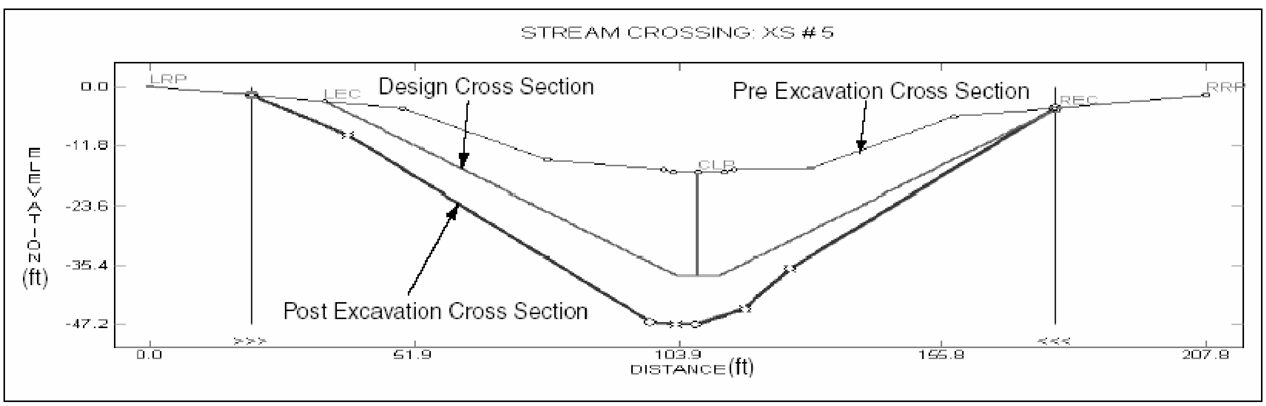


Figure X-D-36. **Redwood Creek 1311 Road Site #3 – Stream Crossing Pre & Post Excavation Cross Sections.**

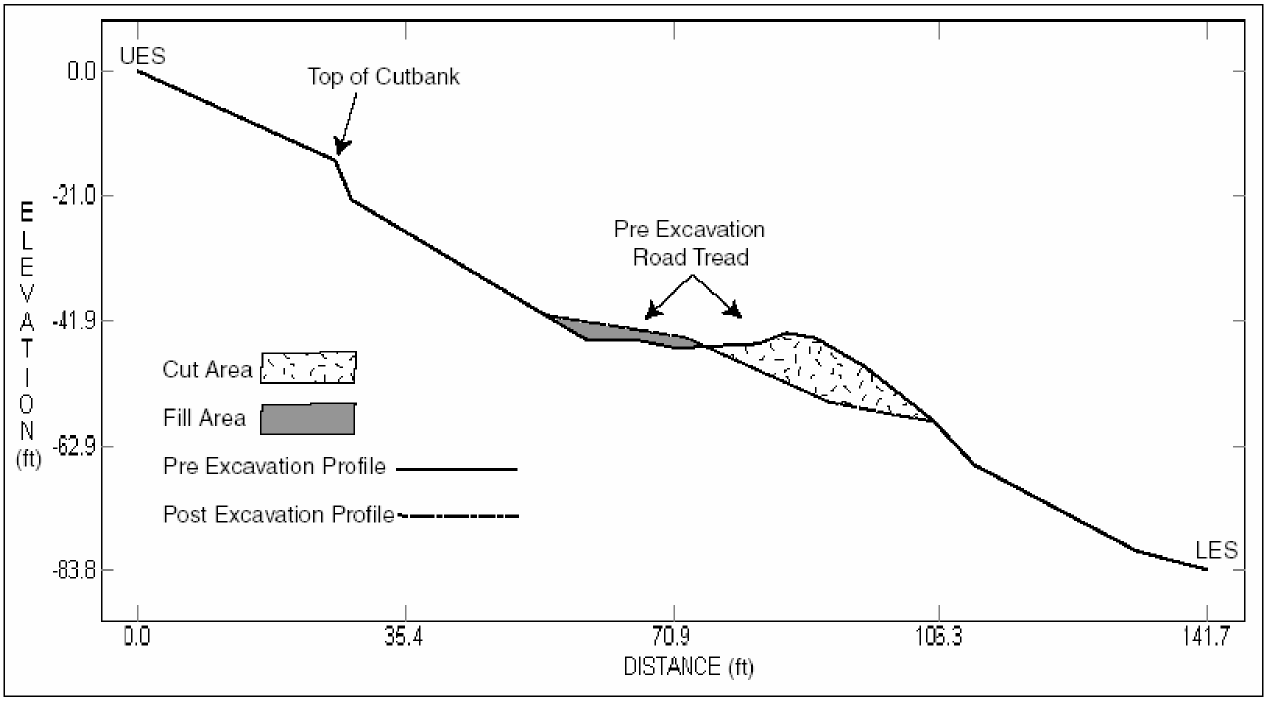


Figure X-D-37. Redwood Creek 1300 Road Site #7 – Road Fill Failure Site Pre- & Post-Excavation Profiles.

Coordinates for Site Locations 2002-2003 Redwood Creek Road Decommissioning Project

Road Name	Site #	X coordinate	Y coordinate
1300	1	423,695.41	4548,833.07
1300	2	423,674.04	4548,834.17
1300	3	423,591.82	4548,870.07
1300	4	423,519.74	4548,914.47
1300	5	423,447.11	4548,942.15
1300	6	423,375.04	4549,023.55
1300	7	423,325.16	4549,100.56
1300	8	423,239.10	4549,141.12
1300	9	423,139.62	4549,466.70
1300	10	423,076.31	4549,498.49
1300	11	422,945.03	4549,706.51
1300	12	422,818.42	4549,715.55
1300	13	422,845.82	4549,792.01
1300	14	422,777.86	4549,909.31
1300	15	422,741.68	4549,936.72
1300	16	422,678.37	4549,918.90
1301	1	423,444.92	4548,999.98
1305	1	423,674.04	4548,864.59
1305	2	423,585.24	4548,922.14
1305	3	423,548.79	4548,953.39
1305	4	423,507.41	4548,984.36
1305	5	423,486.30	4549,015.60
1305	6	423,465.75	4549,057.26
1305	7	423,450.13	4549,093.43
1305	8	423,398.06	4549,155.92
1305	9	423,345.71	4549,207.99
1305	10	423,325.43	4549,234.57
1305	11	423,304.33	4549,266.27
1305	12	423,283.77	4549,296.24
1305	13	423,268.15	4549,358.72
1305	13.1	423,268.43	4549,400.38
1305	14	423,257.74	4549,452.45
1305	14.5	423,247.05	4549,483.70
1305	15	423,231.43	4549,504.80
1305	16	423,211.15	4549,540.70
1305	17	423,195.53	4549,561.80
1305	18	423,185.11	4549,597.70
1305	19	423,156.34	4549,654.44
1305	20	423,116.87	4549,697.19
1305	21	423,085.63	4549,737.75
1305	22	423,049.18	4549,769.27
1305	23	422,977.37	4549,805.44
1305	24	422,919.27	4549,871.22
1305	24.1	422,863.91	4549,932.06
1305	24.2	422,827.19	4549,963.85
1310	1	422,966.96	4549,113.44
1310	2	423,279.66	4548,838.28
1310	3	423,076.58	4549,041.09
1311	1	423,090.83	4547,726.14
1311	2	423,147.84	4547,892.50
1311	3	423,314.74	4548,178.62
1311	4	423,341.05	4548,142.17
1311	5	423,356.40	4548,204.10
1312 Upper	1	423,533.72	4548,432.95
1312 Upper	2	423,408.47	4548,911.73
1312 Upper	3	423,393.12	4548,974.76
1312 Lower	1	423,746.94	4548,645.89
1312 Lower	2	423,710.49	4548,609.99
1312 Lower	5	423,767.49	4548,672.47

Table X-D-13. Universal Transverse Mercator (UTM) coordinates for site locations Redwood Creek Road Decommissioning Project – 1300 Roads Humboldt County, California.

UPSLOPE INVENTORY DATA FORM

ASAP (Y, N)______

GENERAL	Site no:	Treat (Y/N):	Watershed:	Quad:	
	GPS:		CALWAA:	Photo:	
	T/R/S:		Road name/#:	Drivable (Y/N):	
	Mileage:		Inspector(s):	Date:	Year built:
	Surface: □ rock □ native □ paved		Status: □ maintained □ abandoned □ decommissioned		
	Proposed: □ upgrade □ decommission			Sketch (Y/N):	
PROBLEM	Stream crossing (Y/N):		Landslide: □ fill □ hill □ cut	Roadbed: □ bed, □ ditch, □ cut	
	□ ditch relief culvert		□ gully	□ bank erosion	Road related (Y/N):
	Other non-road related site: □ home □ agricultural □construction □ mining □ other site				
LANDSLIDE	□ road or landing fill		□ hillslope debris slide (>50% original ground)		□ cutbank slide
	□ deep-seated landslide		□ potential failure	□ past failure	Slope (%):
	Distance to stream (ft):				
STREAM	□ culvert	□ bridge	□ Humboldt	□ fill	□ ford	□ armored fill
	□ excavated crossing		% excavated:		
	Ditch road length (ft): Left:		Right:	Culvert diameter (in):	
	Pipe condition (O, C, R, P): Inlet:		Bottom:	Outlet:	□ separated
	Headwall (in):		Culvert slope (%):	Stream class (1,2,3):	
	Culvert rust-line (in): Inlet:		Outlet:	Culvert undersized (Y, M, N):	
	Washed out (%):		Diversion potential (Y/N):	□ currently diverted	
	Road grade (%):		Plug potential (H, M, L):	Plugged (%):	
	Channel gradient (%):		Channel width (ft):	Channel depth (ft):	
	Sediment transport (H, M, L):		Drainage area (acres):		
FISH PASSAGE	Culvert outlet drop (in):		Bankfull drop (in):		
	Pool size bankfull width (ft):			Pool size bankfull depth (ft):	
EROSION	Erosion potential (H, M, L):		□ potential for extreme erosion		
	Volume extreme erosion (<500, 500-1,000, 1-2K, 2-5K, >5K):			Past erosion (yd^3) (optional):	
	Past delivery (%) (optional):		Total past delivery (yd^3):		
FUTURE EROSION	Future erosion (ft): Width:		Depth:	Length:	Future erosion(yd^3):
	Future delivery (%):		Total future delivery (yd^3):		

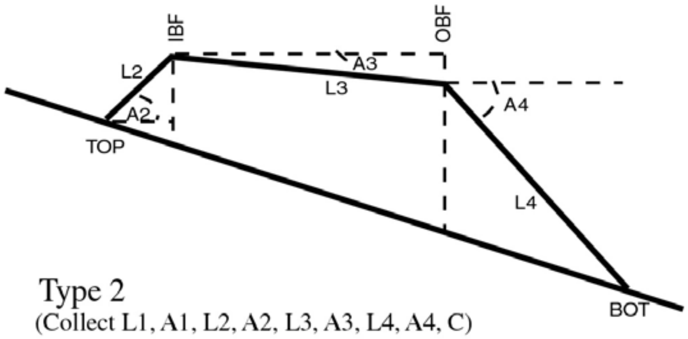
COMMENT(S) ON PROBLEM:

TREATMENT	Immediacy (H, M, L):		Complexity (H, M, L):		
	check culvert size (Y/N):		□ bridge	□ no treatment	Mulch (ft^2):
TREATMENT OPTIONS	□ excavate soil	□ critical dip	□ ford	□ armored fill	Sill height (ft):
	Sill width (ft):	□ trash rack	□ Add downspout: Length (ft):		Diameter (in):
	□ repair culvert	□ clean culvert	□ install/replace culvert		
	Culvert: Diameter (in):		Length (ft):	□ flared inlet: Diameter(in):	
	□ reconstr. fill	□ armor fill face (U, D, B):		Armor area (ft^2): U:	D:
	□ clean or cut ditch, (ft):		□ remove ditch, (ft):		
	□ outslope road, (ft):		□ outslope & remove ditch, (ft):		
	□ outslope & retain ditch, (ft):			□ inslope road, (ft):	
	□ rolling dip, (#):		□ remove berm, (ft):		
	□ ditch relief culvert, (#):		Length (ft):	□ rock road surface, (ft^2):	
	□ cross road drain, (#):		□ other:		
HEAVY EQUIPMENT EXCAVATION DATA	Total vol. excavated (yds^3):		Volume put back in (yds^3):		
	Volume removed (yds^3):		Volume stockpiled (yds^3):		
	Volume endhauled (yds^3):		Distance endhauled (yds^3):		
	Excavation production rate: (yds^3/hr):				
EQUIPMENT HOURS	Excavator:	Dozer:	Backhoe:	Grader:	Loader:
	Dump truck:		Labor:	Other:	

COMMENT(S) ON TREATMENT:

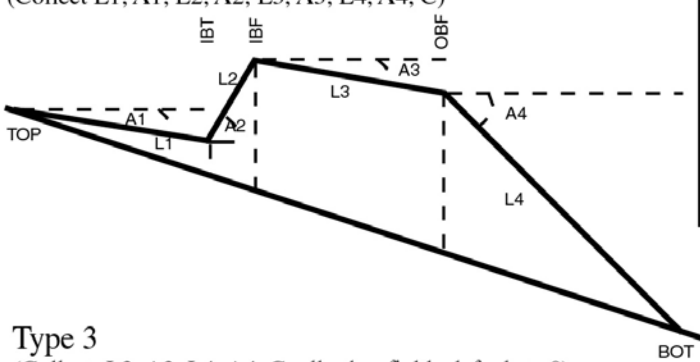
Type 1

(Collect L2, A2, L3, A3, L4, A4, C, all other fields default to 0)



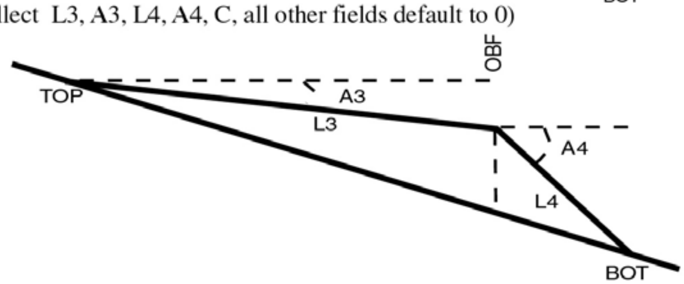
Type 2

(Collect L1, A1, L2, A2, L3, A3, L4, A4, C)



Type 3

(Collect L3, A3, L4, A4, C, all other fields default to 0)



Field data

Length of sediment fan (L1): _____ ft

Angle of sediment fan (A1): _____ degrees

Length of inboard fillslope (L2): _____ ft

Angle of inboard fillslope (A2): _____ degrees

Length of road bed (L3): _____ ft

Angle of road bed (A3): _____ degrees

Length of outboard fillslope (L4): _____ ft

Angle of outboard fillslope (A4): _____ degrees

Channel width (C): _____ ft

Sketch

STREAM BANK INVENTORY DATA FORM

GENERAL	Site no:	Distance (ft):		Date:	Inspector(s):	
	Watershed:			Stream:		
	Air photo:		Location (LB, RB, B):		☐ road related	Treat (Y/N):
PROBLEM	Type:	☐ debris slide	☐ debris torrent		☐ slow, deep-seated landslide	
		☐ torrent channel		☐ bank erosion	☐ LDA	☐ other
	Delivery: ☐ past		☐ future	☐ both	Activity (A, IA, W):	
	Age (decade):		Stream bank slope (%):			
	☐ land use	☐ undercut by stream				
PAST EROSION	Width (ft):	Depth (ft):	Length (ft):		Volume (yd^3):	
FUTURE EROSION	Future erosion potential (H, M, L):		Width (ft):		Depth (ft):	
	Length (ft):			Volume (yd^3):		
COMMENT(S) ON PROBLEM:						
TREATMENT	Immediacy (H, M, L):		Complexity (H, M, L):		Equipment or labor (E, L, B):	
	Equipment access (E, M, D):		☐ local materials		☐ import materials	
TREATMENT OPTIONS	☐ excavate soil	Width (ft):	Depth (ft):	Length (ft):	Volume (yds^3):	
	☐ rock armor/buttress		rock armor size (ft or ton):		rock armor area (ft^2):	
	☐ log protection		Log size: Length (ft):		Diameter (ft):	
			Bank length protected (ft):		Bank area to cover (ft^2):	
	☐ remove logs/debris				☐ boulder deflectors	
	Deflectors (#):		Deflector (yd^3):		☐ bio-engineering	
	☐ plant erosion control		☐ riparian restoration		Area planted (ft^2):	
	☐ exclusionary fencing		Length of fence (ft):		☐ other	
EQUIPMENT HOURS	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor:	Other:
COMMENT(S) ON TREATMENT:						

SKETCH

CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL

PART XI

RIPARIAN HABITAT RESTORATION

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Circuit Rider Productions, Inc. (CRP) developed Part XI, Riparian Habitat Restoration under a grant agreement with the California Department of Fish and Game. Circuit Rider Productions, Inc, is a community-based agency dedicated to the enhancement of human and ecological systems. CRP has been engaged in ecological restoration in California since 1976. The following CRP staff collaborated in the development of Part XI, Riparian Habitat Restoration:

Name and Title	Role in Project
Rob Evans, Restoration Projects Manager	principal plant and habitat photographer
Karen Gaffney, Restoration Ecologist	principal writer, miscellaneous photography
Katherine Gledhill, Environmental Educator	editing, desktop publishing
Cheryl Dean, Ecologist/Research Coordinator	research, editing, technical writing
Greg Fisher, Ecological Services Technician	research, technical writing

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PART XI. RIPARIAN HABITAT RESTORATION

INTRODUCTION

Natural riparian habitat includes the assortment of native plants that occur adjacent to streams, creeks and rivers. These plants are well adapted to the dynamic and complex environment of streamside zones.

Approximately 95% of the historic riparian habitat has been lost in California, making way for cities, agriculture, mining and other development. The riparian area provides one of the richest habitats for large numbers of fish and wildlife species which depend on it for food and shelter. Many species, including coho and Chinook salmon, steelhead, yellow-billed cuckoo and the red-legged frog, are threatened or endangered in California. Others are rapidly declining.

Most landowners wish to protect their riparian resources while optimizing the value and productivity of their property. These two goals sometimes seem to conflict. An understanding of riparian habitat and stream processes can help landowners conserve riparian resources, and still manage their property productively, and even enhance their property value.

California residents, landowners, land managers, and agencies are increasingly interested in conserving and enhancing watersheds and implementing management practices that are more fish friendly. The riparian corridor is the critical interface between terrestrial and aquatic systems. Increasing numbers of individuals and community groups are involved in habitat conservation and restoration projects in riparian areas. Part XI is intended to encourage and help facilitate the stewardship and restoration of riparian habitat in California watersheds.

In addition to providing basic information about riparian corridors, this Part is intended to assist agencies, landowners, schools and community groups with the planning and implementation of native plant revegetation projects. A plant identification section at the end of Part XI provides detailed descriptions and photographs of plants commonly found along central and north coast California rivers and streams.

STREAM PROCESSES AND RIPARIAN HABITAT

The plant species found in riparian communities differ widely depending upon the character of the watershed and the stream's location within the watershed. The composition of a riparian community is determined by many things, including the reach type, stream slope (gradient), channel confinement, aspect, light availability, water availability, flooding and soil conditions.

For example, at the headwaters of a stream, the gradient is often steep and the riparian vegetation may not vary from the surrounding forest plant community. Further downstream, as the gradient decreases, the riparian corridor begins to differ from the surrounding forest plant community. The riparian canopy is often dominated by trees such as alder, ash, maple, box elder, and oaks, while the surrounding forest may be dominated by conifers. In alluvial areas, sunny openings on gravel bars often provide habitat for species such as mulefat and willow.

Different age classes and species of riparian habitat at different elevations

Streams and their tributaries often cut through broad alluvial valleys. In these alluvial zones, where the substrate is dominated by sand, gravel and silt, the stream freely moves (meanders) back and forth over time, creating and removing riparian habitat naturally. The ability of the stream to move through this meander corridor is what allows the development of diverse riparian forests. Streams in these alluvial areas may have historically included a broad floodplain mature forest with backwater sloughs, oxbow lakes and floodplain wetlands. These diverse habitat features are important for salmonids and other wildlife. Riparian corridors that are wide enough to allow for stream meandering should require little maintenance over the long term. A substantial riparian zone can help to reduce erosion damage to adjacent lands, as well as filter sediment and pollutants. However, due to the high value of agricultural lands as well as the proximity of urban development and other land uses, natural stream movement may not be possible in all managed watersheds.

Russian River meander corridor

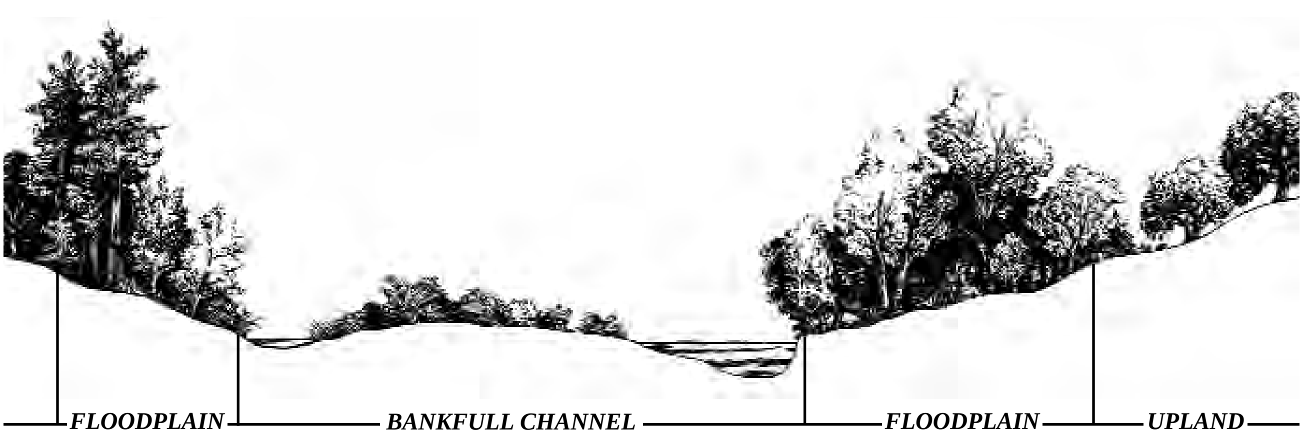
Within the bankfull channel (an area which is regularly flooded), plants are adapted to high levels of flood disturbance during the winter, while tolerating the hot, dry conditions of the gravel bars during the summer. Very few species have the ability to survive in this harsh channel environment; those that do include alder, willow, cottonwood and mulefat. They are called pioneer species, because they colonize recently disturbed sites.


Bankfull channel with small seedlings of pioneer species

The seeds of cottonwood and willow float through the air in the spring just as the water level is beginning to recede. Millions of seeds land on moist gravel bars and germinate there. As the summer progresses, the roots of these tiny seedlings follow the receding water table. Those plants that cannot stay connected to the water table face certain death on the desert-like gravel bar. Those plants that survive the summer drought and winter flood cycle will grow at incredible rates, up to 15 feet per year. As they grow, these pioneer species may begin to trap sediments, and can influence the movement of the stream.

The floodplain is elevated above the bankfull channel and is characterized by many more species than found in the bankfull channel. Floodplain areas support plants that are less adapted to flood scour and do not require as much summer moisture.

Floodplain riparian forests are some of the most important, *and the most impacted*, habitats in California. Intact riparian forests tend to be a dense tangle of large trees in the over-story, and smaller trees, vines, downed wood, and various herbs and fungi in the under-story. The diversity of plants and complexity of habitats in these mature riparian forest zones supports an incredible number of animal species.



Representative cross-section of riparian area

FISH AND WILDLIFE VALUES OF RIPARIAN HABITAT

Salmonids (including coho, Chinook and steelhead) rely on healthy riparian habitat. Riparian trees shade the stream channel, helping to cool the water and retain high levels of dissolved oxygen. Native streamside vegetation provides leaf litter which is eaten by many aquatic insects. These insects are in turn consumed by fish. Roots of riparian plants provide fish with shelter from predators. When large riparian trees fall into the stream, they supply an important structural element in creeks and rivers which helps form pools, sort the substrate, and provide shelter for fish and other aquatic organisms.

Salmonid

Riparian zones along intermittent streams also provide salmonid habitat. Coho salmon and steelhead spawn in the upper reaches of streams and their tributaries while they are flowing in winter. The fry emerge and migrate down to the perennial reaches before the tributaries dry up in summer. These tributaries also serve as important sources of food, spawning gravel, and woody debris that are flushed into the mainstem of a stream during storms. Therefore, alterations to the riparian zones of these seasonal tributaries can have a significant impact on salmonids.

Salmonid

In addition to the important role they play in the salmonid life cycle, riparian areas support an abundance of other wildlife species. Over half of the reptiles and three-fourths of the amphibians in California, including the western pond turtle, red-legged frog and various tree frogs, live in riparian areas. Large numbers of migratory and resident birds rely on streamside habitat. Over one-hundred native species of land mammals are dependent on the riparian zone, including raccoons, ringtails, and river otters. Black-tailed deer utilize riparian zones for fawning.

Pacific tree frog (Hyla regilla)

In an intact riparian corridor, there is a layering effect of plant sizes, shapes and ages that promotes wildlife diversity. A mature riparian forest has a low layer of groundcover, an intermediate layer of shrubs and small trees, and a high canopy of trees and vines. These different layers provide many sites for shelter and food for birds, insects and mammals. In addition, large trees will mature and die, leaving standing snags that provide habitat for cavity nesting birds and other terrestrial wildlife.

Bobcat

Finally, riparian areas act as wildlife corridors, providing important routes for the movement of aquatic species (fish, amphibians, insects), land animals (reptiles and mammals), and birds within a watershed. Stream corridors can be thought of as the circulatory system of the watershed, allowing terrestrial wildlife and fish to migrate up and downstream.

HUMAN VALUES OF RIPARIAN HABITAT

Riparian habitat provides many benefits to streamside landowners. For example, a wide strip of riparian vegetation can offset flood damage to adjacent agricultural lands by acting as a filter for trees and other debris that may wash in during large floods. Riparian vegetation also traps fine sediments and other pollutants contained in terrestrial runoff, thereby preserving instream water quality. Because of their deep roots and dense growth, riparian trees, shrubs, and grasses provide excellent protection against bank erosion, helping to stabilize streambanks.

In addition to assisting with flood protection and erosion control, riparian vegetation may play a role in integrated pest management. Cavity nesting riparian bird species such as kestrels and owls prey on rodents. Other cavity nesting birds such as wrens, tree swallows, oak titmice and bluebirds may help reduce populations of pest insects. Bobcats, coyotes and foxes also use riparian areas to prey on rodents.

Kestrel

Indigenous cultures have relied upon riparian plants for thousands of years, using streamside and wetland plants for basketmaking, as a source of food, and for medicinal purposes.

HUMAN IMPACTS TO RIPARIAN HABITAT

More than 95% of the historic riparian forests in California have been lost due to land use change since European settlement. Logging, urban development, dams, water diversions, gravel mining, and agriculture have all contributed to this loss.

The straightening of creeks for commercial, residential and agricultural activities, and floodplain development, has reduced the width and maturity of the riparian zone, and accordingly changed the river's form through erosional and depositional processes. Dams retain sediment, cut off critical salmonid spawning habitat and may either augment or reduce the natural flow regime. These changes have contributed to the decline of wild salmonids. California rivers once meandered across their forested floodplains, overflowing their banks as a result of winter rains, thus creating a complexity of habitat types. Currently many rivers and creeks have been severely confined, degraded and simplified, resulting in a significant loss of salmonid habitat and biological diversity in general.

Non-Native Invasive Plant Species

Humans have modified riparian areas throughout California in a variety of ways. One of the more serious impacts to native habitats is the introduction of non-native plant and animal species. Invasive plants are a topic of increasing concern for landowners and conservationists. Exotic or non-native plants, such as giant reed (*Arundo donax*) and tamarisk, have spread rapidly and taken over thousands of acres of streamside habitat. These invasive species exclude native vegetation, may increase fire danger and often use large amounts of water, decreasing available resources for fish, wildlife and humans.

Exotic plants usually do not support the same diversity of wildlife found in native riparian forests. If plants such as giant reed or periwinkle dominate the riparian zone, native riparian plants cannot become established. When this happens, the habitat values are often degraded or lost. For example, when an invasive grass such as giant reed becomes established in a riparian area, out-competing native trees such as bay laurel, cottonwood and big leaf maple, the long term consequence is that the large woody debris, shade canopy and leaf litter provided by native species are lost. This results in changes in stream temperature and modification of instream structure and the aquatic food chain. The once complex riparian forest that provided shade, food and structure for salmonids and other species is transformed into a monoculture of grass with very little habitat value. Because riparian species are not especially long lived (20-80 years is typical) invasive species can have extremely negative effects on riparian areas in a relatively short period of time.

Giant reed (Arundo donax)

The following species are common exotic invasive plants found in northern and central California riparian areas, and are pictured in Appendix XI-B:

Common Name	Latin Name	Plant Type
acacia	*Acacia* spp.	tree
cape ivy	*Delairea odorata*	vine
English ivy	*Hedera helix*	vine
eucalyptus	*Eucalyptus* spp.	tree
fennel	*Foeniculum vulgare*	herb
floating primrose	*Ludwigia peploides*	emergent/aquatic
giant reed	*Arundo donax*	grass
Himalayan blackberry	*Rubus discolor*	vine
pampas grass	*Cortaderia selloana*	grass
pepperweed	*Lepidium latifolium*	herb
periwinkle	*Vinca major*	vine
poison hemlock	*Conium maculatum*	herb
tamarisk	*Tamarix* spp.	shrub/tree
teasel	*Dipsacus fullonum*	herb
tree of heaven	*Ailanthus altissima*	tree
yellow star thistle	*Centaurea solstitialis*	herb

Agricultural/Riparian Interface: Pierce's Disease

Pierce's Disease is a fatal disease of grapevines caused by the bacterium *Xylella fastidiosa* which is transmitted by the blue-green sharpshooter insect (*Graphocephela atropunctata*). Certain riparian plants are hosts for the bacteria as well as feeding and breeding hosts for the blue-green sharpshooter. These plants include both native and non-native species and are listed below. In the past, a common practice was to remove all riparian plants adjacent to vineyards in an effort to reduce the incidence of Pierce's Disease. Recent practices have changed to reflect a more surgical approach to removal that only focuses on those plants that are systemic hosts for the bacteria. In systemic host plants, the *Xylella* bacteria spreads systematically throughout the plant after being bitten by the insect. However, in propagative host plants, the bacteria remain at the point of infection and do not spread systemically. Propagative host species are therefore not a high priority for removal. Species such as the invasive, non-native periwinkle (*Vinca major*) are systemic hosts for the bacteria and a breeding/feeding host for the blue-green sharpshooter. These plants are a high priority for removal from an economic perspective, and their removal benefits native riparian habitat as well.

Periwinkle (Vinca major)

The following perennial plants are the major breeding hosts for the blue-green sharpshooter and most are systemic hosts of Pierce's Disease in Napa, Sonoma, and Mendocino counties. Removal of these species has been shown to significantly reduce the number of blue-green sharpshooters in riparian areas and adjacent vineyards (The Pierce's Disease/Riparian Habitat Workgroup, 2000):

NON-NATIVE HOST PLANT LIST

Common name	Latin name
Himalayan blackberry	*Rubus discolor*
periwinkle	*Vinca major*
wild grape*	*Vitis* sp.

* (escaped cultivar or *Vitis californica* hybrid)

NATIVE HOST PLANT LIST

Common name	Latin name
blue elderberry	*Sambucus mexicana*
California blackberry	*Rubus ursinus*
California grape	*Vitis californica*
mugwort	*Artemisia douglasiana*
mulefat	*Baccharis salicifolia*
stinging nettle	*Urtica dioica*

Himalayan blackberry (Rubus discolor)

Mugwort (Artemesia douglasiana)

For more information on the complex topic of Pierce's Disease in north coast streams, visit *www.cnr.berkeley.edu/xylella*, or call your local University of California Cooperative Extension office.

CONSERVATION AND MANAGEMENT OF RIPARIAN HABITAT

Riparian zone in winter with leafless deciduous trees

Many landowners already have intact, healthy riparian corridors on their properties and simply want to preserve these areas in their present state. Others may have riparian areas that are in need of management, due to problems with invasive plants, Pierce's Disease or changes from upstream and downstream land uses. Many landowners are also interested in active restoration of native riparian habitats. The following sections discuss methods for preserving, managing and restoring healthy riparian corridors.

Conserving Riparian Habitat

Healthy riparian corridors require little maintenance over the long term. A stream system that has enough room to move around will sustain a diversity of plant and animal species. Leaving the stream enough elbow room may also protect adjacent land uses from excessive erosion or flood damage.

For those landowners who wish to preserve the integrity of their riparian zones, regular monitoring is recommended. Monitoring can be as simple as walking the stream yearly or seasonally, assessing changes in the stream after a storm or checking for invasive plants or trash that may have been carried in during a flood. More detailed habitat inventory methods are described in Part III of the *California Salmonid Stream Habitat Restoration Manual.*

Conservation of riparian habitat can also be accomplished by placing an easement over the stream corridor. Some conservation easements provide permanent deed guidelines for riparian land uses. Placement of a conservation easement may also provide a tax benefit to the landowner. Some land trust organizations purchase easements from willing sellers.

For more information about conservation easements and land trust organizations, visit the Land Trust Alliance website at www.lta.org.

Managing Riparian Habitats

Vegetation Management

In some cases, active management of the riparian zone may be required. Landowners who have concerns about Pierce's Disease may choose to remove certain plants from the riparian areas adjacent to their farming operation. Additionally, invasive plants, such as giant reed, ivy or tamarisk, should be removed before they become a significant problem.

Manual cutting of giant reed biomass

Surgical removal of native and non-native plants along with re-planting of natives is preferred to the wholesale removal of all riparian habitat. While planning for any riparian vegetation project, contact the Department of Fish and Game for technical assistance. Depending on the project, permits may be required from several different local, state or federal agencies. See Part VI for more information on permits.

Riparian forest invaded by periwinkle

The following non-toxic treatments require a significant commitment of time and labor. These treatments need to be based on an understanding of each plant's physiology (i.e., timing of flowering, size and structure of the root system, etc.). For example, a species such as yellow star thistle may be partially controlled by mowing, but the mowing treatment must take place prior to seed development, or it will cause seed dispersal and make the problem worse. Root removal options will vary according to the species. Young tamarisk or tree of heaven seedlings can be pulled using hand tools, but mature plants may require heavy equipment, potentially a cause of excessive disturbance and siltation in the riparian zone. Disturbed areas should be treated to prevent siltation to the stream. Species such as Himalayan blackberry and periwinkle may have extensive root systems that are difficult to track down and remove. Burning may be accomplished with a backpack torch, but can only take place when there is no threat of wildfire. Tarping is usually implemented after the rainy season has ended. Tarps are then removed prior to the next rainy season. Removal of undesirable plants should be followed with a revegetation program using appropriate native plants which may help to prevent recolonization by other invaders.

There are a variety of non-toxic ways to remove unwanted plant species, and each option should be thoroughly evaluated. Listed below are some non-toxic control options for a variety of invasive non-native plant species. In general, invasive species control will take several years, and will require very careful monitoring and removal of re-growth to ensure success.

Common Name	Latin Name	Removal Options
acacia	*Acacia* spp.	root removal
cape ivy	*Delairea odorata*	root removal
English ivy	*Hedera helix*	root removal, burning
eucalyptus	*Eucalyptus* spp.	root removal
fennel	*Foeniculum vulgare*	root removal, mowing, burning
giant reed	*Arundo donax*	tarping, hand removal (gravel bars)
Himalayan blackberry	*Rubus discolor*	root removal, burning
pampas grass	*Cortaderia selloana*	root removal
pepperweed	*Lepidium latifolium*	root removal, mowing
periwinkle	*Vinca major*	root removal, tarping
poison hemlock	*Conium maculatum*	root removal, mowing, burning
tamarisk	*Tamarix* spp.	root removal, burning
teasel	*Dipsacus fullonum*	root removal, mowing
tree of heaven	*Ailanthus altissima*	root removal
yellow star thistle	*Centaurea solstitialis*	root removal, mowing, burning

If herbicide is being used for the control of invasive plants, extra care should be taken to avoid impacts to the aquatic environment, as well as overspray onto native vegetation. Soils in the riparian zone are very porous. The absolute minimum effective amount of herbicide (per the label) should be used, as excess herbicide is likely to be transported through the air or soils into the stream. Certain herbicides are specially formulated to be less toxic to aquatic organisms and are more appropriate for use in or near aquatic environments. Consultation with your local Agricultural Commissioner's office is required by law.

The following websites provide additional information about invasive species and control options:

http://www.caleppc.org (California Exotic Pest Plant Council)
http://www.cdfa.ca.gov/phpps/ipc/noxweedinfo/ (California Department of Food and Agriculture)
http://ceres.ca.gov/tadn/ (Team Arundo del Norte)
http://endeavor.des.ucdavis.edu/weeds/ (CalWeed Database)

Large Woody Debris

Riparian trees that fall into the stream play an important role in the aquatic system. They provide structure to the stream environment, helping to form pools as well as habitat for a variety of organisms. Large woody debris is an important factor in the recovery of salmonid populations. It is, therefore, desirable to retain a wide riparian corridor with large trees that may be recruited into the stream.

Historically, the approach by many agencies and landowners has been to keep the stream channel clean and open, by removing any log debris accumulation. It was believed that these large trees presented a passage problem for fish. It has since been recognized that fish, especially salmonids, are capable of passing over or through most debris accumulation. Substantial retention of sediment above debris accumulation may indicate a potential fish passage problem. Streams with large woody debris provide good quality salmon habitat.

Large woody debris creates pool habitat

Streamside landowners are understandably concerned that large fallen trees may divert the stream towards their banks, causing massive erosion and loss of land. In these cases, large trees are often removed from the system prior to the next flood event. In recent years, there has been a trend towards modification of large debris accumulation, rather than complete removal. An example of this might include pruning tree limbs and allowing the trunk to remain in the stream. This approach allows for the habitat benefits associated with large woody debris, while resolving problems such as fish passage. Contact the California Department of Fish and Game for more information on this topic. See Part VII on barrier modification and log structures for habitat enhancement.

Large woody debris provides structure to the stream environment

RESTORATION OF NATIVE RIPARIAN HABITATS

Natural Regeneration and Exclusionary Fencing

Riparian systems are often capable of rapid natural regeneration after a disturbance such as a flood, fire or other event causing modification to the landscape. The gravel bars and banks in the bankfull channel will often revegetate on their own within a year or two, provided there is an upslope or upstream source of seeds or plant material. Floodplain areas may take significantly longer and may warrant active revegetation to jump start the natural regeneration process.


Stream floodplain being grazed by livestock

In areas that are being grazed by livestock or are heavily impacted by other native grazing herbivores, exclusionary fencing can give the streambank enough protection to re-create healthy stands of native vegetation. Fencing may be temporary, maintained just long enough to allow native trees and shrubs to re-establish (ten years is often adequate).


Exclusionary fencing along stream headwaters

If fencing is used to allow for the regeneration of riparian habitat, it should be set back far enough to allow the stream to meander and create a diversity of habitat. Fences placed too close to the stream corridor may be damaged during high flows, wasting time and money.

Fencing design, including type of wire, gauge and spacing must be specific to the types of animals you are attempting to exclude. Many fencing supply stores have this information and can help you with construction specifics. Alternative water sources for livestock should be devloped to keep them out of the stream channel. If conditions require that livestock access the stream for pasturing or crossing between pastures, use specialized floating fences (which span the channel) to limit such access. When funding restoration projects, the Department of Fish and Game requires a riparian management plan to be developed and signed by the landowner. For more detailed information on exclusionary fencing, see Part VII.

Erosion Control

Large flood events may create the need for erosion control work in the riparian zone to prevent excess siltation into the stream or loss of land. Whenever possible, a vegetative method for reducing erosion such as bioengineering is preferable to a structural approach such as riprap. Structural approaches to stream bank erosion such as riprap tend to fix the stream in one place, exclude riparian vegetation, and prevent the natural movement that creates diverse habitats. Structural approaches are often more expensive, require permits, and may damage neighboring properties. Over the long term, structural approaches tend to fail or require excessive maintenance. If a structural approach is unavoidable, native vegetation should be incorporated into the structure. Bioengineering will increase the effectiveness of the erosion control method and provide some habitat value as well. See Part VII for descriptions of bioengineering.


Installation of erosion control

Planning and Implementing a Successful Revegetation Project

Revegetation using native plants is effective for enhancing habitat for numerous fish and wildlife species, as well as reducing upslope erosion and sedimentation to streams. Revegetation may include:

- broadcast seeding of native grass or forbs on hillslopes
- instream sprigging of dormant willow cuttings to increase cover and reduce bank erosion
- installation of plants propagated in a native plants nursery
- transplanting of emergent species such as rush, tule or sedge
- direct seeding of native species such as oaks or buckeyes.

The landowner, project personnel, or watershed organization should become acquainted with the stream processes and natural habitat of the area to create a plan that works within the local riparian ecosystem. While planning for any riparian vegetation project, contact the Department of Fish and Game or the Natural Resources Conservation Service for technical assistance. Depending on the project, permits may be required from several different local, state or federal agencies.


Tree shelter installation

Creating and implementing a revegetation project can be a complex process, taking four to six months for design and approval, and several additional months for implementation. In some cases, involving a consultant or watershed group with expertise in the process can save time and be more cost effective. See Part VI for more information on permits.

Riparian Revegetation Project Planning

A successful revegetation project will:

- establish a diversity of native plant types and plant species in the riparian area
- provide fish and wildlife habitat
- reduce erosion
- require minimal annual management.

Revegetation should attempt to replicate the natural system.
In the riparian zone, different species are adapted to distinct microsites, often based on elevation and proximity to the stream. Planning of a riparian revegetation project should take into account where each species occurs in the natural system. It can be helpful to draw a cross-sectional diagram of the riparian zone showing where different species occur. This can help determine planting sites based on elevation above the bankfull channel.

Diverse riparian and upland habitat

In general, container planting in the bankfull channel is not recommended.
If there is a severe bank erosion problem, or the system has lost all upstream sources of seed, some active channel revegetation may be warranted. Since the bankfull channel is subject to regular flooding, installed plants are likely to wash out prior to establishing a root system. Willows, whether as sprigs, a willow mattress or willow wall, are adapted to this flood prone environment, and can be an effective, relatively inexpensive way to stabilize a streambank or introduce cover to the stream. Plants installed in the bankfull channel should not have protective hardware, as it will likely be lost to flooding.

Seeds, cuttings or transplants should be collected as close as possible to the project site.
Local collection of plant material ensures that only genetically appropriate plants (i.e., those that are adapted to local conditions) will be used on site. Introduction of plant material from outside of the project watershed is not recommended. The use of local plant material usually results in higher survival rates.

Valley oak (Quercus lobata) an important native seed

Sources for Native Plant Material

Appropriate, site specific native plants are one of the most important aspects of a successful riparian restoration project. Project planning may need to begin up to 18 months in advance to obtain those species that must be grown in containers. For example, a particular species may have seed that ripens in July. After treatment of the seed and propagation in the nursery, the plant may not be ready for outplanting until the following fall/winter. This is often the most important phase of planning a successful restoration project. If you are not in a position to grow the plants yourself, it is a good idea to order plants from a local native plants nursery as soon as you have selected a restoration site.

Bare-root stock can also be used instead of container stock. However, bare-root stock is often difficult to locate because few nurseries produce it. Spacing of plants depends on the species, the goals of the project, desired densities, and many other factors. General spacing recommendations are included in Table XI-1, page XI-26.

Nurseries specializing in California native plants do things differently than typical landscape nurseries. California native plant nurseries usually custom collect site specific material for particular restoration projects, or at minimum, they track where the plant material was collected. This ensures that you can purchase plant material suitable for your project site.

The California Native Plant Society website, *http://www.cnps.org/links/grow links.htm* includes a variety of resources about California flora, including a list of native plant nurseries.

Common container sizes found in native plants nurseries are listed below:

Container Name	Size	Uses
6" and 8" supercell	1 1/8" x 6" 1 1/8" x 8"	Best for plants with fibrous root systems
deepots	2 1/2" x 10"	Good for trees and shrubs
treepot	4" x 14"	Generally used for trees
treebands	2 1/2" x 5"	Good for trees and shrubs

Native plants nurseries also use unique containers like treepots, deepots or supercells (shown to the left) to develop an optimum root-to-shoot ratio (see example photo, above right). This approach provides plants with a well established root system prior to outplanting at the revegetation site.

Revegetation Techniques

Emergent Transplant Installation

Plants such as rushes, sedges and tules are commonly called emergent plants, because they are often associated with creeks, wetlands and lakes, where they emerge from the water. They may reproduce from seed or from the spreading of underground rhizomes. This vegetative form of reproduction makes emergent species ideal candidates for transplantation into revegetation sites. These species are widely adapted to a range of environments, including high velocity bankfull channels, slow moving backwaters, seeps on hillslopes, and stable, relatively dry floodplains. It is important to identify the species to use and transplant them in an appropriate location. There are also some non-native species of emergents that should not be transplanted into riparian zones. Care should be taken to sensitively harvest these plants so the existing population is not seriously degraded. It is a good idea to take several small clumps from a variety of larger clumps, leaving the majority of each population intact to ensure genetic diversity.

Steps required to transplant emergent species:

- In the winter or early spring, carefully harvest rhizomes and the above-ground portions of the plant with a mattox, sharp trowel or shovel. Make sure one to several intact rhizomes remain for each transplant.

- Store the collected plant in a cool moist location until time for transplanting. Ideally, plants should be stored in moist soil, and should be transplanted as soon as feasible after collection.

- Dig a hole for the transplant that is large enough to accommodate the extended rhizome without bending or breaking it. Place dirt around the rhizome, pack it down, and water it in thoroughly to close any air holes around the rhizome.

- Trim back the above ground portions of the plant in order to stimulate rhizome growth.

Collecting emergent vegetation

Emergent vegetation, rhizomes exposed

Installation of emergent vegetation

Dormant Willow or Cottonwood Sprig Installation

Willows and cottonwoods are in the willow family (*Salicaceae*) and are generally adapted to bankfull channel environments. Species in this family form specialized roots along their stems, allowing for vegetative reproduction in riparian corridors. This feature makes them good candidates for installation as sprigs or dormant cuttings. In general, willows need significant amounts of light and a year-round source of moisture. They are good candidates for revegetation as long as their root zone remains moist during the summer. Because of their ability to withstand flood flows, they are often a good choice for bank stabilization projects in bankfull channel areas. There are many varieties of willow and cottonwood in California. Some (such as the curly willow and Lombardy poplar) are not native and should never be planted in riparian areas. They may not supply the same habitat values as the native plants, and may hybridize with them. Cuttings should be harvested from a variety of parent plants in order to avoid out-planting genetically identical material. These techniques result in a more successful project, will ensure genetic diversity, and do the least damage to the collection site.

Sharp, clean loppers produce high quality sprigs and cuttings

Typical dimensions for willow and cottonwood sprigs

Steps required to install dormant willow and cottonwood cuttings:

- Harvest cuttings during the winter months when plants are dormant (usually December-January). Although willows and cottonwoods will grow from cuttings at other times of the year, dormant cuttings are more resistant to disease, have higher survival rates, and do not require irrigation if planted in the appropriate location. Sprigs may be harvested using sharp, clean loppers, hand shears, or a chainsaw. The cuttings

Store cuttings in a moist environment

may be collected at a range of sizes (i.e., ½ inch to 4 inches diameter and up to 8 feet long). It is important to select material that has not become too woody, and that has several viable buds along the stem.

- Cuttings may be used immediately, stored on-site in the stream, or stored off-site in a bucket of cool water. Ideally, material should be harvested and installed the same day.

- Sprigs should be installed with buds pointing up, with approximately ¾ of the cutting in the soil, and ¼ exposed. Holes may be dug with a pick, with a piece of rebar, with an auger, or a backhoe (for large material). In areas with soft soil, you may avoid digging a hole by cutting the bottom at an angle and pounding it into the ground with a small sledge hammer. If the top is damaged by the hammer, cut off the top of the sprig to allow for clean healing or place a driving shield over the top to drive in the sprig.

Auger used for planting holes

Small sledge hammer for installing sprig

Clean, sharp loppers cut off damaged top of sprig

Container Plant Installation with Shelters
Container plants need to be ordered or propagated months in advance and may be grown by a native plants nursery or an individual practitioner (see page XI-16). Although the installation of container plant material requires more up-front planning than sprigging, emergent transplants and direct seeding, it also allows for the installation of a more diverse plant palette. Some projects use a two-phased approach, with cuttings, emergents and direct seeded species installed the first year, followed by installation of container plants the second year.

Remove weeds from the planting area

Steps required for installing container plants with shelters:

- Plants should be installed during the winter. Plants that will not be irrigated should be planted from December through February, after rains have thoroughly saturated the ground. Plants that will be drip irrigated can be installed at other times during the year. Because of the dangers of planting on the bank of a stream during high flow periods, when stream banks are slippery and the current swift, it may be best to delay some projects until conditions are safe.

Dig the planting hole twice the depth of the root ball

- When installing plants, dig holes to twice the depth of the root-ball of the plant to be installed, crumbling any large soil clumps. Partially refill the hole, firmly tamping the soil to create a firm base for the new plant. Place the plant so the top of the root-ball is slightly above finish grade, to allow for future settling. Fill the hole and tamp firmly to remove any air pockets. Irrigate immediately, ensuring the water soaks deeply, unless the ground is already saturated.

Water the plant immediately, ensuring that the water soaks deeply. If planting in low moisture conditions, plants should be watered during the planting process and therafter until rains begin.

- Where damage from domestic animals and wildlife is a concern, consider protecting plants with shelters (except those that will be in flood-scoured areas). Shelters should be firmly staked and tied so they will remain upright. There are a variety of shelters available, ranging from chicken wire enclosures (screen and collar, shown in photo at bottom) to plastic tubes (a.k.a., *supertubes,* shown in photo at right). All of these methods have proven successful, if they are maintained and weeds are controlled. Shelters should be removed as soon as the plants begin to outgrow them (3-5 years is typical for riparian plants).

- Weeds should be carefully controlled in revegetation areas before and after installation. Plants can become lost in the weeds, increasing maintenance costs and reducing project success. Mow tall weeds before installation, and consider using weed mats (3-foot-diameter sheets of specially designed woven or perforated plastic) around each new plant.

Installation of supertube on newly planted native seedling

Installation of weed mat

Installation of screen and collar protective hardware

Direct Seed Installation

Several riparian species are good candidates for direct seeding. These include large seeded species such as buckeye, native California black walnut, California bay laurel and the native oaks. Large seeds provide these species with a reserve of nutrients that can sustain them during the early phases of seedling development. Although some other seed producing species can be direct seeded under ideal conditions (including weed free environments with good soil moisture), it is generally not a successful technique. Additionally, many seeds are adapted to very specific conditions prior to germination, and may require treatment such as cold stratification or seed coat scarification. In order to ensure genetic diversity and maximize project success, seeds should be collected from several source plants.

Buckeye seed with developing root

Steps required for direct seeding:

- Collect the buckeye, bay, walnut or oak seeds when ripe (fall or winter, depending on the species). Ideally, seeds should be collected from the trees, rather than the ground in order to reduce damage from insects and bacteria. Seeds should come off easily. Check each seed for large numbers of insect holes or mechanical damage, and discard those that appear diseased or feel lighter than the others.
- Store seeds in a cool place until ready for out-planting. If seeds will be stored for more than a few days, they should be placed in plastic bags with perlite and refrigerated.

Careful placement of buckeye seed

- Plant seeds in the winter, when soil moisture has reached a depth of 10 inches or more. Dig a shallow hole at each planting location, and cover seeds with one to two inches of soil. If seeds have begun to germinate, care should be taken to protect the tender new root. For buckeye, only one seed should be required, whereas for the other species you will want to install three to five seeds per planting spot. Once they have germinated, you can select the strongest seedling and clip the others with shears.
- If you choose to protect seedlings from deer browse, the techniques described on the following pages may be used.

Cover seed with 1-2 inches of soil

Project Maintenance

Maintenance of native plant revegetation projects is critical to project success, and often requires an equal or greater expenditure of labor and resources than the installation phase. Maintenance usually includes weeding, watering and general monitoring.

Important maintenance tasks include:

- Regular hand weeding around individual plants during the height of growing season in spring and early summer, as well as one final weeding in the fall. In some cases, where tall weedy species like mustard, hemlock or fennel are present, the whole site may require mowing or mechanical weeding in order to ensure site access and reduce excess shading.

- Soil moisture should be checked on a regular basis during the first two to three growing seasons and plants evaluated for drought stress. The watering regime (whether hand irrigation or a drip system) should be scheduled according to plant needs, rather than an arbitrary schedule. Irrigation should include the minimum amount necessary to keep the plants healthy so they do not become dependent upon additional water. If the plants are appropriate to the location, and installed correctly at the right time of year, they should not require irrigation past year three. Watering should taper off as the plants mature.

- General monitoring should take place at each maintenance visit. Each plant should be checked for signs of disease, rodent or insect browse, and drought stress. Damaged plants should be replaced when possible. Encroachment by invasive species should also be monitored, and these species controlled before they take over the revegetation site.

Mechanical weeding of project site

Hand watering of individual plant

REGULATORY AGENCIES AND REQUIREMENTS

(excerpted from The Pierce's Disease/Riparian Habitat Workgroup, 2000
Riparian Vegetation Management for Pierce's Disease in North Coast California Vineyards)

Several federal, state, and local agencies have regulatory authority over work done in the riparian corridor and may need to be contacted for a revegetation project. It is the landowner's responsibility to be familiar with these agencies and notify them when a project is planned.

Different agencies may have jurisdiction over a project, depending on the character or extent of the project. Most revegetation projects will involve only the removal of specific non-native plants, and replanting of native plants. Such simple revegetation projects will require the least regulatory agency input. The one agency that will certainly require notification, even for a simple revegetation project, is the California Department of Fish and Game. In addition, the Regional Water Quality Control Board may need notification if the project would result in soil erosion, and/or runoff of pesticides into the stream (due to removal of a vegetative buffer).

Some revegetation projects may have a streambank stabilization component. If the stabilization involves re-contouring of the streambed and banks, the United States Army Corps of Engineers and NOAA Fisheries may need notification, in addition to the two agencies mentioned above. Streambank stabilization projects that use bio-technical approaches, such as live vegetation baffles and revetments, will have fewer negative impacts to natural resources and may need less regulatory agency involvement than projects with standard engineering and riprap. The use of standard engineering and riprap is generally discouraged in areas that contain threatened and endangered species, such as salmon and steelhead, because of the negative effects on habitat.

Formal agency notification typically involves completing a form that describes the project, often with a project design map and written description, and paying a fee. Talking to agency representatives about the project before this formal notification can save a significant amount of time. Most agencies encourage informal consultation in the early stages of project planning. The concerns of each party can be addressed, and potential roadblocks eliminated or reduced. In some cases, one agency may pass your project on for review by other agencies, but do not assume this will happen. The landowner and project manager is always responsible for informing all agencies. Many of these agencies charge fees to process the applications and permits. Call each agency for information and a current fee schedule.

Riparian revegetation project, Russian River watershed

Become familiar with the regulatory agencies described below. Even better, get to know the agency staff that work in your area and find out what their interests are, before designing your project (refer to Part VI, Project Planning and Organization).

Activity	Agency to Contact
Native plant revegetation	California Department of Fish and Game
Native plant bio-engineering	California Department of Fish and Game
Streambank stabilization (riprap, other structures)	United States Army Corps of Engineers California Department of Fish and Game
Earth moving & placement of fill	United State Army Corps of Engineers California Department of Fish and Game Regional Water Quality Control Board County Permit and Resource Management Dept. County Planning Department Natural Resources Conservation Service
Herbicide application	Agricultural Commissioners Office Regional Water Quality Control Board
Vegetation removal (native or non-native)	California Department of Fish and Game

Riparian corridor expansion project

Herbicide application

Table XI-1. Native Plants for Revegetation: Planting Location, Container Type and Spacing

The following plants are common in central and north coast watersheds and are recommended for use in riparian revegetation projects. Before choosing plants for a revegetation project, survey your area to determine the appropriate species, or consult with a native plant specialist. This table provides information about the typical location of riparian species, the revegetation approach (e.g., container, direct seed, dormant sprig or transplant) and general spacing suggestions.

COMMON NAME	LATIN NAME	PLANTING LOCATION	REVEGETATION APPROACH	SPACING feet-on-center	PAGE
BROADLEAF TREES					
Big Leaf Maple	*Acer macrophyllum*	floodplain	container	8 – 10’	A-1
Black Cottonwood	*Populus balsamifera* ssp. *trichocarpa*	channel	container, sprig	8 – 10’ 2 – 6’	A-2
Box Elder	*Acer negundo* var. *californicum*	floodplain	container	8 – 10’	A-3
California Bay Laurel	*Umbellularia californica*	floodplain	container	8 – 10’	A-4
California Buckeye	*Aesculus californica*	floodplain	container, direct seed	8 – 10’	A-5
Coast Live Oak	*Quercus agrifolia*	floodplain	container, direct seed	8 – 10’	A-6
Fremont Cottonwood	*Populus fremontii* ssp. *fremontii*	floodplain, channel	container, sprig	8 – 10’ 2 – 6’	A-7
Mountain Dogwood	*Cornus nuttallii*	channel	container	8 – 10’	A-8
No. CA Black Walnut	*Juglans californica* var. *hindsii*	floodplain	container	8 – 10’	A-9
Oregon Ash	*Fraxinus latifolia*	floodplain, channel	container	8 – 10’	A-10
Oregon Oak	*Quercus garryana* var. *garryana*	floodplain	container, direct seed	8 – 10’	A-11
Red Alder	*Alnus rubra*	floodplain, channel	container	8 – 10’	A-12
Sycamore	*Platanus racemosa*	floodplain	container	8 – 10’	A-13
Valley Oak	*Quercus lobata*	floodplain	container, direct seed	8 – 10’	A-14
Water Birch	*Betula occidentalis*	channel	container	8 – 10’	A-15
White Alder	*Alnus rhombifolia*	channel	container	8 – 10’	A-16
Willow	*Salix* spp.	channel, floodplain	container, sprig	8 – 10’ 2 – 6’	A-17
CONIFEROUS TREES					
California Nutmeg	*Torreya californica*	floodplain	container	8 – 10’	A-18
Coast Redwood	*Sequoia sempervirens*	floodplain	container	8 – 10’	A-19
Douglas Fir	*Pseudotsuga menzieii*	floodplain	container	8 – 10’	A-20
Pacific Yew	*Taxus brevifolia*	floodplain	container	8 – 10’	A-21
Western Hemlock	*Tsuga heterophylla*	floodplain	container	8 – 10’	A-22
SHRUBS AND SMALL TREES					
Blue Elderberry	*Sambucus mexicana*	floodplain	container	8 – 10’	A-23
California Blackberry	*Rubus ursinus*	floodplain	container	4 – 6’	A-24
California Hazelnut	*Corylus cornuta* var. *californica*	floodplain	container	4 – 6’	A-25
California Wild Rose	*Rosa californica*	floodplain	container	4 – 6’	A-26
Cascara	*Rhamnus purshiana*	floodplain	container	4 – 6’	A-27
Coffeeberry	*Rhamnus californica*	floodplain	container	4 – 6’	A-28

COMMON NAME	LATIN NAME	PLANTING LOCATION	REVEGETATION APPROACH	SPACING feet-on-center	PAGE
SHRUBS AND SMALL TREES					
Coltsfoot	*Petasites frigidus*	floodplain	container	4 – 6’	A-29
Creambush	*Holodiscus discolor*	floodplain	container	4 – 6’	A-30
Elk Clover	*Aralia californica*	floodplain	container	4 – 6’	A-31
Hawthorn	*Crataegus douglasii*	floodplain	container	4 – 6’	A-32
Mulefat	*Baccharis salicifolia*	floodplain	container	4 – 6’	A-33
Ninebark	*Physocarpus capitatus*	floodplain	container	4 – 6’	A-34
Osoberry	*Oemleria cerasiformis*	channel	container	4 – 6’	A-35
Pacific Wax Myrtle	*Myrica californica*	floodplain	container	4 – 6’	A-36
Red Elderberry	*Sambucus racemosa*	floodplain	container	8 – 10’	A-37
Red Flowering Currant	*Ribes sanguineum*	floodplain	container	4 – 6’	A-38
Red Twig Dogwood	*Cornus glabrata*	floodplain	container	4 – 6’	A-39
Salmonberry	*Rubus spectabilis*	floodplain	container	4 – 6’	A-40
Snowberry	*Symphoricarpos albus*	floodplain	container	4 – 6’	A-41
Spiraea	*Spiraea douglasii*	floodplain	container	4 – 6’	A-42
Stink Currant	*Ribes bracteosum*	floodplain	container	4 – 6’	A-43
Stream Dogwood	*Cornus sericea*	channel	container	4 – 6’	A-44
Thimbleberry	*Rubus parviflorus*	channel	container	4 – 6’	A-45
Toyon	*Heteromeles arbutifolia*	floodplain	container	4 – 6’	A-46
Twinberry	*Lonicera involucrata*	floodplain	container	4 – 6’	A-47
Vine Maple	*Acer circinatum*	floodplain	container	4 – 6’	A-48
Western Azalea	*Rhododendron occidentale*	floodplain	container	4 – 6’	A-49
Western Spicebush	*Calycanthus occidentalis*	floodplain	container	4 – 6’	A-50
Wild Mock Orange	*Philadelphus lewisii*	floodplain	container	4 – 6’	A-51
VINES					
California Wild Grape	*Vitis californica*	floodplain	container	4 – 6’	A-52
Dutchman's Pipevine	*Aristolochia californica*	floodplain	container	4 – 6’	A-53
Honeysuckle	*Lonicera hispidula* var. *vacillans*	floodplain	container	4 – 6’	A-54
Manroot	*Marah fabaceus*	floodplain	container	4 – 6’	A-55
Poison Oak	*Toxicodendron diversilobum*	floodplain	container	4 – 6’	A-56
Virgin’s Bower	*Clematis lasiantha*	floodplain	container	4 – 6’	A-57
EMERGENT AND HERBACEOUS PLANTS					
Bulrush	*Scirpus acutus* var. *occidentalis*	channel	container, transplant	1 – 2’	A-58
Cattail	*Typha latifolia*	channel	container, transplant	1 – 2’	A-59
Creeping Wild Rye	*Leymus triticoides*	floodplain	container, transplant	1 – 2’	A-60
Horsetail	*Equisetum* spp.	floodplain, channel	container, transplant	1 – 2’	A-61
Indian Rhubarb	*Darmera peltata*	channel	container, transplant	1 – 2’	A-62
Mugwort	*Artemesia douglasii*	floodplain, channel	container, transplant	1 – 2’	A-63
Rush	*Juncus* spp.	floodplain, channel	container, transplant	1 – 2’	A-64
Sedge	*Carex* spp.	floodplain, channel	container, transplant	1 – 2’	A-65
Spike rush	*Eleocharis* spp.	channel	container, transplant	1 – 2’	A-66
Stinging Nettle	*Urtica dioica*	floodplain, channel	container, transplant	1 – 2’	A-67

GLOSSARY

Achene: Dry, one-seeded fruit that often looks like a seed. Produced in a one-chambered ovary. Does not open to release the seed.

Allelopathic: Plant produces and releases a toxic substance that results in suppressed growth in other plant species.

Alternate: Describes growth pattern in which new structures develop singularly along axis. For leaves, only one leaf is produced per node so leaves appear to have "alternated" the side of the stem from which they grew (see opposite).

Annual: Plant completes entire life cycle, from germination to seed production and death, in one year or growing cycle (see biannual, perennial).

Asexual: Reproduction by a single individual using a process that is not sexual and does not involve the union of individual cells and the reassortment of genetic characteristics.

Biennial: Plant completes entire life cycle, from germination to seed production and death, in two years or growing cycles. Usually flowers are produced only during the second cycle (see annual, perennial).

Bisexual: Flowers have both female and male fertile reproductive structures (see unisexual, dioecious, monoecious).

Bract: A leaf-like or scale-like structure associated with and usually directly under a flower or cone.

Capsule: Dry, pod-like fruit with fused or partially fused chambers. When ripe, the fruit splits to release multiple seeds.

Catkin: An unbranched inflorescence of closely attached flowers. Flower petals and sepals are inconspicuous or absent but bracts can be showy. Flowers are all the same sex on each catkin.

Compound: Composed of two or more parts or repeating a structural pattern.

Deciduous: Leaves fall off naturally at the end of each growing season and re-grow after a period of leaf-less dormancy (see evergreen).

Dioecious: Male and female flowers produced on separate plants. Each plant produces either male or female unisexual flowers (see monoecious and bisexual).

Elliptic (al): Shaped like a flattened circle, widest at center and tapering almost equally at both ends.

Evergreen: Leaves remain green and on the plant throughout the year, and do not shed en-mass at the end of the growing season (see deciduous).

Gall: An abnormal outgrowth in plant tissue caused by certain parasitic insects, fungi, bacteria, or mechanical injury.

Inflorescence: A cluster of flowers and associated structures such as bracts, petioles and stems (does not include full sized foliage leaves).

Lanceolate: Lance shaped, width widest along lower half and tapers to a point at the tip.

Monoecious: Plant produces both male and female unisexual flowers (see dioecious and bisexual).

Oblong: Longer than wide, with almost parallel sides and rounded corners at each end.

Opposite: Describes a growth pattern in which new structures develop directly across from one another. In leaves, two leaves will grow per node on opposite sides of the stem (see alternate).

Ovate: Egg shaped, widest below middle, tip round or pointed.

Palmate: Radiating from a common point, similar to fingers from the palm of a hand.

Perennial: Plants live more than two years or growing cycles. For this text, description applies to plants that are non-woody above ground and also describes species that lose all above ground structures during dormancy and re-grow from roots (see annual, biannual).

Petiole: Slender stem that supports the leaf, i.e. the leaf stalk.

Pistil: Female reproductive structure of the flower. At the base is the ovary with one or more ascending stalk-like structures (styles) supporting the pollen receiving structure, the stigma (see stamen).

Sepal: Outer most structure of the flower. Similar to petals but usually green.

Stamen: Male reproductive structure of the flower. A stalk like structure (filament) with a pollen-producing anther at the tip (see pistil).

Stigma: Pollen receiving structure of the pistil. Usually located near the flower center, elevated above the ovary. The stigma is often sticky or hairy and sometimes lobed.

Terminal: At the end or tip of a structure.

Unisexual: Flowers that have either male or female fertile reproductive structures but not both (see bisexual, dioecious, monoecious).

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APPENDIX XI-A

CENTRAL AND NORTH COAST NATIVE RIPARIAN PLANTS

BIG LEAF MAPLE

Species Name: *Acer macrophyllum*
Family: Aceraceae (maple family)
Plant Type: Broad-leaf tree

Description: Tree, height to 90 feet, with a broad, rounded shape, deciduous with leaves turning yellow in the autumn.

Leaf: Palmate, opposite, width to 10 inches, with 3-5 deeply cut, irregularly toothed lobes, surface shiny green but paler underneath.

Flower: April-May, bisexual, also separate sexes: develop in long, drooping clusters of petaled, fragrant, greenish-yellow small flowers. Flowers appear after leaves.

Fruit/Seed: Distinctive paired achenes with wings, wings spreading <90°.

Typical Location: Floodplain, streamside, moist shady areas, riparian zone as well as hillsides outside the riparian zone, common; elevations below 5,000 feet.

Revegetation Approach: Container

Key Notes: Related to the box elder (*A. negundo*) and vine maple (*A. circinatum*). Easily distinguished by leaf shape.

Notes: Trees provide shade, shelter and roosting areas. Seedlings, leaves, buds, flowers and seeds provide forage for a range of mammals and birds.

leaf

whole plant

flower

seed

BLACK COTTONWOOD

Species Name: *Populus balsamifera* ssp. *trichocarpa*
Family: Salicaceae (willow family)
Plant Type: Broad-leaf tree

Description: Tree, height to 120 feet, branches wide spreading, forming massive crowns, deciduous.

Leaf: Ovate, base round and tip tapered to point, length to 4 inches, dark green above, silvery or rust colored below, margin finely scalloped.

Flower: February-April, dioecious (separate sex trees): male catkin length 1-5 inches; female catkin length 3 inches in flower, 10 inches at fruit.

Fruit/Seed: Capsule containing many tiny seeds with conspicuous white cottony tufts.

Typical Location: Alluvial bottomlands, floodplains, streamside; elevations below 9,000 feet.

Revegetation Approach: Container or cuttings. Care in correctly identifying species, see Key Notes.

Key Notes: Related to the native Fremont cottonwood, *P. fremontii*. Leaf shape differentiates between species. Also related to the non-native, cultivated Lombardy poplar, *P. nigra* (not shown). Care must be taken to correctly identify.

Notes: Important feature of mature riparian forest, provides habitat for osprey, herons and egrets, stream shading and leaf litter valuable for aquatic insects. Heavy limbed, brittle species. Tallest of the *Populus* species. Susceptible to galls.

leaf

whole plant

flower

seed

Location: channel

Box Elder

Species Name: *Acer negundo*
Family: Aceraceae (maple family)
Plant Type: Broad-leaf tree

Description: Tree, height to 65 feet, deciduous with bright autumn color.

Leaf: Compound leaf composed of 3-5 leaflets. Leaflet coarsely toothed, 3-5 lobed, length to 5 inches with the terminal leaflet longest.

Flower: March-April, dioecious (separate sex trees): female develops small, non-petaled greenish flowers on drooping stalks; male has clusters of small non-petaled flowers.

Fruit/Seed: Distinctive paired achenes with wings, achene initially reddish but ripens to a straw color in the autumn. Produces a substantial quantity of seed, which germinate in great numbers in open areas.

Typical Location: Common canopy species, streamsides, established floodplains, bottomlands; elevations below 6,000 feet.

Revegetation Approach: Container

Key Notes: Related to the vine maple (*A. circinatum*) and the big leaf maple (*A. macrophyllum*). Easily distinguished by leaf shape. *A. negundo* is the only compound leaf maple in North America.

Notes: Provides excellent shelter for wildlife. Seeds provide good forage for birds and small mammals.

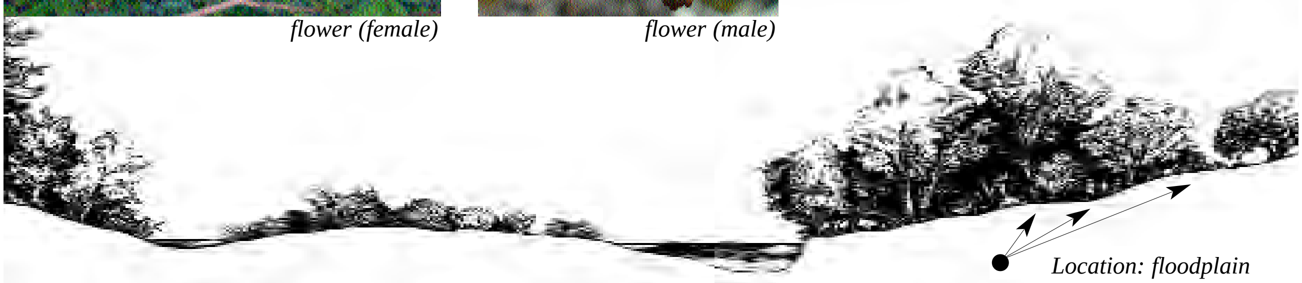
leaf

whole plant

flower (female)

flower (male)

seed



California Bay Laurel

Species Name: *Umbellularia californica*
Family: Lauraceae (laurel family)
Plant Type: Broad-leaf tree

Description: Tree, broad, round topped with height over 90 feet; also a shrub, especially on coastal bluffs, or in dry or poorly drained soils, evergreen.

Leaf: Oblong, length to 4 inches, alternate, highly aromatic when crushed.

Flower: December-May, bisexual, clusters of 6-10 small, greenish-yellow flowers, flowers petal-less, with 6 petal-like sepals, sepal length 1/8 inch.

Fruit/Seed: Round-oval stone fruit, greenish but ripening to dark purple, olive-like appearance, length to 1 inch, ripens in late autumn or winter.

Typical Location: Floodplains, mixed evergreen forests and upland habitat; elevations below 5,200 feet.

Revegetation Approach: Container, direct seed. Gather seed in October-December, remove thin fleshy coat and plant immediately.

Key Notes: Fragrance from crushed leaves is a notable characteristic.

Notes: Provides shade, shelter, roosting and nesting sites. Seeds provide forage for small mammals and birds. Source of large woody debris.

leaf

whole plant

flower

seed

CALIFORNIA BUCKEYE

Species Name: *Aesculus californica*
Family: Hippocastanaceae (buckeye family)
Plant Type: Broad-leaf tree

Description: Tree, height 15-40 feet, deciduous with leaves falling by late summer as a strategy against drought, new leaf growth begins in February.

Leaf: Compound, palmate leaf, generally with 5 leaflets, leaflet finely toothed, length 2-7 inches.

Flower: May-June: Spike-like cluster, length 6-8 inches, with small white to pinkish, sweet smelling flowers (length ½ inch). Pollen and nectar are toxic to honeybees.

Fruit/Seed: Large, pear shaped, grayish-brown, and leathery. Usually a single fruit is born at tip of flower spike and remains on tree after leaf fall. Fruit splits to reveal a large brown seed (said to look like a buck's eye). Seed round, large, diameter 1-2 inches, glossy brown, ripens in September.

Typical Location: Established floodplain forests, borders of streams, canyons, dry slopes; elevations below 5,600 feet.

Revegetation Approach: Container and direct seeding. Seeds easy to grow but toxic. Tolerant of urban pollution and salt spray.

Notes: All plant parts toxic, but seeds provide wildlife with some forage. Roots are good for binding soil. Native Americans used ground seeds to stun fish.

leaf

whole plant

flower

seed

seed

Location: floodplain

COAST LIVE OAK

Species Name: *Quercus agrifolia*
Family: Fagaceae (oak family)
Plant Type: Broad-leaf tree

Description: Tree, wide top, height 35-80 feet, large branches that often touch the ground, evergreen with leaves falling year round.

Leaf: Ovate, leathery, waxy, strongly convex, with small brownish hairs at the intersections of the primary leaf veins on the leaf underside, length to 3 inches, margin wavy, irregular, often spined.

Flower: Female flower tiny, singular or small clusters on new growth; male flower catkin, long, threadlike strand containing 25 - 100 male flowers, located on older growth.

Fruit/Seed: Acorn: slender, pointy tip, length to 1½ inches, wooly interior, ripens in autumn after 6-8 months growth. Cap large with thin, flat scales.

Typical Location: Established floodplain, valleys, mixed-evergreen forest, woodland; elevations below 5,000 feet.

Revegetation Approach: Container, direct seed. Hybridizes with *Q. kelloggii*, *Q. parvula*, *Q. wislizenii*.

Key Notes: Leaf and acorn morphology help distinguish from valley oak (*Q. lobata*) and Oregon oak (*Q. garryana*).

Notes: Trees provide shade as well as roosts and nesting sites for cavity nesting birds and bats. Acorns are an important food source for many wildlife species, especially woodpeckers and squirrels. Native Americans utilized acorns as a staple food crop. Wood made excellent charcoal and was massively harvested by European pioneers. Long-lived, commonly exceeding 250 years.

leaf

whole plant

seed

flower

FREMONT COTTONWOOD

Species Name: *Populus fremontii* ssp. *fremontii*
Family: Salicaceae (willow family)
Plant Type: Broad-leaf tree

Description: Tree, height to 90 feet, branches wide spreading, forming massive crowns, deciduous with leaves turning yellow in autumn but remaining on tree into late winter.

Leaf: Triangular, wider than long (length to 4 inches), abruptly narrowing to a point at apex, same color top and bottom, margin coarsely scalloped.

Flower: March-April, dioecious (separate sex trees), male and female: catkin, 1½-3 inches long, containing small greenish-yellow flowers that appear before leaves.

Fruit/Seed: Capsule containing many tiny seeds with conspicuous white cottony tufts. Seed ripen in early summer.

Typical Location: Alluvial bottomlands, stream channels, floodplains, wet areas; elevations below 6,500 feet.

Revegetation Approach: Container or cuttings. Care in correctly identifying species, see Key Notes.

Key Notes: Related to the native black cottonwood, *P. balsamifera*. Leaf shape differentiates between species. Also related to the non-native, cultivated Lombardy poplar, *P. nigra* (not shown). Care must be taken to correctly identify.

Notes: Important feature of mature riparian forests and provides habitat for osprey, herons and egrets. When young, found in large numbers on open gravel bars. Susceptible to mistletoe. Source of large woody debris.

leaf

whole plant

flower

seed

Location: floodplain, channel

MOUNTAIN DOGWOOD
PACIFIC DOGWOOD
WESTERN DOGWOOD

Species Name: *Cornus nuttallii*
Family: Cornaceae (dogwood family)
Plant Type: Broad-leaf tree

Description: Tree, one or more trunks, height to 80 feet, deciduous with yellow, pink and red autumn color.

Leaf: Elliptical, tapered at both ends, opposite, length 2½-5½ inches, leaf veins follow smooth leaf edges towards apex in curved pattern.

Flower: April-July, appearing before leaves, with second flowering in September, bisexual, petal-like bracts large (length 2 inches), showy, white to pinkish, surround cluster of small greenish flowers.

Fruit/Seed: April-July, autumn, clusters of crowded berries, berries elliptical in outline, ½ inch long, shiny bright red to orange-red, seed smooth.

Typical Location: Forests; elevations below 6,600 feet.

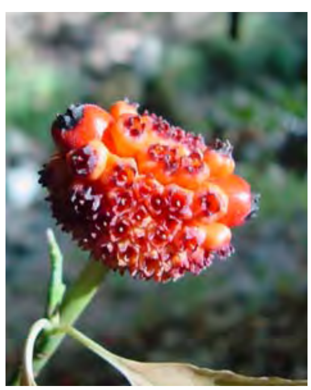
Revegetation Approach: Container.

Notes: Streambank stabilizer. Berries provide forage for small mammals and birds, especially band-tail pigeons. Native Americans used long slender branches to make baby baskets.

leaf

whole plant

flower



seed

NORTHERN CALIFORNIA BLACK WALNUT

Species Name: *Juglans californica* var. *hindsii*
Family: Juglandaceae (walnut family)
Plant Type: Broad-leaf tree

Description: Tree, height 50 to 80 feet, single trunk with broad crown, deciduous.

Leaf: Compound, alternate, with 11-19 leaflets. Leaflet lanceolate to ovate, pointed at tip, length 2-4 inches, margin toothed.

Flower: April-May, monoecious (separate sexes on same tree), female flowers small, petal-less, erect, born in clusters at tip of new growth; male catkin droops, length to 4 inches, grows on old growth.

Fruit/Seed: Round, smooth-shelled nut covered in a fibrous, fleshy black husk, ripens in autumn.

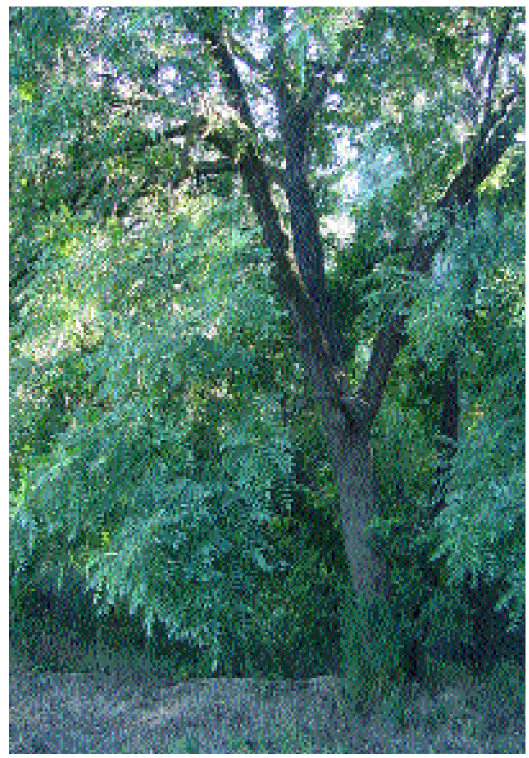
Typical Location: Floodplain, woodlands, valleys; elevations 160-2,000 feet.

Revegetation Approach: Container, direct seed. Hybridizes with the non-native English walnut making precise identification difficult. Care should be taken in collecting from a genetically pure source.

Key Notes: Young plants sometimes confused with the invasive non-native, tree of heaven (*Ailanthus altissima*). Seeds, flowers or careful inspection of leaf characteristics distinguish between species.

Notes: Provides forage, roosting and nesting sites (cavities) for wildlife. Nuts are forage for squirrels and rodents, as well as birds. Used as a rootstock for cultivated English walnut. Drought tolerant and oak-root fungus resistant.

leaf



whole plant

flower

seed

OREGON ASH

Species Name: *Fraxinus latifolia*
Family: Oleaceae (olive family)
Plant Type: Broad-leaf tree

Description: Tree, height to 80 feet, deep-rooted, deciduous.

Leaf: Compound, opposite, length to 12 inches, with 5-7 leaflets. Leaflet oblong to oval, broadest toward tip, tip abruptly pointed, length to 4 inches.

Flower: March-May, dioecious (separate sex trees): female and male flowers tiny, inconspicuous, petal-less, appearing in clusters with or before leaves.

Fruit/Seed: Winged achene, length to 1¾ inches, grows in clusters on female trees, matures in summer.

Typical Location: Floodplain, streambanks, woodlands; elevations below 5,600 feet.

Revegetation Approach: Container.

Notes: Functions as overstory or understory species in late successional areas. Tolerates standing water during winter.

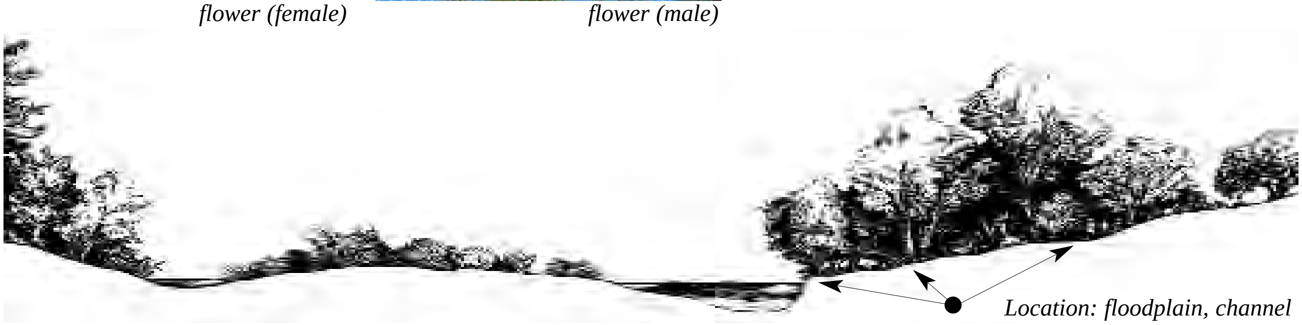

leaf


whole plant


flower (female)


flower (male)


seed



OREGON OAK

Species Name: *Quercus garryana*
Family: Fagaceae (oak family)
Plant Type: Broad-leaf tree

Description: Tree, wide top, height to 65 feet, deciduous with reddish-brown autumn color.

Leaf: Length 2-6 inches, surface dark green, leathery, shiny, underside pale green to rusty with downy hair, margin with 5-7 deep, rounded lobes.

Flower: Female flower tiny, singular or small clusters on new growth; male flower catkin, long, threadlike strand containing 25-100 male flowers, located on older growth.

Fruit/Seed: Acorn: oval to spherical, rounded tip, length to 1 inch, smooth interior, ripens in autumn after 1-year growth (but abundant crop irregular, every 2-5 years). Cap small, shallow, cup-like with smooth to slightly bumpy scales.

Typical Location: Established floodplain, valleys; elevations 1,000 to 5,900 feet.

Revegetation Approach: Container, direct seed. May hybridize with other oak species.

Key Notes: Leaf and acorn morphology helps distinguish from valley oak (*Q. lobata*) and live oak (*Q. agrifolia*).

Notes: Trees provide roosts and nesting sites for cavity nesting birds and bats. Acorns are an important food source for many wildlife species, especially woodpeckers and squirrels. Native Americans utilized acorns as a food crop, but less favored than live oak. Trees harvested for lumber.

leaf

whole plant

flower and leaf

Location: floodplain

RED ALDER

Species Name: *Alnus rubra*
Family: Betulaceae (birch family)
Plant Type: Broad-leaf tree

Description: Tree, single whitish trunk, height to 80 feet, branches slim and drooping forming a narrow crown, deciduous.

Leaf: Elliptical to oval, length 2-6 inches, leaf midrib and major veins indented, surface gray-green, underside rust colored. Margins coarsely toothed and rolled under (look carefully).

Flower: March-April, monoecious (separate sexes on same tree), female catkin erect, length to ¾ inch, develops before leaves; male catkin long (3-7 inches), yellowish-green, develops before leaves, produces large quantities of pollen in February.

Fruit/Seed: Woody, cone-like catkin. Sheds seeds in autumn but cone can remain throughout winter.

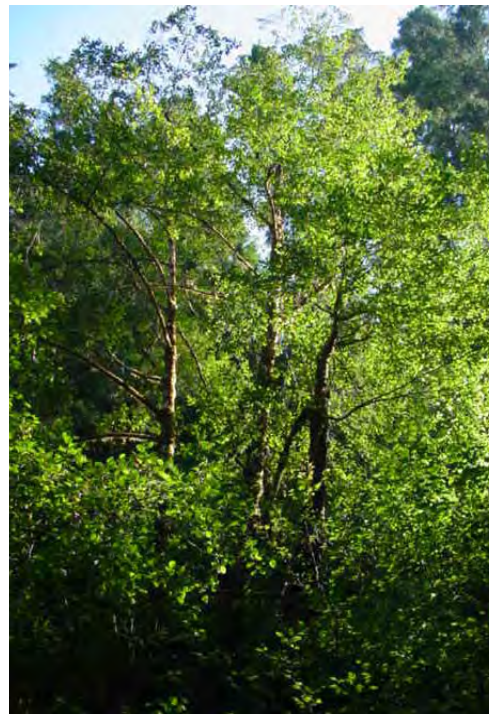
Typical Location: Active channel, floodplain, wet areas; elevations sea level to 3,300 feet.

Revegetation Approach: Container.

Key Notes: Distinguish from white alder, *A. rhombifolia*, by carefully looking at leaf margins and vein structure. Only found near the coast and at lower elevations.

Notes: Important habitat for fish and aquatic insects by shading streams, providing shelter beneath undercut roots and providing a source of large woody debris. Seeds provide excellent forage for birds. Root nodules contain atmospheric nitrogen-fixing bacteria, actinomycetes. Leaf fall enriches the surrounding soils with nitrogen. Stabilizes soil. Tolerant of saline water.

leaf



whole plant

seed and leaf

flower

SYCAMORE

Species Name: *Platanus racemosa*
Family: Platanaceae (sycamore family)
Plant Type: Broad-leaf tree

Description: Tree, height 115 feet, single base trunk, may form secondary trunk that leans and twists, bark peals in reddish-brown plates exposing whitish areas. Branches widely spreading with lower branches twisting.

Leaf: Palmate with 3-5 deep lobes, length to 10 inches, margins smooth edged. Leaves turn brown in early autumn but may remain on tree until new leaf growth.

Flower: February-April, monoecious (separate sexes on same tree), female and male flowers in unisex spherical clusters, 3-7 clusters per stalk, individual flowers tiny.

Fruit/Seed: Spherical cluster (diameter 1 inch) of spiny achenes, ripen in winter.

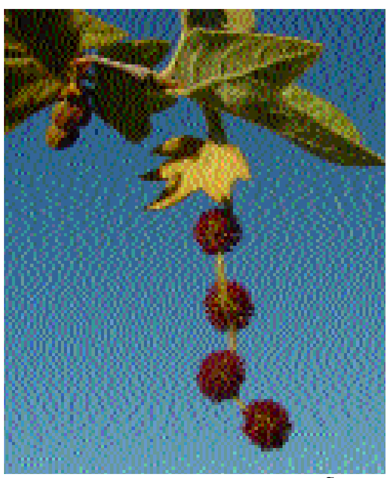
Typical Location: Floodplain, streamsides, canyons; elevations below 6,600 feet.

Revegetation Approach: Container.


leaf


whole plant


trunk


flower


seed

VALLEY OAK

Species Name: *Quercus lobata*
Family: Fagaceae (oak family)
Plant Type: Broad-leaf tree

Description: Tree, wide top, height 50-115 feet (often as wide), may have massive branches sometimes extending to the ground, largest North American oak, deciduous.

Leaf: Length 2-4 inches, surface dark green, underside pale green with felt-like hairs, margin with 6-10 deep, rounded lobes.

Flower: March-April, female flower tiny, singular or small clusters on new growth; male flower catkin, long, threadlike strand containing 25 - 100 male flowers, located on older growth.

Fruit/Seed: Acorn: long, conical, length to 2 inches (largest of California oaks), smooth interior, ripens in autumn after 1-year growth, germinates immediately. Cap with wart-like bumps on scales.

Typical Location: Established floodplain, valleys; elevations below 5,600 feet.

Revegetation Approach: Container, direct seed. Hybridizes with *Q. berberidifolia*, *Q. corneliusmulleri*, *Q. douglasii*, *Q. engelmannii*, *Q. garryana*, *Q. john-tuckeri*.

Key Notes: Leaf and acorn morphology help distinguish from live oak (*Q. agrifolia*) and Oregon oak (*Q. garryana*).

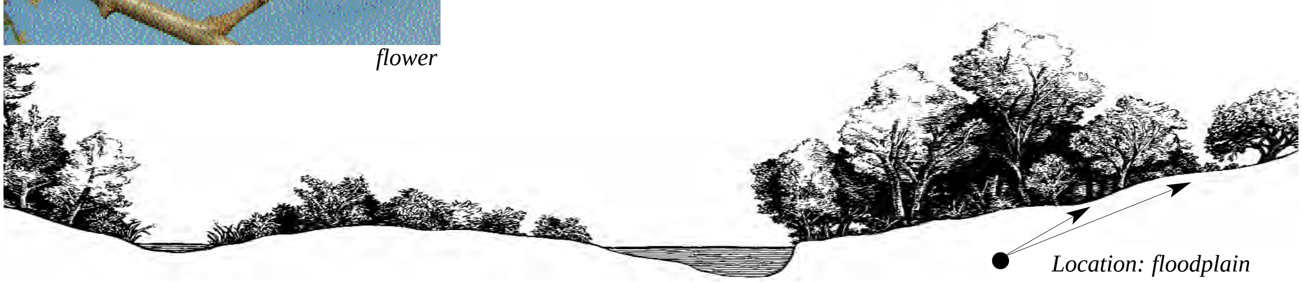
Notes: Trees provide roosts and nesting sites for cavity nesting birds and bats. Source of large woody debris. Acorns are an important food source for many wildlife species, especially woodpeckers and squirrels. Young branches may have dense clusters of spherical insect galls harboring small, native wasp larvae. Native Americans utilized acorns as a food crop. May live for 400- 600 years.


leaf


whole plant


seed


flower


Location: floodplain

WATER BIRCH

Species Name: *Betula occidentalis*
Family: Betulaceae (birch family)
Plant Type: Broad-leaf tree

Description: Tree or large shrub, usually with multiple trunks, height to 30 feet, bark smooth and dark brown/red, deciduous.

Leaf: Widely ovate, tip pointed, margins doubly toothed, length to 2 inches.

Flower: April-June, monoecious (separate sexes on same tree), female catkin erect, length ¾ to 2½ inches; male catkin elongate, length 1 to 2 inches.

Fruit/Seed: Many tiny, winged seeds inside catkin.

Typical Location: Streams, springs, moist areas; elevations 2,000 to 9,500 feet.

Revegetation Approach: Container.

Notes: Important wildlife forage and bank stabilizer.


leaf


whole plant


male catkin


seed

WHITE ALDER

Species Name: *Alnus rhombifolia*
Family: Betulaceae (birch family)
Plant Type: Broad-leaf tree

Description: Tree, single whitish trunk, height to 115 feet, branches slim and drooping forming a narrow crown, deciduous.

Leaf: Elliptical to oval, length 2-6 inches, leaf midrib and major veins not indented, surface gray-green, underside yellowish. Margins coarsely toothed and not rolled under (look carefully).

Flower: March-April, monoecious (separate sexes on same tree), female catkin erect, length to ¾ inch, develops before leaves; male catkin long (3-7 inches), yellow-greenish, develops before leaves, produces large quantities of pollen in February.

Fruit/Seed: Woody, cone-like catkin. Sheds seeds in autumn but cone remains throughout winter.

Typical Location: Active channel, floodplain, wet areas; elevations 300 to 8,000 feet.

Revegetation Approach: Container.

Key Notes: Distinguish from red alder, *A. rubra*, by carefully looking at leaf margins and vein structure.

Notes: Important habitat for fish and aquatic insects by shading streams, providing shelter beneath undercut roots and providing a source of large woody debris. Seed provide excellent forage for birds. Root nodules contain atmospheric nitrogen-fixing bacteria, actinomycetes. Leaf fall enriches the surrounding soils with nitrogen. Stabilizes soils.

whole plant

whole plant

catkins (male and female)

leaf

WILLOW

Species Name: *Salix* spp.
Family: Salicaceae (willow family)
Plant Type: Broad-leaf tree

Description: Tree or shrub, stems slender, flexible, most hairy, bark reddish or yellowish brown, height to 50 feet, some species spread by roots (developing clonal thickets), deciduous.

Leaf: Elliptical, slender or wide (almost ovate), length variable (2-6 inches), hairy, one central vein, margins smooth or toothed, tip pointed or rounded.

Flower: February-May, dioecious (separate sex trees), female and male catkins on leafy shoot, length 1- 4 inches, appear just before or with leaves.

Fruit/Seed: Dry, 2 part fruit, length 1/4-1/3 inch, contains many tiny seeds. Seeds disperse by wind and water.

Typical Location: Active channel, streamsides, marshes, wet ditches, springs; elevations below 9,000 feet.

Revegetation Approach: Container or cutting.

Key Notes: Accurate identification requires an understanding of flower characteristics. Distinguish from mulefat (*Baccharis salicifolia*) by leaf vein pattern.

Notes: Excellent for streambank stabilization and habitat restoration. Dense growth provides excellent cover for aquatic organisms, terrestrial wildlife and birds. Native Americans used stems in basketry and bow making. Willows produce salicin, a chemical similar to acetylsalicylic acid (aspirin).

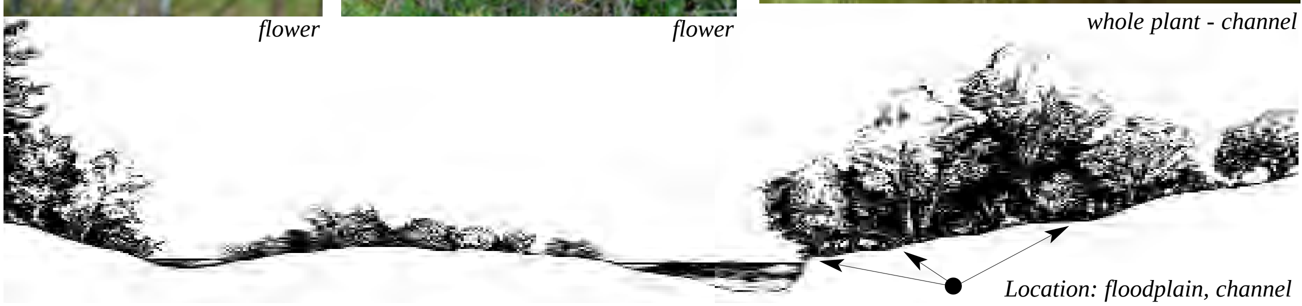

leaf


whole plant - floodplain


whole plant - channel


flower


flower


Location: floodplain, channel

CALIFORNIA NUTMEG

Species Name: *Torreya californica*
Family: Taxaceae (yew family)
Plant Type: Coniferous tree

Description: Conifer, pointed crown, rounding as it matures, widely spaced horizontal branches, height to 140 feet, aromatic leaves and fruit, evergreen.

Leaf: Needle, dark green, 2 white bands on underside, length 1-2¾ inches, rigid with slightly upturned tip, tip sharp, needles arranged in 2 almost parallel rows, aromatic.

Flower: Monoecious, female cone develops into olive shaped fruit, male cone a stalked cluster with 6-8 whirls.

Fruit/Seed: Olive-like fruit, oblong, pale green with purplish markings, longitudinally grooved, length to 2 inches, seed completely contained within fruit.

Typical Location: Shady canyons in forest, woodland and chaparral; elevations 100 to 6,900 feet.

Revegetation Approach: Container.

Notes: Trees provide shelter and habitat diversity in watersheds. Seeds are an important forage.

leaf

whole plant

seed

Location: floodplain

COAST REDWOOD

Species Name: *Sequoia sempervirens*
Family: Taxodiaceae (bald cypress family)
Plant Type: coniferous tree

Description: Tree, height to 350 feet, narrow crown, horizontal branches grow straight out from trunk and slightly upward at ends, mature trees generally free of branches in the lower half, red bark thick and fibrous, evergreen.

Leaf: Needle, length ½-¾ inch, branchlets with needles in 2 rows, arranged in one plane (feather-like).

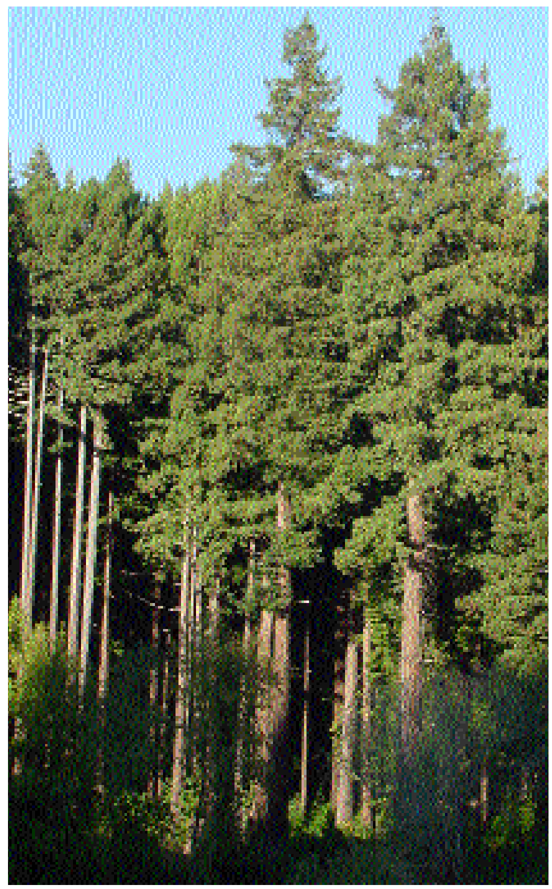
Fruit/Seed: Spherical, reddish cone, length 1¼ inch, found mostly near the top of the tree, clustered at the end of branchlets, ripens in autumn.

Typical Location: Northern California coastal drainages south to Monterey; elevations sea level to 3,600 feet.

Revegetation Approach: Container.

Notes: Long-term source of woody debris in streams, cools streams by providing dense shade, undercut roots provide vital aquatic shelter. Tallest trees in North America. Generally re-sprouts from cut stems or trunk, and after fire. Mainstay of the California lumber industry from 19th century to the early 20th century.

leaf



whole plant

trunk

seed

DOUGLAS FIR

Species Name: *Pseudotsuga menziesii*
Family: Pinaceae (pine family)
Plant Type: coniferous tree

Description: Conifer, height to 220 feet, rounded crown, large upper branches, branches typically curl upward, evergreen.

Leaf: Soft needles, flat, rounded tips, length ¾-1½ inch, blue-green to dark green, radiate in all directions from stem, persistent to eight years, fragrant.

Flower: Monoecious (separate sexes on same tree), female cone woody, reddish, near branch tip; male cone (bud like) small, oblong, reddish, not woody, near branch tip.

Fruit/Seed: Cone, reddish brown, length 2-3½ inches, scales rounded with distinctive 3-pronged bracts, hangs down, matures in August.

Typical Location: Mixed-evergreen, mixed-conifer forests; elevations below 7,200 feet.

Revegetation Approach: Container.

Notes: Trees provide shelter for wildlife, shading for streams and a source of large woody debris. Seeds are an important forage for small mammals and birds.

leaf

whole plant

seed

Douglas fir forest

PACIFIC YEW

Species Name: *Taxus brevifolia*
Family: Taxaceae (yew family)
Plant Type: coniferous tree

Description: Conifer, tree or large shrub, branches may droop slightly, height to 60 feet, trunk width often irregular, bark reddish-brown and often peels, leaves and fruit non-aromatic, evergreen.

Leaf: Needle, yellowish-green on top but lighter underneath, length up to 1 inch, tip pointed, needles arranged in 2 almost parallel rows that may spiral along stems, non-aromatic.

Flower: Dioecious, female cone small, singular, greenish, develops on branch underside; male cone a stalked cluster with 4-8 whirls, roundish, yellow, diameter 1/6 inch, develops on branch underside, numerous cones produced.

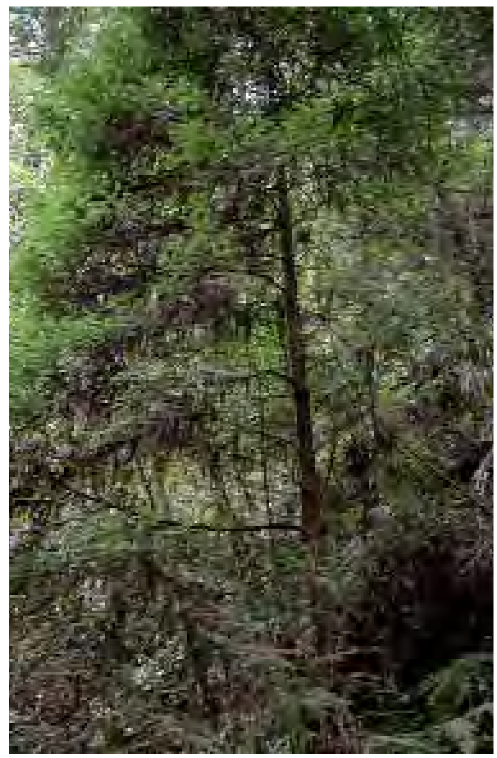
Fruit/Seed: Cup-like, fleshy, reddish, diameter up to 1/2 inch, contains one seed that is visible at the end. Fleshy coat is edible (sweet) but seed is poisonous to humans.

Typical Location: Understory of shady mixed-evergreen forests, slopes and canyon bottoms, tolerates shade; elevations 30-5,000 feet.

Revegetation Approach: Container.

Notes: Trees provide large woody debris, shelter, habitat diversity, and nesting sites, as well as shade that maintains cool water temperatures. Fibrous roots bind and stabilize soil. Seeds are an important forage for birds and small mammals. Leaves and bark provide forage for grazers. The cancer-fighting drug Taxol is produced in the bark and, to a lesser extent, in the leaves.

leaf



whole plant

seed

WESTERN HEMLOCK

Species Name: *Tsuga heterophylla*
Family: Pinaceae (pine family)
Plant Type: coniferous tree

Description: Conifer, crown conical and narrow, height to 160 feet, drooping branches, thin reddish-brown bark, stem hairy, evergreen.

Leaf: Needle, white bands on underside, tip rounded, 2 rows of short needles (length ¼-¾ inch), persistent for 4-7 years.

Flower: Monoecious (separate sexes on same tree), female cone oval, length ½-3 inches, hangs down from branch tip, immature greenish, ripens to brown and woody; male cone small, yellowish, not woody, occurs on previous year's growth.

Fruit/Seed: Woody oval cone, length ½-3 inches, hangs down from branch tip, scales open first season releasing seeds, seed length to ¾ inch.

Typical Location: Coastal conifer and mixed evergreen forests, especially in flat or low slope areas; elevations below 2,300 feet.

Revegetation Approach: Container.

Notes: Trees contribute large woody debris to stream and provide shelter, habitat and nesting sites (cavities) for wildlife. Foliage and seeds provide forage, especially for small mammals and birds. Harvested for paper pulp.


leaf


whole plant


seed

BLUE ELDERBERRY

Species Name: *Sambucus mexicana*
Family: Caprifoliaceae (honeysuckle family)
Plant Type: Shrub / small tree

Description: Shrub, lacking main trunk, height to 25 feet, often as wide as tall, deciduous.

Leaf: Compound, opposite with 3-9 elliptic to ovate, sharply toothed leaflets (length to 7 inches). Leaflet base often asymmetrical, terminal leaflet much longer than paired leaflets.

Flower: March-September, large (12 inches wide), showy, flat topped clusters of small white flowers.

Fruit/Seed: Clusters of round berries, berry diameter 1/3 inch, almost black with whitish bloom thus appearing bluish, contains 3-5 small seeds.

Typical Location: Streambanks, open areas in forest, established floodplains; elevations below 9,800 feet.

Revegetation Approach: Container.

Key Notes: Related to the red elderberry (*S. racemosa*). Distinguished by flower, fruit shape and fruit color.

Notes: Important source of forage for wildlife, especially for some species of migratory birds. Berries edible to human and used for jellies, pies and wine. Pierce's Disease host plant (see page XI-7 for more information).

leaf

flower

seed

whole plant

CALIFORNIA BLACKBERRY

Species Name: *Rubus ursinus*
Family: Rosaceae (rose family)
Plant Type: Shrub

Description: Mound building, vine-like shrub with tip rooting, running stems. Stems grayish with slender, delicate, straight thorns.

Leaf: Compound with 3 leaflets, leaflets irregularly toothed, length 1-4 inches.

Flower: March-June, generally dioecious (separate sex shrubs): Singular or clusters of white flowers, petal length to 1 inch.

Fruit/Seed: Blackberry (aggregate of black stone fruits), round to oblong, red ripening to black, highly edible, ripens in summer. Multiple small seeds inside a single blackberry.

Typical Location: Moist areas, shade, floodplain stream banks; elevations below 5,000 feet.

Revegetation Approach: Container, plants grow rapidly.

Key Notes: Often confused with the non-native Himalayan blackberry (*R. discolor*). Distinguished by leaf and thorn shape.

Notes: Dense growth provides excellent foraging, nesting and hiding habitat for wildlife. Edible berries are an important food source for many species of mammals and birds. Spreading growth binds soil for erosion control. Pierce's Disease host plant (see page XI-7 for more information on Pierce's Disease).

leaf and fruit

flower

stem

whole plant

Location: floodplain

CALIFORNIA HAZELNUT

Species Name: *Corylus cornuta var. californica*
Family: Betulaceae (birch family)
Plant Type: Shrub / small tree

Description: Shrub or small tree, spreading with multiple stems, open shape, height 5-13 feet, deciduous with bright yellow autumn color.

Leaf: Round to ovate, velvety hairy on both sides, length to 4 inches, coarsely toothed.

Flower: January-April, monoecious (separate sex on same plant): Female flower, tiny cluster (½ inch) containing 2 flowers with bright red stigma, grow as terminal buds, appear before leaves; male flower catkin, length to 2½ inches, remain after leaf fall.

Fruit/Seed: Smooth nut (1-inch-diameter) enclosed in 2 fused, papery, leaf-like bracts, ripen in early autumn.

Typical Location: Streamsides, moist, shady floodplain forests, often found in the understory of redwood and Douglas fir forests; elevations below 7,000 feet.

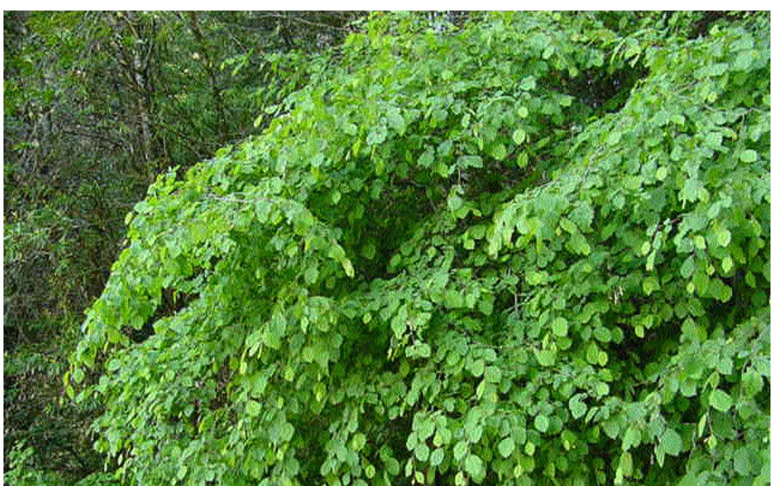
Revegetation Approach: Container.

Notes: Edible nut is an important food source for many species. It is related to the European hazelnut (filbert). Native Americans used the flexible stems in basket making.


leaf


male flower/catkin


seed


whole plant


Location: floodplain

CALIFORNIA WILD ROSE

Species Name: *Rosa californica*
Family: Rosaceae (rose family)
Plant Type: Shrub

Description: Thicket building shrub, height 3-8 feet, stems with compressed, curved thorns.

Leaf: Compound with 5-7 leaflets. Leaflets ovate to oblong, toothed, length to 1½ inch.

Flower: May-August, singular or in clusters, pinkish, ¾ inch petals.

Fruit/Seed: Round, reddish, fleshy rose hip, ¾ inch diameter.

Typical Location: Moist areas, streamsides; elevations below 5,300 feet.

Revegetation Approach: Container. Hybridizes with non-native cultivated roses, care must be taken in collection.

Notes: Important understory species, and good soil stabilizer. Species extremely variable. Rose hip high in vitamin C and important forage for wildlife.


leaf


flower


seed


whole plant in flower

CASCARA

Species Name: *Rhamnus purshiana*
Family: Rhamnaceae (buckthorn family)
Plant Type: Shrub / small tree

Description: Erect shrub or small tree, height to 30 feet, branch ends often tufted with leaves, deciduous showing yellow autumn color.

Leaf: Elliptic, alternate, prominent veins, length 2-6 inches, margin smooth.

Flower: May-June, bisexual, small cluster of greenish flowers develop at leaf axis.

Fruit/Seed: Round berry, black when ripe, diameter to 1/2 inch, contains 3 seeds.

Typical Location: Floodplains, coniferous forests, coastal scrub; elevations below 6,500 feet.

Revegetation Approach: Container.

Key Notes: Related to coffeeberry (*R. californica*).

Notes: Berries are attractive forage for birds and mammals, including ringtail and raccoon. Can be toxic to small children.

leaf

flower

seed

whole plant

Location: floodplain

COFFEEBERRY

Species Name: *Rhamnus californica*
Family: Rhamnaceae (buckthorn family)
Plant Type: Shrub / small tree

Description: Shrub, erect or low and spreading, height to 16 feet, evergreen.

Leaf: Variable, elliptic, alternate, variable in thickness, length 1-3 inches, edges smooth or toothed.

Flower: April-June, bisexual, clusters of 5-60 inconspicuous flowers produced on new growth.

Fruit/Seed: Round berry, ripening from green to red then black when ripe, diameter to ½ inch.

Typical Location: All soil types, woodlands, forests, coastal scrub, chaparral; elevations below 7,500 feet.

Revegetation Approach: Container.

Key Notes: Related to cascara (*R. purshiana*).

Notes: Leaves and berries provide forage for deer, birds feed on berries as well.


leaf


seed


flower


whole plant


Location: floodplain

COLTSFOOT

Species Name: *Petasites frigidus*
Family: Asteraceae (sunflower family)
Plant Type: Shrub

Description: Perennial herb with creeping rhizomes, dormant in winter with erect stems appearing before leaves in spring, no branches, height 6-24 inches.

Leaf: Grow from stem base, palmate, roundish, multi-lobed, width 2-10 inches, edges coarsely toothed, underside densely hairy.

Flower: March-April, produced at top of a long stalk (length to 24 inches) before leaf-out. Clusters of small, disk-like, white-orange flowers, male and female usually not produced on same disk, sometimes dioecious (separate sex plants).

Fruit/Seed: Achene with thread-like bristles, length <¼ inch.

Typical Location: Streamside, wet soils, deep shade in wood areas; elevations below 1,300 feet.

Revegetation Approach: Container.

Notes: Rhizomatous growth helps stabilize soil.


leaf


flower


whole plant


seed

CREAMBUSH/OCEANSPRAY

Species Name: *Holodiscus discolor*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Shrub, densely branched, stems hairy, bark light brown to gray and shredding with age, height 4-18 feet, deciduous. Has both long stems and short, each with different leaf size.

Leaf: Ovate, alternate, edges coarsely toothed or scalloped. Long stem leaf length 2-5 inches; leaf length ¾ to 1½ inch.

Flower: May-July, showy, large (length 4-10 inches) branched clusters of small, white flowers produced at the ends of mature branches.

Fruit/Seed: Achene, tiny.

Typical Location: Floodplains, moist woodlands, rocky slopes, variety of plant communities below 6,000 feet.

Revegetation Approach: Container.

Notes: Showy flowers attract birds.


leaf


flower


seed


whole plant

ELK CLOVER

Species Name: *Aralia californica*
Family: Araliaceae (ginseng family)
Plant Type: Shrub

Description: Erect shrub, height 3-9 feet, deciduous. Roots large, contain milky juice.

Leaf: Compound, large with 3-5 leaflets. Leaflet ovate, tip pointed, margins small-toothed, length 6-12 inches.

Flower: June-August, long stalk (length 14-18 inches), multiple branches of small, ball-like clusters of white, sticky flowers.

Fruit/Seed: Berry, round, black, <¼ inch diameter.

Typical Location: Moist shady areas, streamsides, canyons; elevations below 6,500 feet.

Revegetation Approach: Container.

Notes: In same family as non-native English ivy, *Hedera helix*.

leaf

flower

seed

whole plant

Location: floodplain

HAWTHORNE
WESTERN BLACKHAW

Species Name: *Crataegus douglasii*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Erect shrub or small tree, height to 30 feet, densely branched, armored with strong thorns (length over ½ inch), deciduous.

Leaf: Base wedge shaped, top lobed with double-toothed margin, length 1-3 inches, dark green, shiny.

Flower: May-July, clusters at branch tips, flowers cup-shaped, white, 5-petaled, width ½ inch, fragrant.

Fruit/Seed: Berry-like, black, fleshy, sweet, diameter to ½ inch, contains tiny nutlet.

Typical Location: Floodplains, meadow edges, forest, grassland, sagebrush scrub; elevations 2,300 to 5,500 feet.

Revegetation Approach: Container.

Notes: Fruit provides excellent forage for birds and flowers attract bees.

leaf and flower

flower

seed

whole plant

MULEFAT

Species Name: *Baccharis salicifolia*
Family: Asteraceae (sunflower family)
Plant Type: Shrub

Description: Erect shrub, spreads to form thickets, height 6-12 feet, evergreen.

Leaf: Lanceolate, length to 6 inches, margins smooth to slightly toothed, underside with 3 large veins.

Flower: March-July, dioecious (separate sex shrubs), clusters of small white disk flowers (width <¼ inch) form at the tips of lateral branches.

Fruit/Seed: Tiny, finely bristled achene.

Typical Location: Dry streambeds, active channel, gravel bars across California at elevations below 4,000 feet.

Revegetation Approach: Container.

Key Notes: Sometimes confused with young willow growth: mulefat has three large veins on the leaf, the willow only has one.

Notes: Important gravel bar colonizer and stabilizer. Native Americans used the straight-growing, woody stems for arrows.

leaf

flower

seed

whole plant

NINEBARK

Species Name: *Physocarpus capitatus*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Erect, spreading shrub, height 3-8 feet, peeling bark distinctive, deciduous.

Leaf: Rounded palmate with 3-5 lobes, length to 5½ inches, margin toothed.

Flower: April-July, dense, round clusters of small, white flowers (petal length <¼ inch).

Fruit/Seed: Round clusters of dry, inflated fruit, fruit contain 2-4 seeds.

Typical Location: Moist banks, floodplains, coniferous forests; elevations below 4,600 feet.

Revegetation Approach: Container.

leaf

flower

whole plant in flower

seed

Location: floodplain

OSOBERRY

Species Name: *Oemleria cerasiformis*
Family: Rosaceae (rose family)
PlantType: Shrub / small tree

Description: Shrub or small tree, height to 15 feet, stems mostly straight and slender, bark gray to reddish, deciduous.

Leaf: Elliptical, alternate, length 2-5 inches, margin smooth, smells like cucumber when crushed.

Flower: January-April, dioecious (separate sex shrubs) with some bisexual flowers, hanging clusters (length 1-4 inches) of 5-10 flowers produced at branch ends, female and male flowers small, fragrant, petals white, clawed, blooms before leafing.

Fruit/Seed: Berry, bean-shaped, waxy, peach colored turning bluish when ripe, diameter ½ inch.

Typical Location: Floodplains, chaparral, shaded coniferous forest, streamsides; elevations below 5,600 feet.

Revegetation Approach: Container.

Key Notes: Name changed to *Oemleria* from *Osmaronia*.

Notes: Berries provide forage for birds.

leaf

flower

seed

whole plant

Location: floodplain

PACIFIC WAX MYRTLE

Species Name: *Myrica californica*
Family: Myricaceae (wax myrtle family)
Plant Type: Shrub / small tree

Description: Erect shrub or small tree, densely branched, height 6-30 feet, bark smooth and gray to light-brown, evergreen.

Leaf: Lanceolate to oblong, dark green, glossy, length to 5 inches, spicy scent.

Flower: March-April, monoecious (separate sexes on same shrub), female and male catkin scaly, length to 1 inch.

Fruit/Seed: Round, dark purple nut with pale waxy coating, diameter ¼ inch.

Typical Location: Coastal areas (including sand dunes) north of Santa Monica county into Washington, canyon walls and moist slopes below 500 feet.

Revegetation Approach: Container.

Notes: Wax myrtle berries are important forage for many bird species. The name comes from the waxy coating on the berries, which were historically used in the making of soaps and candles.

leaf and flower

seed

whole plant

Location: floodplain

RED ELDERBERRY

Species Name: *Sambucus racemosa*
Family: Caprifoliaceae (honeysuckle family)
Plant Type: Shrub / small tree

Description: Shrub, lacking main trunk, height to 20 feet, deciduous.

Leaf: Compound, opposite with 5-7 leaflets, leaflets ovate to lanceolate, base often asymmetrical, length to 6 inches, margin sharply toothed.

Flower: March-July, domed shaped clusters (width to 4 inches) of small whitish flowers.

Fruit/Seed: Clusters of berries, berry bright red, round, diameter ¼ inch, contains 3-5 small seeds.

Typical Location: Moist areas, coastal.

Revegetation Approach: Container.

Key Notes: Related to the blue elderberry (*S. mexicana*). Distinguished by flower and fruit shape.

Notes: Important forage for birds. Berries bitter tasting to humans and sometimes toxic.

leaf

flower

seed

whole plant

Location: floodplain

RED FLOWERING CURRANT
PINK WINTER CURRANT

Species Name: *Ribes sanguineum*
Family: Grossulariaceae (gooseberry family)
Plant Type: Shrub / small tree

Description: Erect shrub, height to 12 feet, stems thin, spreading, deciduous.

Leaf: Palmate, dark green, finely haired, lobes rounded, margin irregularly toothed, length 2-4 inches.

Flower: January-June, bisexual, drooping clusters (length 2-4 inches) of 1-20 flowers, flowers small, red to pink.

Fruit/Seed: Berry, blue-black with whitish bloom, diameter to ½ inch.

Typical Location: Floodplains, open spaces, chaparral, woodland, mixed evergreen and closed pine forests; elevations to 6,000 feet.

Revegetation Approach: Container.

Notes: Flowers and fruit attract birds.


leaf


flower


seed


branch


Location: floodplain

RED TWIG DOGWOOD
BROWN DOGWOOD

Species Name: *Cornus glabrata*
Family: Cornaceae (dogwood family)
Plant Type: Shrub / small tree

Description: Shrub or small tree, generally forms dense thickets, height to 20 feet, stems slender, brown to red, deciduous.

Leaf: Lanceolate to elliptical, tapered at both ends, length to 2 inches, leaf veins in 3-4 pairs.

Flower: May-July, bisexual, flat topped clusters (2 inch width) of small, white flowers.

Fruit/Seed: Berry, white to bluish, length ¼ inch, seed with almost smooth sides, ripens in late summer.

Typical Location: Floodplains, moist areas; elevations below 5,000 feet.

Revegetation Approach: Container.

Key Notes: Leaf and seed morphology distinguish from stream dogwood (*C. sericea*).

leaf

flower

seed

whole plant

SALMONBERRY

Species Name: *Rubus spectabilis*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Erect shrub, height 6-12 feet, branches with few short, straight thorns, mature branches woody, bark shredding, forms dense thickets, deciduous.

Leaf: Compound with 3 leaflets. Leaflets palmate with 3 shallow lobes, length 2-4 inches, edges irregularly toothed.

Flower: March-June, singular and clusters, petal length to ½ inch, red-purple, papery.

Fruit/Seed: Raspberry-like (aggregate of stone fruits), yellow to red, edible, ripen in summer.

Typical Location: Moist shady areas, streamsides; elevations below 5,000 feet.

Revegetation Approach: Container.

Key Notes: Related to the blackberry, raspberry and thimbleberry.

Notes: Edible berries provide forage for wildlife.


leaf


flower


seed


whole plant


Location: floodplain

SNOWBERRY

Species Name: *Symphoricarpos albus* var. *laevigatus*
Family: Caprifoliaceae (honeysuckle family)
Plant Type: Shrub / small tree

Description: Erect shrub, branching stems, height to 6 feet, spreads rhizomatously, deciduous.

Leaf: Oval to almost round, opposite, length ½ to 2½ inches.

Flower: May-June, cluster of 8-16 pinkish, bell shaped flowers, flowers hairy inside.

Fruit/Seed: Distinctive snow-white berry (½ inch diameter), ripens in autumn and persists on bare branches throughout winter. Two tiny seeds per berry.

Typical Location: Mature riparian forest, shady woods, streambanks, north facing slopes, well-drained soils; elevations below 4,000 feet.

Revegetation Approach: Container.

Notes: Provides erosion control. Important understory species in riparian floodplains. Berries are an important food source for wildlife but may be toxic to humans. Foliage and twigs browsed by deer. Native Americans used the wood for construction of ceremonial tobacco pipes.


leaf


flower


seed


whole plant

SPIRAEA

Species Name: *Spiraea douglasii*
Family: Rosaceae (rose family)
Plant Type: Shrub

Description: Erect shrub, height 3-6 feet, spreads rhizomatously forming large clumps, deciduous.

Leaf: Elliptic, alternate, rounded tip, length 1-5 inches, margin toothed.

Flower: June-September, inflorescence long (2-5 inch length), thin with clusters of small, rose pink flowers, develop at branch ends.

Fruit/Seed: Fruit pod-like, dry, small.

Typical Location: Moist areas, coniferous forests, valley flats, streamside, seeps; elevations below 6,500 feet.

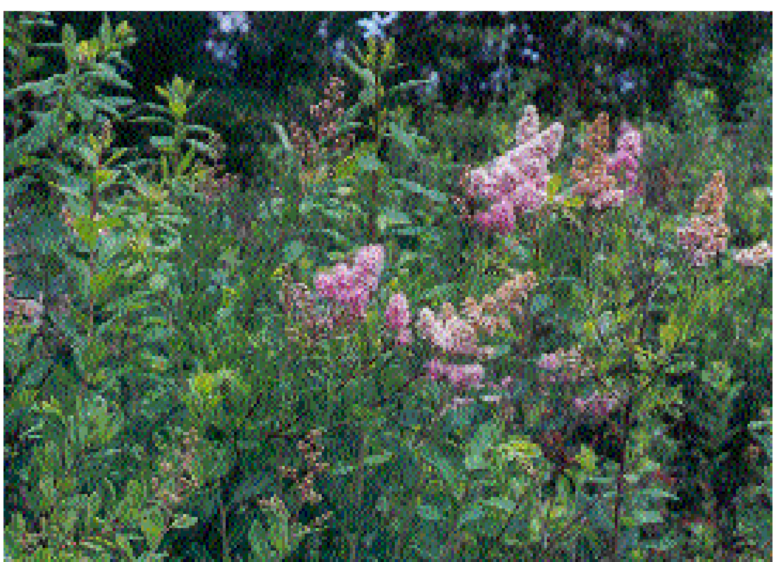
Revegetation Approach: Container.

Key Notes: *Spiraea douglasii* is replaced by *Spiraea denisflora* at higher elevations.

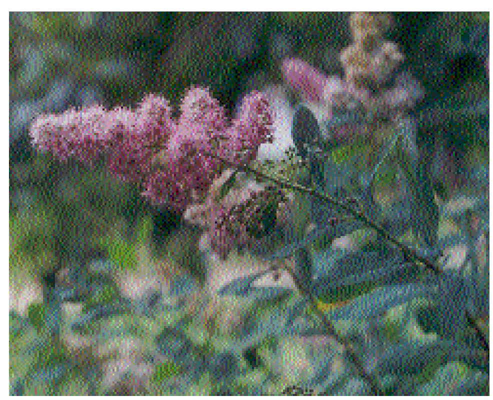
Notes: Good ground stabilizer on moist banks. Rose color of flowers is unique to this shrub.

leaf

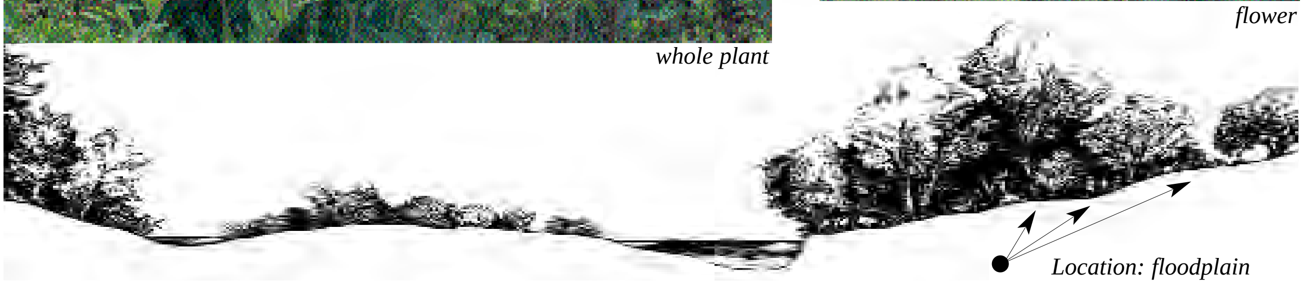
seed



whole plant



flower



Location: floodplain

STINK CURRANT

Species Name: *Ribes bracteosum*
Family: Grossulariaceae (gooseberry family)
Plant Type: Shrub / small tree

Description: Erect shrub, height to 13 feet, stems sparsely hairy, aromatic with an unpleasant odor.

Leaf: Deeply 5-7 lobed, length 1½-8 inches, upper surface shiny, dull below, margins toothed.

Flower: February to June, erect clusters of 20-50 flowers, flowers small, base saucer-like, petals small, white.

Fruit/Seed: Round berry, black with a whitish bloom, diameter to ½ inch.

Typical Location: Moist forests; elevations below 4,600 feet.

Revegetation Approach: Container.

Notes: Berries provide forage for wildlife.

leaf

flower

seed

whole plant

STREAM DOGWOOD

Species Name: *Cornus sericea*
Family: Cornaceae (dogwood family)
Plant Type: Shrub / small tree

Description: Shrub, spreads by branch tip rooting and underground stems, height to 15 feet, branches reddish to purple, deciduous with bright red autumn color.

Leaf: Lanceolate to elliptical, tapered at both ends, length to 4 inches, leaf veins in 4-7 pairs.

Flower: May-July, bisexual, flat topped clusters (2 inches wide) of small, white flowers appearing with and after leaves.

Fruit/Seed: Berry, white to cream colored, length to 1/4 inch, seed with grooved sides, ripens in late summer.

Typical Location: Active channel, streamsides, floodplains, moist areas; elevations below 9,000 feet.

Revegetation Approach: Container.

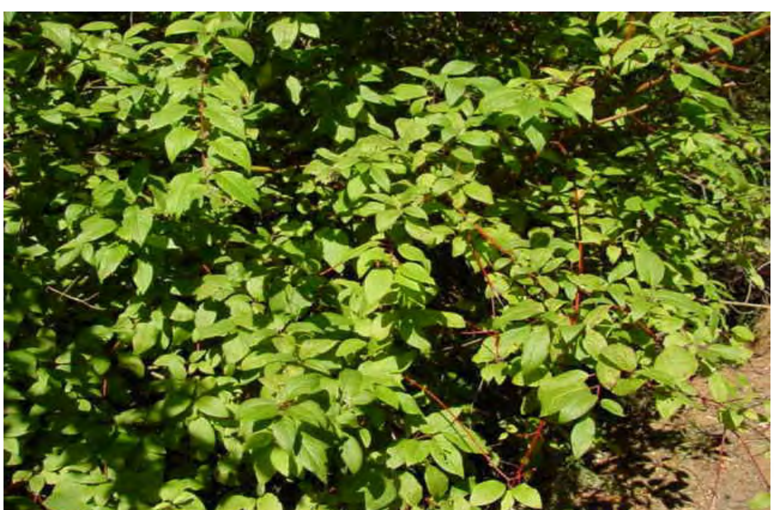
Key Notes: A good identifying characteristic is to look for thin latex threads when leaf is pulled apart. Leaf and seed morphology distinguish from red-twig dogwood (*C. glabrata*).

Notes: Seeds ripen in summer and persist into winter, making excellent wildlife forage. Native Americans used plant in basket weaving.

leaf

flower

seed



whole plant

Location: channel

THIMBLEBERRY

Species Name: *Rubus parviflorus*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Erect shrub, height 3-6 feet, branches with soft hairs rather than thorns, mature branches woody, bark shredding, forms thickets, deciduous.

Leaf: Palmate with 5 unequal lobes, length 2-6 inches, surface soft, margin toothed.

Flower: March-August, clusters at branch ends, only a few per plant, petals length to 1 inch, white, floppy looking.

Fruit/Seed: Raspberry-like (aggregate of red stone fruits), dull red ripening to deep red, edible, ripens in summer.

Typical Location: Moist shady areas, streamsides, floodplains; elevations below 8,200 feet.

Revegetation Approach: Container.

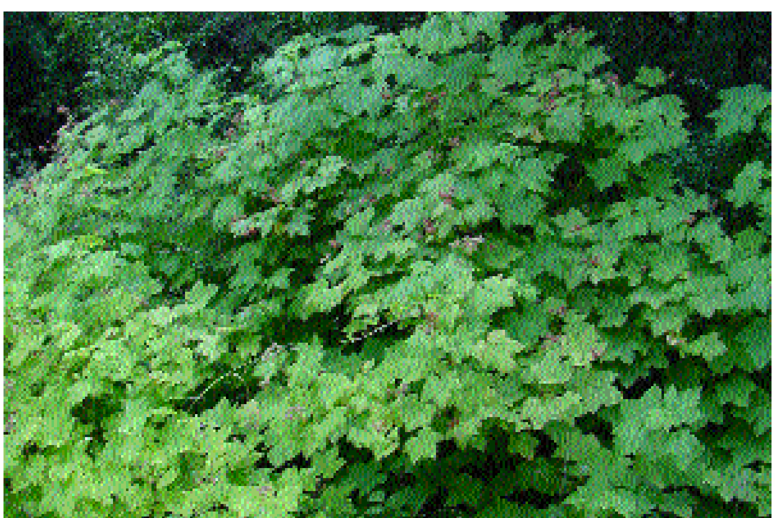
Key Notes: Related to the blackberry, raspberry and salmonberry.

Notes: Edible berries provide forage for wildlife. Name derived from its distinctive berry, which looks like a thimble when removed from the plant.

leaf

flower

seed



whole plant

TOYON
CALIFORNIA HOLLY
CHRISTMAS BERRY

Species Name: *Heteromeles arbutifolia*
Family: Rosaceae (rose family)
Plant Type: Shrub / small tree

Description: Shrub or small tree, multi-trunked, height to 30 feet, bark gray, evergreen.

Leaf: Oblong, leathery, glossy, dark green, length to 4 inches, margin sharply toothed.

Flower: June-July, flat toped clusters, flowers white, small (petal length to <¼ inch), produced at ends of older branches.

Fruit/Seed: November-January, bright-red berry, fleshy, diameter ¼ inch, persistent, contains 3-6 brown seeds.

Typical Location: Chaparral, oak woodland, floodplains, mixed-evergreen forest, dry to semi-dry slopes and canyons; elevations below 4,200 feet.

Revegetation Approach: Container.

Notes: Vital forage for California birds, especially during late winter.


leaf


flower


seed


whole plant

TWINBERRY

Species Name: *Lonicera involucrata*
Family: Caprifoliaceae (honeysuckle family)
Plant Type: Shrub / small tree

Description: Erect densely foliaged shrub, branches slender, height to 10 feet, deciduous.

Leaf: Elliptical to ovate, length 2-4 inches.

Flower: March-July, paired tubular flowers (½ inch long), yellow with reddish tinge. "Leaf-like" bracts fuse to form cup underneath flower pair. Bracts darken to red or purple as flower matures.

Fruit: Distinctive paired round berries (1/3 inch diameter) containing tiny seeds, surrounded by colorful cup-like bracts.

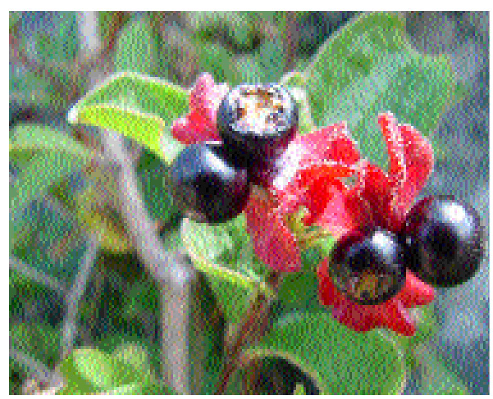
Typical Location: Floodplains, moist, shady areas, streamsides; elevations below 9,500 feet.

Revegetation Approach: Container.

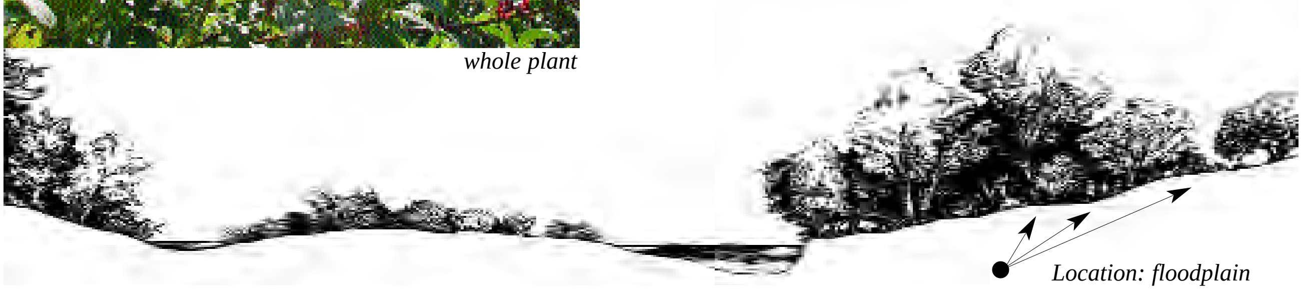
Notes: Close relative to the native honeysuckle, *L. hispidula* var. *vacillans*.


leaf


flower


seed


whole plant



VINE MAPLE

Species Name: *Acer circinatum*
Family: Aceraceae (maple family)
Plant Type: Shrub / small tree

Description: Small tree or shrub, often reclining, rooting and vine-like (especially in shaded areas), height to 20 feet in full sun, deciduous with bright autumn color.

Leaf: Palmate, 5-7 lobes, width 2-5 inches.

Flower: April-May, clusters of 4-10 small, inconspicuous flowers, sepals deep red, petals pale green.

Fruit/Seed: Distinctive paired achenes with wings, achene round, reddish, wings spreading almost 180°.

Typical Location: Shaded stream banks, floodplains; elevations below 5,000 feet.

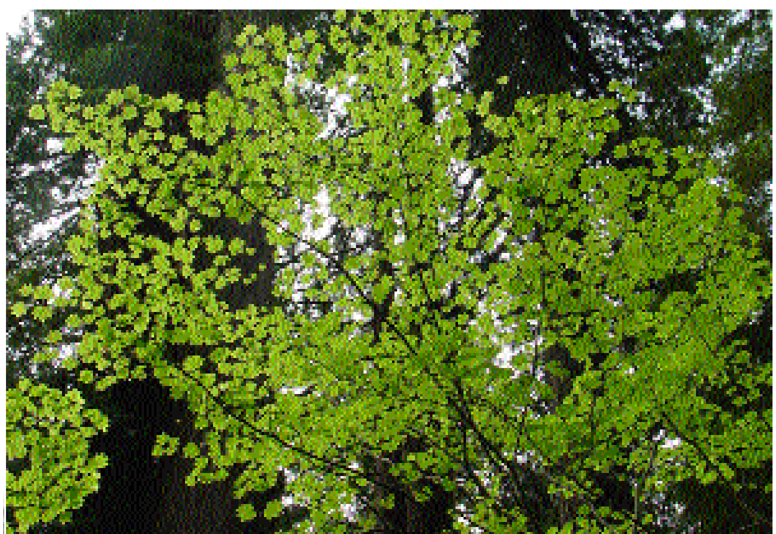
Revegetation Approach: Container.

Key Notes: Related to the big leaf maple (*A. macrophyllum*) and box elder (*A. negundo*). Easily distinguished by leaf shape.

Notes: Foliage provides forage for deer. Flowers, buds and seeds provide forage for birds and small mammals. Squirrels will cache seeds.


leaf


flower


whole plant


seed

WESTERN AZALEA

Species Name: *Rhododendron occidentale*
Family: Ericaceae (heath family)
Plant Type: Shrub / small tree

Description: Erect shrub, densely branched with slender twigs, height 5-16 feet, deciduous.

Leaf: Elliptic, thin, mid-vein not sunken, length 1-3½ inches, edges smooth.

Flower: April-August, clusters of large, showy, white or pinkish flowers, length to 2 inches, 3-4 petals fused, strong fragrance.

Fruit/Seed: Dry capsule with many scale-like seeds.

Typical Location: Streambanks, seeps, floodplains, coniferous forests; elevations below 7,200 feet.

Revegetation Approach: Container.

Notes: *Rhododendron* is a Greek word meaning "rose tree", as signified by the showy, fragrant flowers.

leaf

flower

seed

whole plant

Location: floodplain

WESTERN SPICEBUSH

Species Name: *Calycanthus occidentalis*
Family: Calycanthaceae (sweet-shrub or calycanthus family)
Plant Type: Shrub / small tree

Description: Erect shrub, bushy round shaped, aromatic (described as old wine barrel smell), height to 9 feet, deciduous with yellow autumn color.

Leaf: Oval to oblong, opposite, length 2-6 inches, slightly hairy underneath, aromatic when crushed.

Flower: April-August, bisexual, terminal single flower, deep reddish-brown, diameter 2 inches, looks like a tiny water lily, smells "spicy".

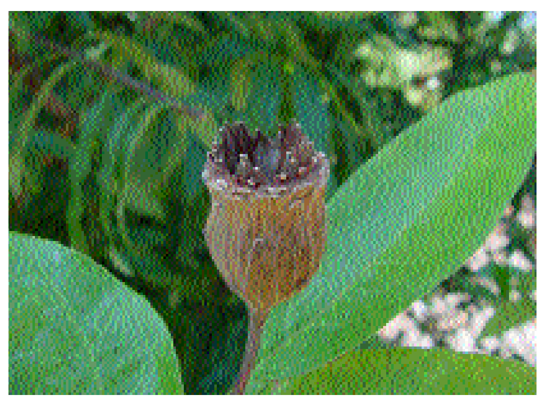
Fruit/Seed: Oval, leathery, cuplike receptacle containing velvety, whitish-brown seeds that ripen in the autumn.

Typical Location: Moist, shady areas, floodplains, canyons, streamsides, seeps; elevations below 5,000 feet.

Revegetation Approach: Container.


leaf


flower


fruit with seed inside


whole plant


Location: floodplain

WILD MOCK ORANGE

Species Name: *Philadelphus lewisii*
Family: Philadelphaceae (mock orange family)
Plant Type: Shrub / small tree

Description: Erect shrub, loosely branched, many trunks, young bark reddish, older bark gray and peeling, height to 10 feet, deciduous.

Leaf: Ovate, opposite, margin partially toothed, length 1-3 inches.

Flower: May-July, terminal clusters of 6 or more flowers, white, width ¾-1 inch, numerous stamens, fragrant.

Fruit/Seed: Dry, multi-seeded capsule.

Typical Location: Slopes, canyons, forest openings, rocky slopes, canyons; elevations below 5,000 feet.

Revegetation Approach: Container.

Notes: Dense growth provides good cover. Seeds eaten by quail and squirrels.


leaf


flower


seed


whole plant


Location: floodplain

CALIFORNIA WILD GRAPE

Species Name: *Vitis californica*
Family: Vitaceae (grape family)
Plant Type: Vine

Description: Sprawling woody vine, climbs surrounding vegetation, bush-like without support, tendrils produce opposite leaves, bark peeling, deciduous.

Leaf: Rounded with 0-3 shallow, palmate lobes, alternate, hairy especially on the underside, margins finely toothed.

Flower: May-July, numerous clusters of unisexual, greenish-yellow, small, fragrant flowers.

Fruit/Seed: Clusters of spherical berries, purple with whitish bloom, diameter ½ inch.

Typical Location: Streamsides, floodplains, springs, and canyons; elevations below 3,200 feet.

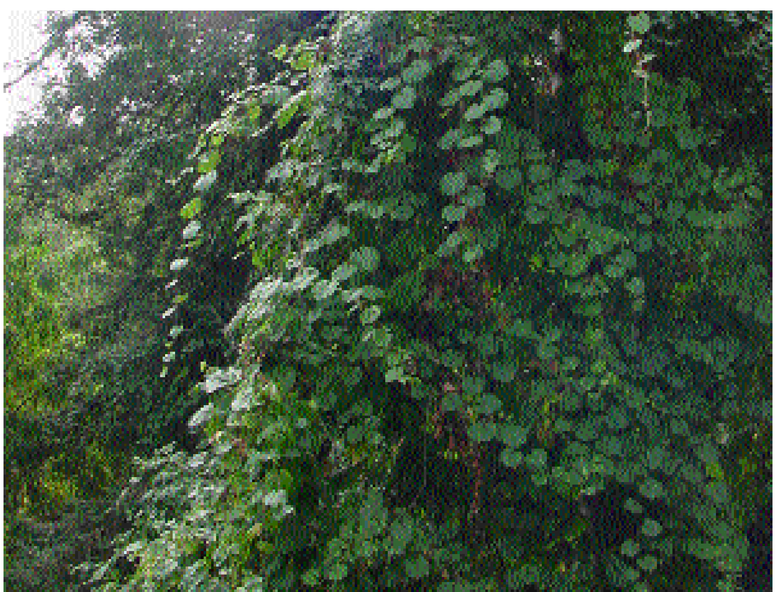
Revegetation Approach: Container, care in collection should be taken as the wild grape readily hybridizes with European imports.

Notes: Berries are an important forage for wildlife.

leaf

flower

seed



whole plant

DUTCHMAN'S PIPEVINE

Species Name: *Aristolochia californica*
Family: Aristolochiaceae (pipevine family)
Plant Type: Vine

Description: Semi-woody vine, slender stems with fine short hairs, twining stems, length to 16 feet, deciduous.

Leaf: Heart shaped, bright green, soft-hairy, alternate, length 1-6 inches, margins smooth.

Flower: January-April, U-shaped (pipe-like), hanging, green to brown, veins purple, interior lined with pink-red, length 1-1½ inches, appear before leaves, metallic fragrance.

Fruit/Seed: Capsule, angular, light green, length to 2 inch.

Typical Location: Streamsides, floodplains, forest, chaparral; elevations below 2,300 feet.

Revegetation Approach: Container.

Notes: Provides food for the pipevine swallowtail larvae and is, in turn, pollinated by the pipevine swallowtail butterfly. Produces a specialized glycoside, known to cause heart attacks in vertebrates, which provides swallowtail larvae with a defense against predators. Other butterflies mimic pipevine swallowtail coloration as a predator defense strategy.

leaf and seed

flower

whole plant

seed with pipevine swallowtail caterpillar

Location: floodplain

HONEYSUCKLE

Species Name: *Lonicera hispidula*
Family: Caprifoliaceae (honeysuckle family)
Plant Type: Vine

Description: Climbing vine, slender stems, length to 20 feet.

Leaf: Oblong, opposite, length to 3 inches, upper pairs connected around stem.

Flower: April-July, clusters of paired flowers, flowers funneled, double-lipped blooms, upper lip four-lobed, very fragrant, purple to pink, length to ½ inch.

Fruit/Seed: Round, red berry, diameter ¼ inch.

Typical Location: Streamsides, floodplain, wooded slopes, canyons; elevations below 3,600 feet.

Revegetation Approach: Container.

Notes: Related to the native twinberry, *Lonicera involucrata*.


leaf


flower


whole plant


seed

MANROOT
WILD CUCUMBER

Species Name: *Marah fabaceus*
Family: Cucurbitaceae (gourd family)
Plant Type: Vine

Description: Perennial vine, climbs, builds mounds and sprawls, stems soft/not-woody, sometimes with prickles, climbs using lateral tendrils, length to 21 feet, large root or tuber.

Leaf: Palmate, 5-7 lobes, large.

Flower: February-April, monoecious (separate sexes on same vine), female and male similar, white to yellowish-green, cup shaped, width to ½ inch, female flowers solitary, male flowers in clusters.

Fruit/Seed: Spiny gourd, rounded with pointed tip, diameter 1½-2 inches, contains 4 large, often flat, brown seeds.

Typical Location: Streamsides, floodplains, washes, shrubby areas, open areas, and slopes; elevations below 5,200 feet.

Revegetation Approach: Container.

Notes: The common name "manroot" relates to the very large tuber root that can grow 4-8 feet long. Native Americans traditionally used pounded root in tidepools and stream pools to stun fish.


leaf


flower


seed


whole plant

POISON OAK

Species Name: *Toxicodendron diversilobum*
Family: Anacardiaceae (sumac or cashew family)
Plant Type: Vine

Description: Shrub, occasionally tree-like (height 1½-14 feet) or vining (length to 85 feet) into tree canopies, gray to red-brown twigs, deciduous.

Leaf: Compound with 3 (occasionally 5) leaflets, leaflets resinous, smooth, shiny, red in autumn, lobed, terminal leaflet length to 3 inches, lateral leaflet length to 2¾ inches.

Flower: April-May, clusters of small, cream-colored flowers, petals ovate.

Fruit/Seed: Round berry, white, leathery, diameter <¼ inch.

Typical Location: Floodplains, canyons, slopes, chaparral, oak woodlands; elevations below 5,400 feet.

Revegetation Approach: Not recommend for cultivation.

Notes: Resin on leaves, stems and flowers causes painful dermatitis to humans. Latin name means "poisonous tree". Fruit is an important winter forage for wildlife.


leaf


flower


seed


whole plant

VIRGIN'S BOWER
PIPESTEM

Species Name: *Clematis lasiantha*
Family: Ranunculaceae (buttercup family)
Plant Type: Vine

Description: Semi-woody vine, stems slender, climbs surrounding vegetation with tendril-like leaf petiole, deciduous.

Leaf: Compound with 3-5 leaflets, leaflets elliptic/ovate, coarsely toothed or 3-lobed, length 1-2 inches.

Flower: January-June, single flower, showy, diameter 1¼ inch, no petals but 4 cream-colored sepals showy and petal-like.

Fruit/Seed: Head-like clusters of small achenes with distinctive long feathery tails.

Typical Location: Floodplains, hillsides, chaparral, open woodlands; elevations below 6,600 feet.

Revegetation Approach: Container.

leaf

flower

seed

whole plant

BULRUSH
TULE

Species Name: *Scirpus acutus* var. *occidentalis*
Family: Cyperaceae (sedge family)
Plant Type: Emergent

Description: Erect perennial, spreads by rhizomes forming dense clusters, stems round, width to ½ inch, height 5-13 feet.

Leaf: Reduced to a membranous flat blade along stem base, length to 3 inches.

Flower: May-August, bisexual, erect, 1-7 branched clusters, straw colored or orange to dark reddish brown, produced at stem tip, flowers spiny.

Fruit/Seed: Achene, slightly angled sides, beaked, gray-brown, wind and water dispersed.

Typical Location: Active channel, streamsides, marshes, lakes; elevations below 8,200 feet.

Revegetation Approach: Container or transplant.

Notes: May provide critical juvenile fish habitat. Important nesting and escape cover for small mammals, waterfowl and other birds. Seeds provide forage for waterfowl. Thick rhizome root system provides some river and lake bank stabilization. Native Americans used *Scirpus* roots for basketry.

flower

whole plant

Location: channel

CATTAIL

Species Name: *Typha latifolia*
Family: Typhaceae (cattail family)
Plant Type: Emergent

Description: Erect perennial, dense clumps of tall blades (height 5-10 feet), creeping rootstock.

Leaf: Blade, alternate, flat on the inside, rounded on the outside, interior spongy, tip pointed, height to over 6 feet.

Flower: June-July, cattail, terminal flowers on a round stalk, male flowers above female flowers, no separation between male and female clusters, female flowers green in flower, turn brown as seeds ripen.

Fruit/Seed: Tiny, brown nutlets, length 1/25 inch, released with white mass of wooly hairs, seeds disperse by floating on wind or water.

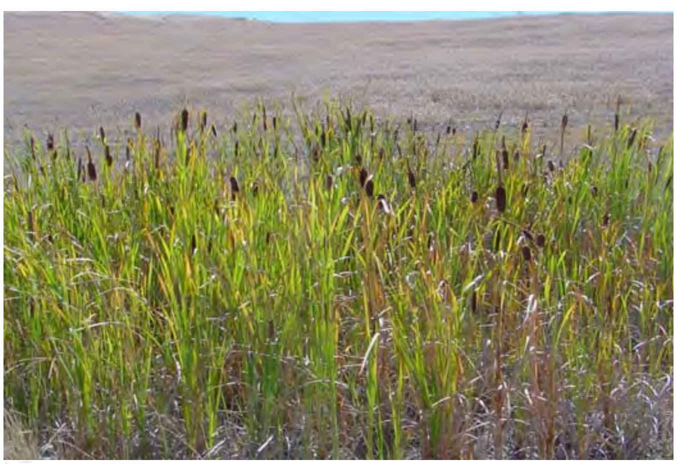
Typical Location: Lakes, marshes, any slow moving or stagnant water; elevations below 6,600 feet.

Revegetation Approach: Seed, transplant.

Notes: Nest building habitat and shelter for birds and waterfowl. Tolerates saline conditions.

leaf and flower

seed



whole plant

Creeping Wild Rye

Species Name: *Leymus triticoides*
Family: Poaceae (grass family)
Plant Type: Herbaceous

Description: Mat forming grass, height 1½-4 feet, perennial, stems smooth to slightly hairy, spreads by rhizomes, may remain green even in dry season, leaf blades lean away from stem.

Leaf: Blade, flat, surface slightly rough.

Flower: Cluster of grass spikelets at end of tall stem (height 2-8 inches), spikelets 1-3 per node.

Fruit/Seed: Achene-like grain.

Typical Location: Streamsides, floodplains, moist meadows and areas subject to flooding; elevations below 7,500 feet.

Revegetation Approach: Container, transplant.

Notes: Useful in binding soil for erosion control, lies flat when flooded and recovers quickly. Tolerates saline conditions.


whole plant


whole plant

HORSETAIL SCOURING RUSH

Species Name: *Equisetum spp.*
Family: Equisetaceae (horsetail family)
Plant Type: Emergent

Description: Perennial from spreading rhizomes, erect annual (some perennial) stems, stem is segmented with distinct rings, ring may have whirl of wiry leaf-like branches, spore producing non-woody cone forms at stem tips, may have separate sterile and fertile stems, height 4 inches to 6 feet.

Leaf: None or scale-like, close growing, brown (wiry branches are leaf-like, but not leaves).

Flower: None, sexual reproduction by a spore producing non-woody cone (not a flowering plant).

Fruit/Seed: Spore, spherical, green.

Typical Location: Streamsides, moist areas, roadside ditches, seeps, disturbed areas; elevations below 9,800 feet.

Revegetation Approach: Container or transplant.

Notes: Provides soil stabilization. Native Americans made tea for medicinal uses and used the fertile stems of *E. telmateia* as sandpaper. Outer surface has high silica content.

whole plant with branches

whole plant with fertile stems

INDIAN RHUBARB
UMBRELLA PLANT

Species Name: *Darmera peltata*
Family: Saxifragaceae (saxifrage family)
Plant Type: Herbaceous

Description: Perennial herb, stemless, flowers and leaves from ground, flowers before leaves appear, spreads by rhizomes, height to 5 feet, leaves turn bright red in autumn.

Leaf: Palmate, multi-lobed, height to 5 feet, broad (width to 3 feet), stem attached towards center of leaf, margins with irregular teeth.

Flower: April-July, umbrella shaped cluster of small, white to pale pink flowers, grows on long stalk (length 1 to 5 feet) before leaves.

Fruit/Seed: 2 dry red follicles, length to ½ inch.

Typical Location: Rocky streambanks; elevations below 6,000 feet.

Revegetation Approach: Container, transplant.

Notes: The common name "umbrella plant" describes the leaves, which look like umbrellas blown inside out.

leaf

flower

whole plant

Location: channel

MUGWORT

Species Name: *Artemisia douglasiana*
Family: Asteraceae (sunflower family)
Plant Type: Herbaceous

Description: Perennial erect herb, stems in dense clump, height to 8 feet, spreads by rhizomes.

Leaf: Coarsely 3-5 lobed, evenly-spaced, alternate, underside hairy and grayish, aromatic (sage-like), length to 6 inches.

Flower: June to October, dense clusters on elongated leafy stems, length 4-12 inches, disk flowers small (diameter <¼ inch), bell shaped, greenish.

Fruit/Seed: Tiny dry achene.

Typical Location: Moist low places, open and shady places, drainages; elevations below 7,200 feet.

Revegetation Approach: Container.

Notes: Common, stabilizes soil. Pierce's Disease host plant (see page XI-7 for more information).

leaf

flower

whole plant

RUSH

Species Name: *Juncus* spp.
Family: Juncaceae (rush family)
Plant Type: Emergent

Description: Erect grasslike annual or perennial, usually spread by rhizomes forming dense clumps, stems wiry, round or flat, height to 4 feet.

Leaf: Wiry, round or flat, sometimes greatly reduced to just tip of stem.

Flower: May-August, bisexual, lateral clusters near stem tip, 1-50 flowers, flower green or purplish-brown, inconspicuous.

Fruit/Seed: Many, tiny beaked seeds.

Typical Location: Active channel, streamsides, marshes, seeps, springs; elevations below 12,000 feet.

Revegetation Approach: Container or transplant.

Key Notes: Accurate identification requires an understanding of flower characteristics.

Notes: Thick rhizome root system provides streambank stabilization. Native Americans used rushes for basketry and fish trap construction.

whole plant and flower

Juncus effusus

whole plant

Location: channel, floodplain

SEDGE

Species Name: *Carex* spp.
Family: Cyperaceae (sedge family)
Plant Type: Emergent

Description: Perennial, bladed (grass-like) with 3-sided stems and flat blades, forms clumps or tufts, height to 4 feet, often evergreen, some species spread by rhizomes.

Leaf: Blade, usually flat, can be rolled, thick (width ¼-½ inch).

Flower: Unisexual, male spikelets sit above the female spikelets near the blade tip, flower stalk solid and without nodes.

Fruit/Seed: Tiny, 2-4 sided achene.

Typical Location: Depends on species: active channel, floodplain, wet areas, valley slopes, seasonally wet areas; elevations below 13,000 feet.

Revegetation Approach: Container, transplant.

Key Notes: Identification to species usually requires microscopic evaluation of flowering parts.

Notes: With over 1,000 species, sedges comprise one of the largest genera of plants in the world. Native Americans traditionally used certain species of *Carex* in basket weaving.

Carex nudata

Carex spp.

SPIKE RUSH

Species Name: *Eleocharis spp.*
Family: Cyperaceae (sedge family)
Plant Type: Emergent

Description: Erect annual or perennial, spreads by rhizomes, stems round, wiry, generally grooved, height to 3 feet.

Leaf: Generally without or reduced to sheath around stem, sometimes leaves from base.

Flower: Bisexual, erect, single cluster at stem tip, flowers few to many.

Fruit/Seed: Achene, 2-3 sided or round.

Typical Location: Streamsides, marshes, meadows; elevations below 8,500 feet.

Revegetation Approach: Container or transplant.

Notes: Stems, roots and seeds are all forage for waterfowl.

whole plant and flower

flower

whole plant

STINGING NETTLE

Species Name: *Urtica dioica*
Family: Urticaceae (nettle family)
Plant Type: Herbaceous

Description: Perennial erect herb, stems with fine hairs, spreads by rhizomes, height to 10 feet.

Leaf: Lanceolate to widely ovate, margin toothed, veins 3-5 originating at base, length to 1½ inches.

Flower: April, mostly dioecious flower clusters (length to 3 inches) in leaf axis, male and female flowers small, sepals greenish, without petals.

Fruit/Seed: Ovate achene.

Typical Location: Streambanks, woodland marshes, moist waste areas; elevations below 10,000 feet.

Revegetation Approach: Container.

Key Notes: A subspecies is native to Eurasia and naturalized in North America, care must be taken in identification.

Notes: This plant contains tiny hollow hairs, which, upon contact with human skin, releases an irritating, stinging acid (formic acid), hence the name. Pierce's Disease host plant (see page XI-7 for more information).


leaf


flower


whole plant


flower


Location: channel, floodplain

APPENDIX XI-B

CENTRAL AND NORTH COAST INVASIVE NON-NATIVE PLANTS

ACACIA

Species Name: *Acacia* spp.
Family: Fabaceae (legume family)
Plant Type: Exotic invasive tree

Description: Tree, height to 40 feet, evergreen.

Leaf: Distinctive primary and secondary leaflets, silver-gray, hairy. Primary leaflet: 10-25 pairs of secondary leaflets; secondary leaflet: 20-50 pairs of tiny, thin, overlapping leaflets (length to <¼ inch).

Flower: Bisexual, spherical clusters of 25-30 tiny, bright yellow flowers.

Fruit/Seed: Pod, straight or slightly curved, slightly indented between seeds, length 2-3 inches.

Typical Location: Disturbed areas, roadsides, elevations below 1,600 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

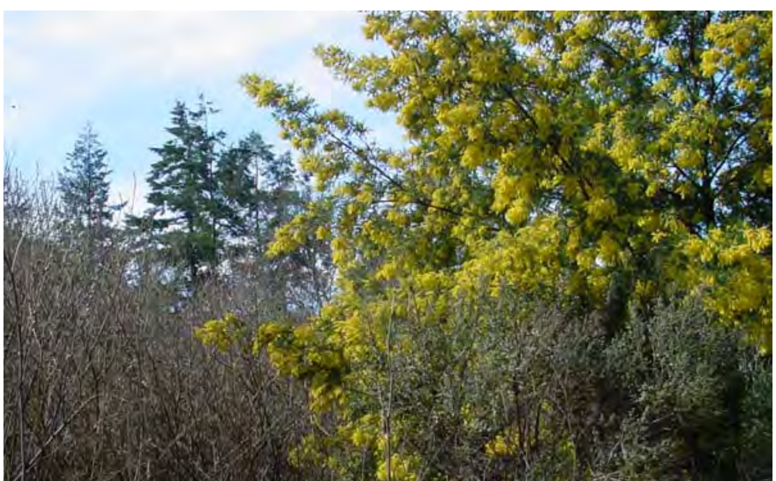
Key Notes: Members of the family Fabaceae have root nodules that contain atmospheric nitrogen-fixing bacteria.

Notes: Ornamental species brought from Australia. Highly invasive and has little wildlife value. Chemicals leaching from trees may cause allelopathic effects resulting in reduced or inhibited germination and growth in native plants.

leaf

flower

seed



whole plant

Location: floodplain

CAPE IVY

Species Name: *Delairea odorata*
Family: Asteraceae (sunflower family)
Plant Type: Exotic invasive vine

Description: Perennial vine, stems green or purple, older stems woody, ground cover develops to 30 inches high, climbs to considerable heights, spreads by runners that root at nodes.

Leaf: Palmate with 5-9 pointed lobes, shiny, greenish-yellow, length 1-3 inches.

Flower: Spring blooming, disk-like flowers, bright yellow, numerous.

Fruit/Seed: Achenes, tiny, wind dispersed, mostly sterile in California.

Typical Location: Moist forest, riparian areas, seasonal wetlands, coastal areas; elevations below 650 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Key Notes: Name changed to *Delairea odorata* from *Senecio mikanioides*.

Notes: Native to South Africa. Highly invasive and grows rapidly. Extreme pest with climbing behavior resulting in smothering and exclusion of native vegetation.

leaf

flower

whole plant

English Ivy

Species Name: *Hedera helix*
Family: Araliaceae (ginseng family)
Plant Type: Exotic invasive vine

Description: Woody vine, ground cover or climber with aerial rootlets, spreads by runners, evergreen.

Leaf: Variable shape, palmate with 3-5 lobes to ovate or diamond shaped, length to 4 inches, base width to 4 inches, edges smooth.

Flower: Branches with small, ball-like clusters of greenish flowers.

Fruit/Seed: Round berry, black, diameter <¼ inch.

Typical Location: Moist shady areas, elevations between sea level to 3,300 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Key Notes: Very similar to non-native Algerian ivy (not pictured), *H. canariensis*, although Algerian ivy has larger leaves (width 5-8 inches) that are more widely spaced.

Notes: Non-native, planted as soil stabilizing ground cover, introduced from Europe, highly invasive. Prevents native plant germination. Ground cover and vining behavior kill both understory and overstory native plants by shading. Harbors slugs, snail and rodents.

leaf

flower

whole plant

Location: floodplain

EUCALYPTUS
GUM TREE

Species Name: *Eucalyptus* spp.
Family: Myrtaceae (myrtle family)
Plant Type: Exotic invasive tree

Description: Tree, tall and slender, height 30-150 feet, peeling bark, evergreen.

Leaf: Variable among species, always longer than wide (length 2-8 inches), leathery, usually lanceolate, edges smooth, pointed at tip, highly aromatic containing volatile oil.

Flower: Mostly spring/summer, sometimes through autumn, bisexual, cup-like receptacle contains flower, petals inconspicuous but stamen showy white, yellow, pink or red.

Fruit/Seed: Woody capsule, angular sides, flat top, contains many tiny seeds.

Typical Location: Disturbed areas; elevations below 1,000 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Native to Australia and imported as a wood source. Removal sometimes controversial because native wildlife, especially birds and Monarch butterfly, use tree for roosting or nesting. Allelopathic and shading effects result in reduced and inhibited native plant germination and growth. Thick leaf, bark and limb litter create fire hazard.


leaf


whole plant


flower


seed


Location: floodplain

FENNEL

Species Name: *Foeniculum vulgare*
Family: Apiaceae (carrot family)
Plant Type: Exotic invasive herb

Description: Perennial herb with large taproot, erect, solid stems, height 3-10 feet, woody dry stems with seed heads remain visible after winter die back, new leaves form from base in late winter. Entire plant has strong licorice or anise-like aroma.

Leaf: Large triangle leaf, finely divided into thread like sections.

Flower: May-September, bisexual, umbrella like clusters (width to 4 inches) with 15-40 rays containing clusters of small, yellow flowers.

Fruit/Seed: Oblong, ribbed, length 1/8 inch, seed face flat.

Typical Location: Streamsides, roadsides, disturbed areas; elevations sea level to 1,200 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Native to Europe, escaped from cultivation. Spreads rapidly and excludes native vegetation. Disturbed, open soil encourages establishment. Dispersal of seeds by water result in downstream invasions.


whole plant


flower


seed


whole plant in flower

FLOATING PRIMROSE, WATER PRIMROSE

Species Name: *Ludwigia peploides/Ludwigia hexa-petala*
Family: Onagraceae (evening primrose family)
Plant Type: Exotic invasive emergent/aquatic

Description: Perennial herb, spreads by rooting nodes over stream edges and water forming floating mats (roots in water up to 18 inches deep, 10-15 feet from shore). Stems straight or branching, prostrate or erect, length 1-10 feet.

Leaf: Oblong to round, alternate, length to 2½ inches.

Flower: May-October, bisexual, showy, bright yellow, petal length to 1 inch. Flowers on stalks arising from leaf axis (point where leaf joins stem).

Fruit/Seed: Capsule, hard, long, cylindrical, 5-sided, with tiny seeds embedded in fruit walls.

Typical Location: Stream banks, ditches, ponds; elevations below 3,000 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

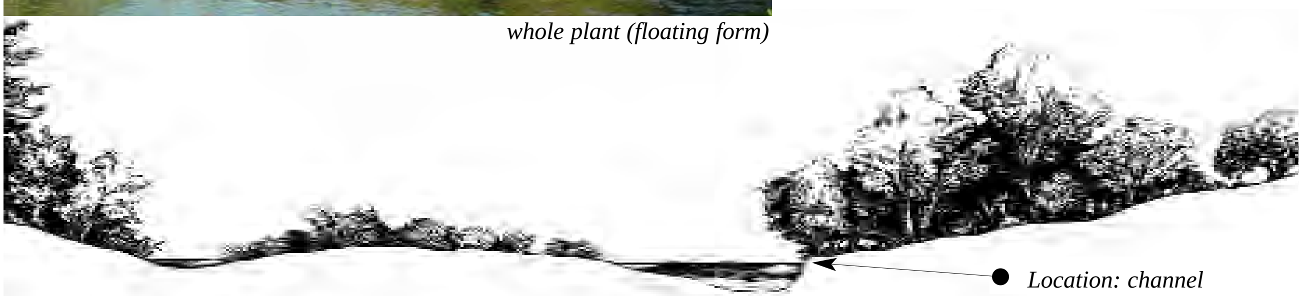
Notes: Native to Southern U.S., cultivated as ornamental for landscaped ponds. Floating aquatic and emergent, depending on season and water level.

leaf and flower (erect fom)

flower

whole plant (floating form)

whole plant (floating form)



GIANT REED

Species Name: *Arundo donax*
Family: Poaceae (grass family)
Plant Type: Exotic invasive grass

Description: Many stemmed, dense clumps of cane or bamboo-like grass, stem hollow but divided by partitions at nodes (like bamboo), height 9-30 feet, spreads by rhizomes and rooting at nodes, semi-dormant in winter (turns brownish).

Leaf: Blade-like, flat, length to 3 feet, width to 2 inches at base, tapers to point at tip, alternate, arranged in a single plane (corn-like).

Flower: March-September, plumed terminal cluster, length 1-2 feet, brown or purple.

Fruit/Seed: No viable seed produced in North America.

Typical Location: Streamside, floodplains, drainages, ditches; elevations below 1,600 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Introduced from Asia and one of the greatest vegetative threats to the health of California's waterways. It is highly flammable, provides limited stream shading, and minimal habitat for native wildlife. Forms dense monocultures that may exclude native vegetation.

leaf

whole plant

node

whole plant

Location: floodplain, channel

HIMALAYAN BLACKBERRY

Species Name: *Rubus discolor*
Family: Rosaceae (rose family)
Plant Type: Exotic invasive vine

Description: Thicket forming, mound building (height to 10 feet or more), sprawling, vine-like, cane length to 20 feet, stems 5 angled, thorns large and curved, stem tips root.

Leaf: Compound with 5 leaflets, leaflet ovate, margins sharply toothed, length 2-4 inches.

Flower: April-June, clusters of white to pale pink flowers, petal length 1/2 inch.

Fruit/Seed: Blackberry (aggregate of black stone fruits), oblong, red ripening to black, highly edible, ripening in summer. Multiple small seeds inside single blackberry.

Typical Location: Common, disturbed moist areas, streamsides, roadsides, fencerows; elevations below 5,200 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Key Notes: Often confused with the native California blackberry (*R. ursinus*). Distinguished by leaf and thorn morphology.

Notes: The dense brambles choke out native vegetation and dominate the riparian forest floor. Thickets provide shelter and forage for wildlife, and erosion control. Removal requires revegetation with native vegetation. Pierce's Disease host plant (see page XI-7 for more information).

leaf

flower

seed

stem

whole plant

Location: floodplain, channel

PAMPAS GRASS

Species Name: *Cortaderia selloana*
Family: Poaceae (grass family)
Plant Type: Exotic invasive grass

Description: Perennial grass, dense clumps, height 6-14 feet, width 12 feet.

Leaf: Blades greenish-gray, width 1-3 inches, tapering at tip, sharp edges can cut.

Flower: Summer, dioecious (separate sex grasses) but can reproduce asexually, long stalks (length to 14 feet) with distinctive plum-like silvery flower head.

Fruit/Seed: Tiny seeds, wind dispersed, ripen in autumn.

Typical Location: Moist areas, disturbed sites, elevations below 1,000 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Ornamental brought from South America. Produces wind-born seeds asexually, results in rapid spread. Dominates landscape and excludes native vegetation.

Pampas grass

whole plant

seed

PEPPERWEED

Species Name: *Lepidium latifolium*
Family: Brassicaceae (mustard family)
Plant Type: Exotic invasive herb

Description: Perennial herb, erect, branching, height to 6 feet. Spreads by creeping roots (rhizomes) up to 10 feet from original plant. Dies back during winter months.

Leaf: Lanceolate, toothed or entire, waxy, distinctive white veins, lower leaves larger (length to 1 foot, width 2-3 inches) than upper leaves (width to 1 inch).

Flower: May-July, bisexual, dense clusters of tiny, white, 4 petaled flowers produced at stem tips.

Fruit/Seed: Round, pod-like, slightly hairy, diameter 1/12 inch, contains 2 tiny, reddish-brown seeds, spread by wind, water and possibly waterfowl.

Typical Location: Riparian areas/wetlands, roadsides, disturbed areas, saline soils; elevations below 6,200 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Key Notes: Flowers have 4 petals, a characteristic of the mustard family.

Notes: Native to Eurasia, accidentally brought to U.S. Successful competitor in riparian and wetland areas forming dense clusters that exclude native vegetation. Does not hold soil well resulting in streamside erosion. Reproduces and spreads by seeds and root fragments.

leaf

flower

whole plant

whole plant

PERIWINKLE

Species Name: *Vinca major*
Family: Apocynaceae (dogbane family)
Plant Type: Exotic invasive vine

Description: Spreading, low growing, with erect flowering stems (height 9-20 inches) and trailing non-flowering stems (length to 6 feet), stems root at tips, deciduous. Stems produce milky latex if broken.

Leaf: Oval, tip pointed, opposite, length to 3 inches.

Flower: Spring-Summer, bisexual, single flowers, diameter 1-2 inches, light blue-purple, produced from leaf axis (point where leaf joins stem).

Fruit/Seed: Rarely produces viable seed in California.

Typical Location: Sheltered places, floodplains, streamsides usually escaped from cultivation; elevations below 650 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Native to Mediterranean region, commonly planted as ground cover. Low value to native wildlife and insects. The scientific name, Vinca, translates in Latin to "bind or conquer". Vinca lives up to its name with an aggressive, spreading growth that prevents native plants from becoming established. Pierce's Disease host plant (see page XI-7 for more information).


leaf and flower


flower


whole plant


Location: floodplain, channel

Poison Hemlock

Species Name: *Conium maculatum*
Family: Apiaceae (carrot family)
Plant Type: Exotic invasive herb

Description: Perennial herb, erect, branched, stems hollow, generally purple spotted/striped, height 2-10 feet, taproot solid, whitish, parsnip like. Plant gives off unpleasant "mouse-like" odor when bruised.

Leaf: Compound, length 2-12 inches. Leaflets very small, finely divided, delicate.

Flower: May-September, bisexual, umbrella like clusters (width 1-2 inches) with 5-15 rays containing clusters of small, white flowers.

Fruit/Seed: Round to ovate, sides ribbed, diameter <¼ inch.

Typical Location: Wet areas; elevations below 3,200 feet.

Revegetation Approach: Do not plant in riparian areas!

Notes: Native to Europe. Very toxic if eaten, all parts (leaves, seeds, roots) contain high levels of conine and related pyridine-type alkaloids. The Greek philosopher Socrates was executed by drinking prepared poison hemlock. May have allelopathic effects that suppress germination of native plants.

leaf

flower

whole plant

seed

TAMARISK
SALT CEDAR

Species Name: *Tamarix* spp.
Family: Tamaricaceae (tamarisk family)
Plant Type: Exotic invasive shrub

Description: Shrub or small tree, thin, narrow crown, height to 26 feet, branches jointed and often drooping, deep taproot, spreads extensively by rhizomatous roots, deciduous.

Leaf: Scale-like, tiny (length to <¼ inch), overlap, can excrete salt.

Flower: March-September, small cluster (length to 2 inches) of small, pink, short- petaled (length to ¼ inch) flowers, insect pollinated, highly fecund.

Fruit/Seed: Seeds tiny, tuft of hair at one end, spread by wind and water.

Typical Location: Floodplains, riverbanks, ditches, marshes; elevations below 2,600 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Native to Asia. Invades wet areas especially after human disturbance, requires great quantities of water, can lower water table. Spreads by seed, rhizomes and re-rooting of fractured root fragment. Accumulates salt in leaves, falling leaves may result in accumulation of salt in topsoil. May be long lived (50-100 years). Excludes native vegetation, provides little value to native wildlife and insects, and may change soil and water conditions.


leaf and seed


flower


seed


whole plant in flower


whole plant


Location: floodplain, channel

TEASEL

Species Name: *Dipsacus fullonum*
Family: Dipsacaceae (teasel family)
Plant Type: Exotic invasive herb

Description: Biannual herb/small shrub, stems branched, armed with thorns, height to 6 feet.

Leaf: In pairs, partially fused around stem, toothed.

Flower: Early spring to late autumn, bisexual, flower head egg-shaped, spiny. Flowers small, lavender-white, appear in rows around head.

Fruit/Seed: Achene, hairy, box-like, length ¼ inch.

Typical Location: Roadsides, pastures, moist sites; elevations below 5,600 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

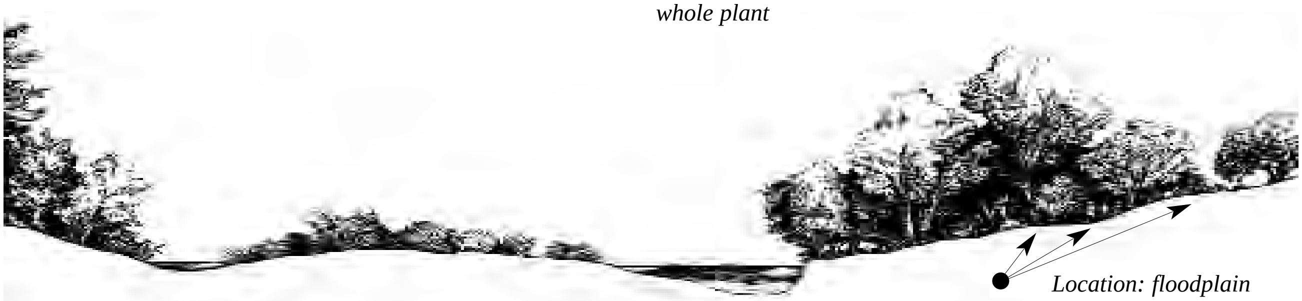
Key Notes: Distinctive bristly dried flower heads persist through winter.

Notes: Native to Europe. Imported in 19th century and grown for the bristly flower head. The dried flower head was used to brush woolen fabrics to bring up the nap.

whole plant

flower

whole plant



Location: floodplain

TREE OF HEAVEN

Species Name: *Ailanthus altissima*
Family: Simaroubaceae
(quassia or simarouba family)
Plant Type: Exotic invasive tree

Description: Tree, bark gray-brown and thin, height to 65 feet, fast growing, often grows in clumps, deciduous.

Leaf: Compound, length 1-3 feet, with 13-25 leaflets. Leaflets lanceolate, margins with few teeth, pointed at tip, length 3-5 inches, produce a bad smell when crushed.

Flower: April-July, dioecious (separate sex trees), occasionally bisexual, female and male flowers similar, non-descript, yellow-green. Flowers grow in 3-8 inch clusters. Male flowers have unpleasant odor.

Fruit/Seed: Winged achene, green-yellow or showy orange-red, seed at center, length 2 inches, wind dispersed, female trees produce large quantities, ripen September-October.

Typical Location: Disturbed areas, roadsides, tolerant of pollution; elevations below 4,100 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Key Notes: Young plants sometimes confused with the native black walnut (*Juglans californica*). Seeds, flowers or careful inspection of leaf characteristics distinguish between species.

Notes: Brought to California from Asia during the gold rush era. Highly invasive, grows rapidly and spreads both vegetatively and by seed.


leaf


whole plant


flower


seed

YELLOW STAR THISTLE

Species Name: *Centaurea solstitialis*
Family: Asteraceae (sunflower family)
Plant Type: Exotic invasive herb

Description: Annual, early spring growth from taproot, green, low to ground; in late spring through autumn the plant bolts to become stiff branched, bluish-green, develops stem leaves and flowers, height to over 3 feet.

Leaf: Lower leaves lobed, length 2-6 inches, bristly, lost before flowering; upper leaves not lobed, narrow, leaf ridge extends down stem past point of attachment (winged appearance), bluish-green, length to over 1 inch.

Flower: May-December, numerous, solitary, ovoid flower head with long spines (length to 1 inch), bright yellow, can have 2 flowering seasons per year (spring then autumn).

Fruit/Seed: Achene, 2 types, outer seedhead achenes are dark brown, inner are light brown with tiny bristles.

Typical Location: Pastures, roadsides, grasslands, woodlands, disturbed areas; elevations below 4,200 feet.

Revegetation Approach: Do not plant in riparian areas! Remove where feasible.

Notes: Introduced from southern Europe, believed to be accidentally moved with livestock feed. Considered one of the western United States' most noxious weeds. Displaces native plants and animals, and reduces soil moisture reserves in grasslands. Long spines limit access to recreational areas. Reduces land value, poisonous to horses and poor forage for livestock.

flower

whole plant in flower

Location: floodplain

PART XII

FISH PASSAGE DESIGN AND IMPLEMENTATION

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ADVISORY NOTE

This manual describes fish passage approaches and techniques used with varying degrees of success by passage and watershed restoration specialists. The approaches and techniques described here are not all-inclusive and represent only a starting point for project design and implementation. They are not surrogates for, nor should they be used in lieu of, a project design that is developed and implemented according to the unique physical and biological characteristics of the site-specific landscape and ecology.

The techniques and approaches described in this manual do not replace the need for services of professionals with the appropriate expertise, 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).

Part XII replaces “Human Induced Obstructions, Fishways and Culverts” (pages VII – 51 through VII – 61) in the February 1998 version of the *California Salmonid Stream Habitat Restoration Manual*.

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INTRODUCTION

There are numerous barriers to the movement of fish and other aquatic organisms in streams and rivers in California. Barriers range from highways, flood control projects and large dams to small road crossings and water diversion dams. Such barriers can exclude species from tributaries, and often greatly fragment habitats and isolate populations of fish and other aquatic organisms.

This document provides technical guidance for the design of fish passage projects at stream crossings, small dams and water diversion structures. Options include, in order of preference, range from having no structure to constructing fishways.

Complex facilities at large dams are not included, though many of the principles apply. This document is intended to help guide the designer through the general process of selecting an appropriate design approach to improve passage for fish and other aquatic organisms (simply referred to as fish passage in the remainder of Part XII). It provides concepts, a design framework, and procedures to design stream crossings and fishways that satisfy ecological objectives.

This document is intended to be a guide for the designer through the general process of selecting a design approach for passage improvement. It provides concepts, a design framework, and procedures to design stream crossings and fishways that satisfy ecological objectives, including the passage of fish and other aquatic organisms.

These guidelines are meant to supplement existing state fish passage criteria (Appendix IX-A) and federal guidelines (Appendix IX-B). The designer should refer to those and other documents, standards and experts for structural, roadway, geotechnical, and other engineering and environmental considerations associated with the design.

Each site is unique, and conditions will often require individual solutions. These guidelines advocate a principle that the best fish passage design is the one that provides for all or most of the following ecological objectives:

- Efficient and safe passage of all aquatic organisms and life stages
- Continuity of geomorphic processes such as the movement of debris and sediment
- Accommodation of behavior and swimming ability of organisms to be passed
- Diversity of physical and hydraulic conditions leading to high diversity of passage opportunities
- Projects that are self-sustaining and durable
- Passage of terrestrial organisms that move within the riparian corridor.

A design that emulates natural systems is the one most likely to satisfy ecological objectives. Designs described here might at least partially accommodate for movement of terrestrial species, but these guidelines do not attempt to design specifically for this objective.

Figure XII-1 shows a range of project types, design approaches, and solutions in a spectrum of ecological value. This figure is a basic guide to this manual; it shows many of the tools discussed in this guide in more or less the order that they are presented.

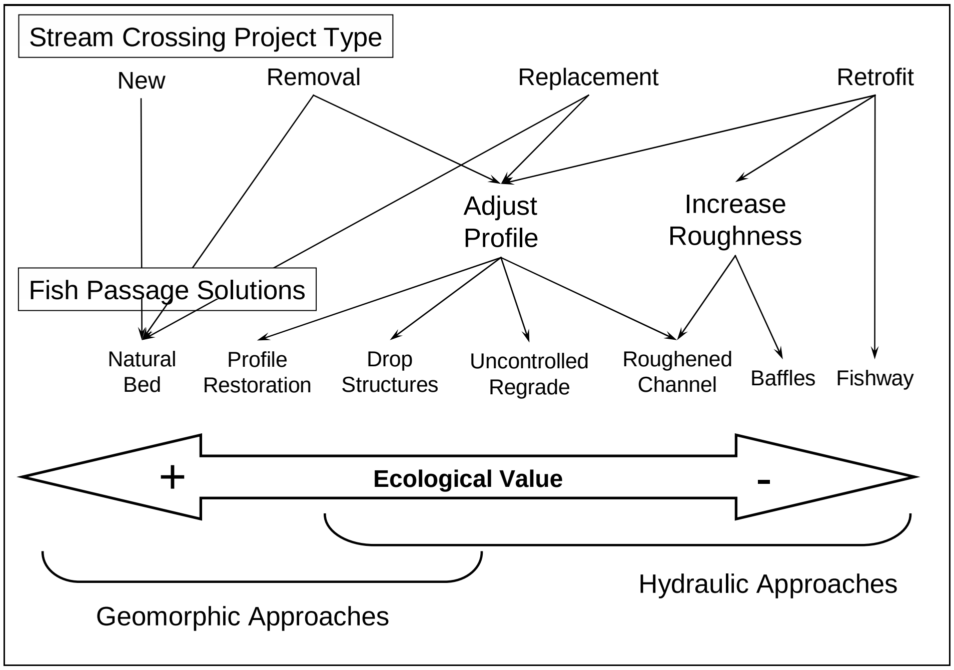


Figure XII-1. Spectrum of Ecological Solutions for Fish Passage.

Across the top of Figure XII-1 are examples of fish passage projects encountered. Projects range from the construction of a new stream crossing culvert to the retrofit of an existing culvert or dam. The type of project leads to one or several tools or solutions shown in the lower rows of Figure XII-1. The tools and solutions that are chosen and shown connected in the figure are generally based on the ecological principles described above. Profile adjustments and roughness are tools in the design process. These project types and the solutions presented in the figure are generally in order of ecological value with highest values to the left. For example, a natural bed solution has a greater ecological value than use of profile control, adding baffles to a culvert, or a constructing a fishway.

The solutions on the left are based on geomorphic principles; they mimic natural conditions and are flexible and resilient. The solutions on the right are based on structural and hydraulic principles and are more rigid. The terms geomorphic and hydraulic solutions are the basic classification of fish passage solutions used in this manual. A geomorphic solution is based on the premise that a channel that simulates characteristics of the natural channel will present no more of a challenge to movement of organisms than the natural channel. A hydraulic solution is based on the premise that a structure with appropriate hydraulic conditions will allow target species to swim through it. These approaches are further described in Select the Design Approach (page XII-15).

Some of the approaches and analyses described are more rigorous than is necessary for simple sites; an experienced design team will be able to streamline the process in many cases. Many sites however have unique challenges that can only be solved by applying an in-depth understanding of the biological, hydrologic, geomorphic, and structural components of the design. For complex sites, the use of an interdisciplinary design team is encouraged. To be successful, it is important to recognize where a higher degree of rigor is needed and to engage specialists in the design when appropriate. This document is not comprehensive for all situations. It refers to other guidance documents that have additional detail. This document does not cover passage at large dams that might require complex facilities such as trap-and-haul systems, auxiliary water systems, or multiple fishway entrances.

Figure XII-2 shows a general design process for fish passage projects. The layout of this guideline generally follows this sequence of steps.

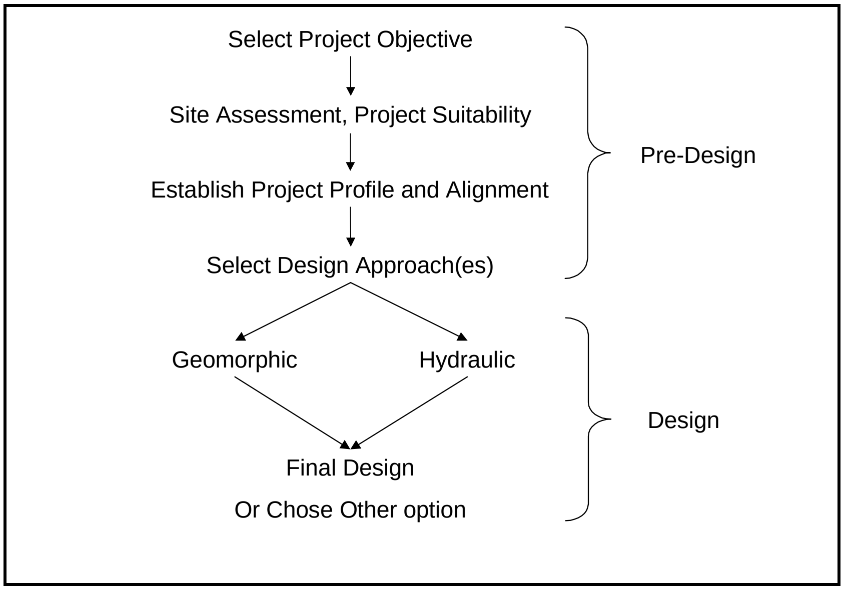


Figure XII-2. General Fish Passage Design Process.

The development of objectives, preliminary site assessment, and an understanding of potential project layout and profile are necessary before selecting the preferred design approach. These steps are considered pre-design, which are discussed in Pre-Design for Fish Passage Projects (page XII-3) and Stream Crossing Layout: Alignment and Profile (page XII-16). Additional pre-design steps might be needed depending on the design approach selected. The formal design process includes design criteria, the detail design, and steps specific to the selected design approach. These design steps are described in Geomorphic Designs at Stream Crossings (page XII-28 through Fishways (page XII-107). The final design comprises of final dimensions and details, structural elements, and construction considerations necessary to complete the project. Designs are often not as simple as implied here. Steps may be iterative as solutions or assumptions are selected, tested, and modified.

PRE-DESIGN FOR FISH PASSAGE PROJECTS

Pre-Design

Pre-design is a step in a stream crossing project that accounts for characteristics of the stream and inter-relationships of the road or dam, stream, and target species. It includes establishing clear project objectives and evaluating channel stability, alignment, and transitions. Watershed and site conditions, including geomorphic context are assessed. Through pre-design, a *project profile* and *planform* stream crossing alignment is developed (Note: words included in the Glossary page XII-139 are identified in the text by being italicized the first time they are used).

When a project fails to satisfy fish passage objectives, it is often because of an inadequate pre-design. This step is needed regardless of the ultimate fish passage design approach used; the design approach should be selected or confirmed at the conclusion of pre-design.

The design process is not necessarily linear. Iterations are needed to complete some parts and a previous phase may have to be re-visited if a satisfactory design cannot be completed with the current assumptions and design decisions.

The scale of project should be appropriate for the ecological resources at stake. Information needed and the process used to identify the appropriate fish passage design strategy for a site includes gathering information on site-specific issues such as the project objectives, site constraints, channel morphology, species, and existing and potential habitat characteristics and values.

The pre-design should provide a framework for designers and interested parties to make decisions requiring trade-offs regarding channel profile, self-sustainability and habitat issues.

Pre-Design Site Assessment

Any structure set into a dynamic stream channel should fit the context of the system without interrupting the geomorphic processes that define the system. For a project to fit the context of the watershed, reach, and site, relevant information is gathered and interpreted. Information requirements and level of detail will vary from site to site depending on the scale of the project, site complexity, project objectives, and the design approach used.

An inter-disciplinary approach is very helpful for this part of the design and the pre-design assessment is the most important stage for a range of disciplines to be involved. The inter-disciplinary team may include experts in aspects of biology, geomorphology, geology, hydraulics, sediment transport, hydrology, construction, structural design, and others. Characteristics that might lead to seeking additional expertise include failing banks, heavy debris loads, large amounts of sediment stored upstream of an existing crossing, *headcut* issues, channel instabilities, complex channel shapes, and unusual alignments or road configurations.

Aspects of a site assessment might include physical and habitat surveys, channel characterization, pebble counts, hydrologic correlations, geotechnical investigations, etc. Careful and thorough documentation of the various assessment procedures is essential. Assessment data needs will vary by project and will include many of the following parameters:

- A description of existing structures; dimensions, conditions, history, etc.
    - Stream, road, culvert alignments and road vertical alignment
- Recent flood history and flood evidence at the site
- Channel characteristics
    - Survey the longitudinal profile of the existing channel thalweg (long profile). Record survey points at unique and repeatable geomorphic features such as heads of riffles and step crests (see Harrelson et al. 1994).
    - The long profile should extend upstream and downstream further than the existing or new culvert might affect the channel. The survey length depends on the scale of the project, the vertical drop through the existing crossing, and the *mobility* of the streambed. A sand-bedded channel may mobilize for thousands of feet upstream; a steep boulder dominated channel may not be affected at all. Survey low and high-flow hydraulic controls, bed controls, and grade breaks. Note channel dimensions, key bed and bank features, bed material, and *floodprone width.*
    - For stream simulation design, consider what reach will likely be a *reference reach* and include it in the profile if it is contiguous with the project channel reach, or survey it separately if it is not.
    - Identify *key features*, observations of unique channel characteristics, and locations where channel characteristic were measured.
    - Measure representative *bankfull* channel, *active channel*, and/or *ordinary high water* width.
    - Survey channel cross-sections immediately upstream and downstream of any existing structure and two additional cross-sections upstream and two additional cross-sections downstream of the influence of any existing structure.
    - Identify general bed and bedform characteristics. Various channel classification systems are useful to describe the channel (see Montgomery and Buffington 1997 and Rosgen 1996).
    - Identify any features that might affect the long profile or channel alignment for the life of the project such as debris and sediment sources and current or likely bank erosion. Identify size, spacing, function (*profile control*, *roughness*, confinement, and bank stability), bed drop, and permanence (*mobility* and condition) of *key*

channel features and grade controls. Key features are permanent or semi-permanent structures such as bedrock outcrops, large woody debris, stable debris jams, boulder steps, and human made structures that control the channel shape and/or grade, *bedforms*, and bed material sorting.

- Representative floodprone width
  - Estimate conveyance of floodprone area using an assessment of floodplain characteristics such as width, elevation, and roughness.
- Geomorphic stage and evolution of the channel
  - Channel history (e.g., historical realignment, placer mining, splash dams, removal of large wood from channel, upstream dams and debris basins).
  - Assess the potential headcut impacts upstream of the crossing (see Headcut Issues page XII-25).
  - Establish the *vertical adjustment profiles*, estimating range of elevations the channel might experience through the reach in the lifetime of the new stream crossing. This is a key to setting the elevation of the culvert and/or profile control structures (see Channel Vertical Adjustment Profiles page XII-20).
- Channel stability
  - Identify the dominant controls of profile and alignment.
  - Determine the likelihood of channel *aggradation* or *incision* in the lifetime of the crossing. Consider the likelihood of changes to hydrology, sediment input, development, base level change, loss of major profile controls, etc. Roni (2005).
- Bed mobility
  - A mobile bed is characterized by bedforms that indicate recent deposition. General characteristics include sand to gravel bed material, steep faces on bars, no vegetation on bars, no moss on bed material, no *armor layer* or *imbrication*, and bed material loose rather than compacted.
  - An immobile bed does not move frequently compared to the life of the structure. Characteristics include cobble to boulder bed, exposed bedrock, *cascade* or *step-pool* channel, vegetation or other evidence of infrequent bed movement, well *armored* or imbricated bed. An immobile bed may be present with mobile bed material moving over it.

- Hydrology
    - Continuous flow gaging, peak flow gaging, basin correlations, hydrologic regressions
    - Qualitative hydrologic characteristics of basin
    - Expectations of future watershed conditions that might affect hydrology
    - Hydrology assessment products
        - Fish passage design flows
        - High structural design flow
- Other nearby infrastructure.

The key is to understand the potential use of each parameter or procedure and apply standard assessment protocols appropriately for that use. Detailed methods and protocols for these assessments are described in other parts of the *California Salmonid Stream Habitat Restoration Manual* and by USFS (2008) and Harrelson et al. (1994).

Results of the pre-design assessment should be adequate to inform another designer of enough detail of the watershed, site, and decision process that they can do an appropriate and independent design.

Design Data Forms

Several design data forms are included in Appendix XII-A to guide, document, and assist the design and review of stream crossing projects. There are two data forms, one for stream simulation design and a second for use with either of the hydraulic design approaches (baffles, profile control). The design data forms include only fish passage, geomorphic, and hydrologic design information; also document other aspects of the project (e.g., traffic, geotechnical, road characteristics) during pre-design. Attach a plan view sketch and a long profile to the design data form. See the design guide for background for all data and details recommended on sketches.

Summarize data to show design milestones, assumptions, and conclusions. The last step of the pre-design, as described here, is selection of the approach for fish passage design. It is important to document project milestone decisions such as how the design approach was selected.

Establishing Project Goals and Monitoring Objectives

The primary goal for fish passage projects is to obtain unimpeded fish passage; however, projects may have additional goals to meet the needs of particular interest parties. For example, instream crossing projects may also include road and transportation goals. There may also exist program (e.g., funding limitations), and environmental goals to accommodate as well. When the goals of the various interested parties appear to conflict, their basic needs and objectives need to be understood and addressed. A good project manager will recognize potential conflicts early in the process so they are resolved before they unnecessarily stall the project. Consider using an independent facilitator if differences are substantial.

Fish passage projects should include an expected and achievable level of fish passage as an objective. In addition, specific, measurable objectives need to be developed to address other project goals adopted. CDFG biologists, in consultation with NOAA Fisheries biologists, will evaluate needs for aquatic species passage and ecological considerations for in-channel structures on a case-by-case basis. Biologists will consider the following in determining the need for passage of aquatic organisms at a site:

- Presence/absence and health of aquatic species populations
- Aquatic species and life-stages currently or historically present and watershed goals for species or fish community restoration
- Potential habitat gain upstream
- Presence of exotic and/or invasive species; on occasions, passage may not be desirable at a stream crossing structure in order to maintain separation of aquatic species
- Condition and value of habitat upstream (and downstream) that might be affected by the project (i.e., is incision acceptable with regards to meeting project objectives)
- Movement needs of non-fish aquatic species
- Movement needs of terrestrial wildlife.

Clear project objectives are needed to ensure all project goals are achieved. They are the specific measures (e.g., construct a self-sustaining stream simulation bed) used to determine whether the project was successful in achieving the objectives.

Objectives are often stated as written quantitative design criteria, which should be referred to when making design and planning decisions. By clarifying expectations (e.g., how many, to what degree, under what conditions, etc.) specific objectives make it clear to all parties what is needed to achieve the project goals. Project objectives should become the basis of the monitoring plan. For example, an objective measure of “self sustaining” can be assessed by conducting an as-built survey then monitoring the project over time. A “stream simulation” can be evaluated by comparing the project to the reference reach.

Any of the following measurable objectives might be applied to a specific project:

- Design and construct a self-sustaining stream simulation streambed.
- Design and construct passage for the target species as per the CDFG fish passage criteria that requires no more than a single day of maintenance effort per year
- Entirely mitigate the loss of any riparian habitats and any sediment impacts of the project
- Design the road crossing to have a 50% probability of a longevity of 50 years.

Implementation Monitoring

Implementation monitoring helps to both ensure the project fulfils all of its design objectives, and to document as-built conditions. This requires establishing realistic objectives and developing a design appropriate for the site that is capable of meeting the project objectives and constraints, and then constructing the project as designed. Although Part XII focuses largely on design development, correct implementation of the design is an essential component of a successful project. Construction of fish passage and other in-stream projects frequently requires skills and expertise outside of those typically needed for standard civil construction projects. It is important for the project manager to ensure that those constructing the project have the required skills and fully understand the intent of the design. It is important someone knowledgeable about the specific and most critical elements of the design perform regular field inspections and provide on-site guidance during construction. Elevations and slope are critical elements to any fish passage design, and should be regularly checked during construction. Materials and sources should be approved before the material is produced and hauled to the site. Unanticipated site conditions encountered during construction often require making onsite modifications to the design, which must be documented. The best person to perform this task is usually the project designer, with approval coming from the project manager.

Implementation monitoring is conducted to determine if the project was constructed as designed. This includes an as-built survey and as-built drawings that document any modifications to the original design. Additionally, it is advisable to establish photo-points before construction. Take photos from the established photo-points regularly during and immediately following construction. Refer to Part VIII, “Project Monitoring and Evaluation”, and Roni (2005) for more information on conducting implementation monitoring.

Effectiveness Monitoring

Monitoring the effectiveness of a project through time provides information that benefits future designs by identifying activities that are successful and activities that lead to unintended consequences. When effectiveness monitoring identifies problems, action can be taken to remedy the situation. Conducting effectiveness monitoring requires that pre-project objectives, expected project performance, and anticipated channel responses be well documented and implementation monitoring be completed.

The level of monitoring required depends on the type of project, the risk and uncertainty regarding its performance, and the consequences of it failing to meet project objectives. An effectiveness monitoring plan, at its simplest involves at least one post-project visit to make qualitative observations and retake photo-points. The initial post-project visit should occur the first year after the normal high flow period, with revisits occurring after large flood events. Monitoring activities requiring longer-term extensive physical and/or biological surveys might also be appropriate. Physical monitoring may include assessing geomorphic changes to the channel, or in the case of stream simulation, it may involve comparing the channel geometry and profile inside the culvert to those in the adjacent channel reaches. For hydraulic designs, physical monitoring may include measuring water depth, velocities, and hydraulic drops at specific flows to ensure the structure satisfies project criteria. Biological monitoring may include performing fish distribution, population abundance, or spawning surveys upstream and downstream of the crossing, or evaluating the success of revegetation efforts.

A number of the design approaches and techniques described in Part XII are relatively new and their long-term performance has yet to be assessed. Therefore, effectiveness monitoring of these types of projects will help develop a track record and improve guidance for design and construction. For more information on developing an effectiveness monitoring plan, refer to Part VIII, “Project Monitoring and Evaluation”, and Roni (2005).

Ecological Considerations of In-Channel Structures

The placement of artificial structures such as road-stream crossings and dams can result in impacts to aquatic habitats that should be avoided, minimized, or otherwise mitigated. These impacts may be associated with the structure itself or with channel modifications necessary to install, repair or retrofit a structure for passage of fish or other aquatic organisms.

This guideline focuses on passage of aquatic organisms at such structures. Other goals should not be ignored though. The general health of fish populations may be a broader goal and it may depend as much on other impacts as on passage at the structure.

Defining Ecological Connectivity

Connectivity is the capacity of a landscape to support the movement of organisms, materials, or energy (Peck 1998). It generally includes passage of aquatic organisms as described above, but also includes linkages of biotic and physical processes and materials between upstream and downstream reaches.

The health of fish populations ultimately depends on the health of their ecosystems, which includes processes and materials moving through the stream. Biotic linkages includes but is not limited to upstream and/or downstream movement of mammals, birds, and fish, and the upstream flight, and downstream drift of insects and other invertebrates. Physical processes include the movement and distribution of woody debris, sediment and migration of channel patterns.

It is important that woody debris and bed material pass unhindered through the stream crossing structure. When debris becomes trapped at the inlet of a structure, aquatic organism passage barriers are created, and habitat may be degraded both above and below the stream crossing.

Road fills, stream crossings, fords and dams that are small relative to the stream corridor may block some of these functions. These issues are difficult to quantify but can be significant to the health of aquatic ecosystems.

Passage of Fish and other Aquatic Organisms

Designing for passage of fish and other aquatic organisms is the primary focus of Part XII. Barriers whether dams, culverts or road fords that interrupt the movement of organisms may lead to the following impacts to aquatic communities:

- Loss of resident populations by preventing re-colonization of upstream habitats after disturbance events, such as fires, floods or droughts
- Partial or complete loss of populations of migrant species due to blocked access to critical spawning, rearing, feeding or refuge habitats
- Altered aquatic community structure (e.g., species composition, distribution)
- Reduced genetic fitness of aquatic populations making communities more vulnerable to changing or extreme conditions.

These biological impacts result from restricting the movement of aquatic organisms within the stream network. Many fish species move daily, seasonally, and/or during different life stages. Juveniles of many fish and salamander species will also move to disperse after hatching and to find suitable rearing habitat.

To maintain native fish assemblages at appropriate densities, all fish and other aquatic organisms should be free of human-caused barriers to movement. When designing for passage, consider more than just the large and strong adult salmonids. Other native fish may become extirpated from the watershed upstream during a disturbance event (drought, fire) and not be able to repopulate the area. This extirpation of non-salmonids may have adverse affects on salmonids (e.g., loss of food source).

In addition to adult salmon and steelhead moving during higher flows to access suitable spawning habitat in spring and fall, juvenile salmonids also move during and in anticipation of low flows. The moderating effect of groundwater on extreme water temperatures can also provide motivation for fish movement.

Many crossings may provide “partial” or “temporal” passage, i.e., passage for specific species or size classes, or only under certain flow conditions. In addition to excluding weaker swimming species and life stages, significant migration delays may occur for others (Lang et al. 2004), leaving fish vulnerable to predation, disease and overcrowding, and potentially affecting reproductive success. Fish on spawning migrations will often attempt to pass these structures under impassable conditions and unnecessarily expend critical energy reserves during a physiologically stressful period. Lang et al. (2004) observed adult salmon attempt nearly 600 leaps at one culvert with only five successful entries through the structure. Multiple partial barriers within a stream system can magnify these impacts.

Passage of Wildlife

A consideration for each project is the movement of non-aquatic and semi-aquatic wildlife in some situations, which may or may not be at streams. No specific guidance is given for passage of non-aquatic species. The focus of Part XII is passage of aquatic species but non-aquatic species can certainly benefit from application of some of the designs presented, such as stream simulation.

Many species of amphibians, reptiles, and mammals use riparian zones as travel corridors (Naiman et al. 1993) and the movement of these species may be impacted by certain crossings. Small animals will often use culverts and bridge openings to pass under roads. At some sites, keeping animals off the road can also be a significant public safety benefit. Replacing stream crossings can provide a great opportunity to address both fish and wildlife passage in a single project.

Direct Loss of Aquatic Habitat

Aquatic habitat includes all areas of the environment where aquatic organisms reproduce, feed, and seek shelter from predators and environmental extremes. Stream crossing installations often require some level of construction in the stream channel, which often replaces native stream material and diversity with a uniform concrete or steel surface. Sometimes habitat changes are due to hydraulic effects of the structure.

Each species salmonid, whether anadromous or resident, require specific spawning conditions related to the water velocity, depth, substrate size, gradient, accessibility and space. All salmonids require cool, clean water in which to spawn. Upwelling of groundwater is also important features of spawning habitat. A culvert or other structure placed in spawning habitat replaces the natural gravel used for spawning with a metal or concrete surface. Even if natural substrates are recruited within the structure, the spawning habitat might be shallow or unstable and it will be disconnected from groundwater influence. Spawning habitat loss is especially important because it is usually irreplaceable (Saldi-Caromile et al. 2004).

Juvenile salmonids use almost all segments of the stream environment during some stage of their freshwater residence. Habitat usage is highly variable depending upon the species, life stage and time of year. Pools with large woody debris are valuable habitat. Trees on the stream banks also provide important habitat features, serving as cover and a source of insects and large woody material, both of which critical to rearing fish. The food chain in the stream environment begins with leaves, seeds, branches, and large wood provided by nearby trees, shrubs and grasses. Aquatic invertebrates like mayflies, stoneflies and caddisflies feed on these organic materials and in turn provide an important food source for fish. In addition, mature trees along stream banks provide shade, overhead cover, a source of terrestrial insects and large woody material, which are critical to rearing fish. Removal of riparian vegetation for culvert placement and associated roadway fill impacts these organic inputs and aquatic habitat values. If undersized, stream crossings may also block the recruitment of woody debris to downstream reaches.

Crossings often cause changes to channel alignment, channel diversity, and hydraulic conditions, which may degrade habitats above and below the structure. The configuration and connection of the channel, floodplain, and side channels may also be altered. Mitigation for direct loss of fully functioning natural stream habitats may be difficult. Stream crossing designs that maintain natural stream substrates within the structure, and minimize disruption to the channel and riparian corridors are therefore encouraged.

Floodplain Flows

Floodplains are important components of the aquatic system. During floods, water, sediment, and woody debris may move across floodplains, creating and maintaining unique habitats. In many situations, it is important to maintain floodplain continuity. Floodplains can provide refugia for fish away from the high velocities in the channel. Side channels are often important habitats on active floodplains that provide aquatic organisms passageways to move upstream during floods. Inundated floodplains can connect to off-channel ponds and wetlands that can provide excellent foraging habitat for juvenile salmonids.

The stability of a stream channel depends on its connection to the floodplain. Active floodplains can convey a substantial portion of the total flow during floods and can become depositional areas for sediment and debris. Eliminating a floodplain and *constricting* flood flows to the channel increases scouring forces on the stream's bed and banks and can cause a channel to become unstable.

Road-fills at stream crossing approaches are often raised above the floodplain surface, constricting floodplain flows into the culvert. This causes a discontinuity in the floodplain and can change the erosion and depositional processes that maintain diverse floodplain habitats. Stream crossing design should consider the importance of maintaining flow conveyance on the floodplain and continuity of side channels and other important habitat features.

Risk of Structure Failure

When overwhelmed by high flow, often combined with debris and sediment, a stream crossing structure and roadway fill can act like a dam across the valley and can result in catastrophic failure and/or stream diversion. Structure failures can cause extensive damage to habitat that persists for many years. Failures can be a result of inadequate design, poor construction or maintenance, beaver damming, deterioration of the structure, or severe natural events. The process of evaluating, designing, and installing fish passage or road crossing structures should consider the risk of failure. Typical situations that might entail high risk include presence of large debris, high road fills, and presence of valuable habitat. Sizing a structure for passage of extreme flood events and associated debris and sediment can minimize this risk. Crossing structures should typically designed to accommodate a 100-year flood event. Designing to minimize consequences of failure, such as the consequence of road overtopping, also reduces risk.

Designing road-crossing structures for passage of aquatic organisms is not without risk of failure. There is an inherent risk of failure to provide passage of aquatic organisms with any culvert design. Some designs have more risk and uncertainties than others do. Structures that span the entire channel without constricting it are preferred, compared to engineered solutions described in Part XII that are narrower than that. In some cases, resource values and risk assessment may dictate that engineered solutions are not acceptable.

Other Water Quality Impacts

Storm water runoff from roadways can affect aquatic habitats at road crossings regardless of the type of crossing. Road ditches often drain directly into the stream at a crossing, potentially being a chronic source of sediment and other contaminants. The presence of the road can also increase the risks of slope failures directly entering the stream. Mitigate the quality and quantity of storm water runoff by applying best management practices (BMP's). In general, treat road runoff by minimizing direct discharge to the stream (see Part X).

Channel Maintenance

Undersized, poorly sited, or poorly aligned culverts can create chronic sediment and debris problems (Figure XII-3). Highways are often placed at the fringe of river floodplains and cross the alluvial fans of small streams entering the floodplain. These areas are natural depositional zones, where streams are prone to frequent lateral channel movement. Stream crossings in these locations tend to fill with bed material. To keep the structure from plugging and the water overtopping the road, periodic and in some cases annual channel dredging becomes necessary.

Figure XII-3. Poorly aligned culvert. Note log causing a blockage.

Dredging may affect channel stability, spawning and rearing habitat, and water quality for some distance upstream and downstream. The interruption of bed movement to downstream reaches may also trigger channel adjustments, which may lead to additional channel maintenance activities such as bank armoring.

Poorly designed culverts and bridges can also cause localized bed and bank scour of the upstream and/or downstream channel, which often leads to additional channel armoring.

Construction Impacts

Impacts during construction of a crossing might include the release of sediment or pollutants, the creation of temporary barriers to movement, stranding or killing fish and aquatic organisms, removal of stream bank vegetation, and the alteration of flow. Timing of construction, water, erosion and sediment control planning, and post-construction revegetation, can mitigate some of these issues (see Part IX pages 51-53 for detailed measures). Construction plans submitted for regulatory approval must include fish relocation, and sediment and erosion control plans.

Select the Design Approach

Types of Fish Passage Designs

The design for passage of fish and other aquatic organisms at culverts, fords and dams can be defined in two general categories, geomorphic and hydraulic.

Geomorphic Designs

> Stream Simulation Design: A channel that simulates characteristics of the natural channel, will present no more of a challenge to movement of organisms than the natural channel.

The specific geomorphic design described below is Stream Simulation. The premise of this design approach is a channel that simulates characteristics of the natural channel will present no more of a challenge to movement of organisms than the natural channel. It is a natural channel design. There is no part of the design specifically directed at target species or their swimming capabilities. In the case of stream simulation in a culvert, the size of the culvert is specified by the stream simulation design. The approach is therefore used for new and replacement stream crossings. It is also used where a culvert is replaced with a bridge, a culvert is permanently removed, or for any new channel design. Details of stream simulation design are described in Geomorphic Designs at Stream Crossings (page XII-28).

> Low Slope Design: the design of an oversized culvert in a low risk site can be simplified and built with little risk.

A simplified version of stream simulation is the Low Slope Approach. It is a conservative design applied only to low risk sites. It is intended for simple culvert installations and is based on the premise that the design of an oversized culvert in a low risk site can be simplified and built with little risk to passage, habitat, and the channel.

Details of low-slope design and its limitations including what is meant by "low risk" are described in Low-Slope Stream Simulation (page XII-41).

Hydraulic Designs

> Hydraulic Design: a structure with appropriate hydraulic conditions will allow target species to swim through it.

A traditional design for fish passage is the hydraulic design. It is based on specific fish passage design criteria that reflect the migration timing, swimming ability, and behavior of selected target species. It is based on the premise that a structure with appropriate hydraulic conditions will allow target species to swim through it.

The hydraulic design is used primarily for culverts that are retrofitted to improve fish passage, fishways, and flumes.

Details of the hydraulic design are described in Overview of the Hydraulic Design Approach (page XII-50) and for fishways in Fishways (page XII-107).

STREAM CROSSING LAYOUT: ALIGNMENT AND PROFILE

Project layout includes alignment and profile. Together, they describe the crossing, road, and adjacent channel in space. Alignment is the orientation of the crossing structure and the road relative to each other in plan view or to the adjacent stream channel. Profile can be thought of as the elevation of the channel thalweg at a series of points that describe the crossing and adjacent channel.

Alignment

Culvert alignment is designed concurrently with the *project profile*; which is the channel profile through a crossing that will be constructed or will initially develop following completion of the project. If either changes, the other is affected. In the simplest situation, a straight channel meets the road at right angles, and the upstream and downstream reaches are easily connected through a straight crossing. Alignments are often not so simple.

A culvert that is skewed relative to the upstream channel is hydraulically inefficient. A skewed alignment increases the risk of debris plugging and decreases the capacity of the culvert. It can cause upstream ponding, sediment deposition, and bank scour even if the inlet is not plugged. These risks are associated with high flows, so think of the flow patterns at those flows when considering alignment.

Risk is minimized when a culvert is aligned with the upstream and downstream channels and increased with the angle of the skew. Aligning the crossing structure with the upstream channel often results in a skewed alignment relative to the road however, requiring a longer structure or headwalls.

An objective of culvert replacement projects should be to improve the existing alignment if it is poor. The disturbance of realigning the culvert and channel might be balanced by the reduction of risks of culvert skew.

Due to existing alignments of the road and stream and to other site limitations, there is often no feasible perfect alignment; design alignment is a compromise among several variables. Change of road location and/or alignment might be the best solution. There are situations, such as steep channels controlled and/or confined by bedrock or other features, where realignment is not practical.

Culvert Length

The risk that fish or other organisms will be blocked increases with longer culverts. The likelihood of any erroneous design assumptions or construction inadequacies are increased by added length of culvert. Conversely, culverts are often installed off the channel alignment to minimize length of the culvert and save costs in materials. An objective should be to install the appropriate length of culvert in alignment with the stream channel while minimizing the risk of passage failure and keeping costs reasonable or in line with projected budgets.

A longer culvert is more likely to cut off channel bends, reducing overall channel length. This can have a significant effect on channel stability in the adjacent reaches of sinuous channels. If the meandering channel is in a wide floodplain, the crossing may have compounding risks of concentrating over-bank flow through the crossing. Minimize structure length to manage risk. In some locations, shifting the road location to avoid a bend can be a solution. Additional methods for shortening structures include adding wingwalls, lowering the road elevation, or steepening the road embankment.

These modifications may have inherent implications of cost, safety, and road fill stability. The risks associated with long culverts can also be partially mitigated by increasing structure width. This will allow additional lateral variability in the channel and provide some width for over-bank flows inside the culvert.

Skewed and Bend Alignments

Roads crossing streams at a skew and crossings at channel bends are common culvert alignment challenges. Some solutions for a skewed alignment are shown in Figure XII-4.

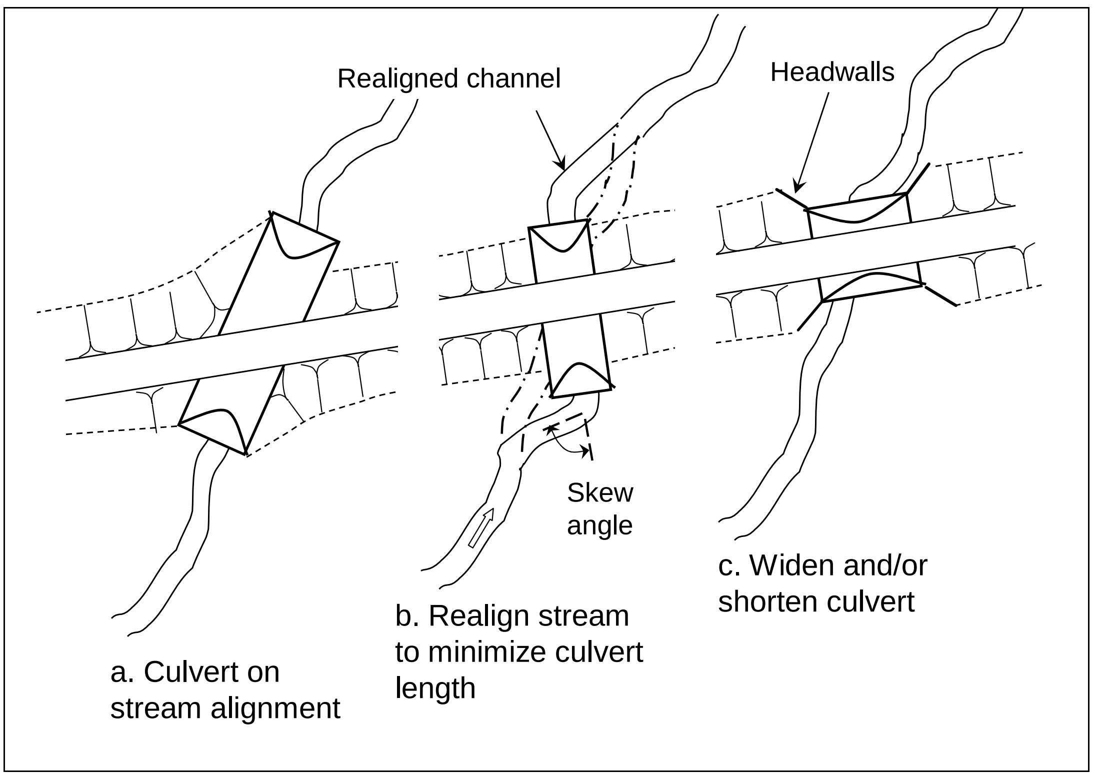


Figure XII-4. Alignment options at a skewed culvert and their trade-offs: (1) match the channel alignment, (2) realign the stream to minimize culvert length, and (3) widen and/or shorten the culvert.

Matching the channel alignment has the least risk of debris blockage and maximizes the capacity of the culvert. However, this may require a longer culvert, which results in additional direct loss of habitat.

Realigning the channel creates a skewed inlet and outlet, which increases the likelihood of debris blockage and reduces the culvert capacity. This option potentially disrupts more riparian and stream habitat, oversteepens the banks, and has a greater risk of bank erosion due to the skew and inefficient inlet.

Though technically the culvert is still skewed, widening and/or shortening the culvert can reduce or eliminate the effects of the skew. This option has the greatest capacity and the least likelihood of debris blockage. It might have a cost more than the other options if wingwalls are used to shorten the culvert.

Each option requires some level of design compromise. None of these options necessarily stands alone; a project will often combine aspects of the three options.

Crossings located at a bend in the channel are a second common alignment challenge. The three options described above for the skewed alignment should be considered.

In any case, consider also the road alignment and elevation. Investigate opportunities of changing the road alignment or lowering the road to reduce the culvert length and mitigate poor stream-to-road alignments. Depending on the road usage and floodplain characteristics, there may also be opportunities to add floodplain causeways, bridges, culverts, or high flow spillways over the road to diminish extreme velocities through the crossing. These opportunities might be important for protection of floodplain and in-stream habitats as well as passage through the crossing.

Consider how far the channel is likely to migrate laterally during the life of the project. This is especially important for a crossing on a bend. Options to accommodate expected changes include widening the culvert, offsetting the crossing in the direction of meander movement, and controlling the meander shift at the inlet with appropriate bank stabilization measures or training structures.

Transitions

Transitions from the upstream channel to the culvert and then from the culvert to the downstream channel should be designed to minimize abrupt changes in cross-sectional shape and channel alignment. Providing good transitions can reduce failure risks, eliminate effects of previous culverts, and affect performance, capacity and passage through the culvert.

An undersized culvert typically causes an hourglass shape in the channel (Figure XII-5). Channel widening upstream and downstream of the culvert are caused by deposition in the enter of the channel upstream and scour downstream. The upstream effects can further decrease the capacity of the culvert and increases the risk of debris blockage. Downstream effects can interrupt passage corridors and jeopardize a streambed in the culvert.

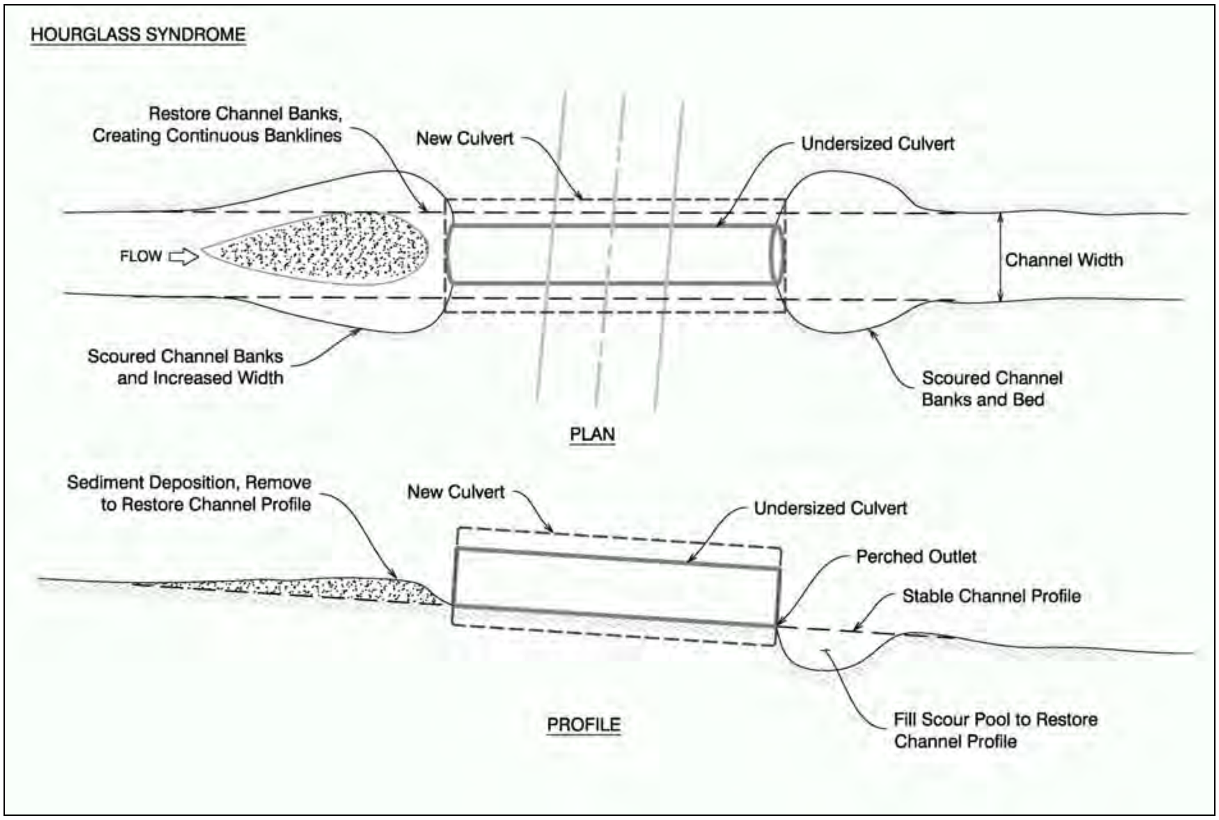


Figure XII-5. Hourglass syndrome at an existing culvert and with transitions to restore banklines.

To minimize these risks, the culvert dimensions and alignment should gradually transition into the natural channel cross section. This is especially true for banks on the outside of a channel bend. The ideal situation is for the culvert cross-section dimensions to equal the natural channel dimensions, forming a continuous channel through the project. For stream simulation designs, the upstream and downstream banklines should be restored to be continuous with the banklines within the culvert. Channel banks should be modified if necessary to restore the shape of the natural channel cross-section. Any unnatural mid-channel deposition should be removed to restore the entire cross-section.

A scour hole downstream of a culvert that is replaced with a stream simulation design should be filled so banklines can be restored and to provide a base for the stream simulation bed. If a scour hole is valuable rearing habitat, its loss may have to be mitigated by replacing it with other scour structures elsewhere. If there is a scour hole downstream of an existing culvert that is retrofitted internally for fish passage, consider leaving it in place as an energy dissipation feature to protect the channel further downstream. In the case of a retrofitted culvert (e.g., addition of baffles), consider the additional energy dissipation that might be required as a result of a raised hydraulic profile within the culvert.

Project Profile Design

Channel Vertical Adjustment Profiles

The final *project profile* represents the slope and elevation of the initial stable streambed through the project reach and is a primary tool for establishing the elevation of the crossing. It should seamlessly connect stable points in the upstream and downstream channel segments. It is based on the slope of the *reference reach* and will ideally fit between estimates of possible high and low channel profiles through the site.

The elevation of the culvert floor or footings may depend on the design method used and characteristics of the natural channel. If there is to be a streambed within the culvert, the floor or footings are somewhere below that bed. The intent is that the crossing *tailwater* elevation will match the normal water level exiting the culvert so there is no drop and no unnatural backwater. This condition should persist for the life of the project. Culvert elevation in stream simulation designs is discussed in Culvert Elevation and Height (page XII-39).

If a culvert is being replaced, the effect of the existing and new culverts on the profile must be understood. If the culvert is perched, the project profile may be long, perhaps including adjacent reaches that will be restored to natural grade, or where artificial profile controls will be installed.

The dimensions of natural alluvial channels vary through time and location. The slopes and elevations of unstable channels also raise (*aggrade*) or lower (*degrade* or *incise*) over time. Culverts can become either *perched* or plugged with sediment if they are not designed for vertical adjustments to the streambed that will likely happen during the life of the culvert.

The pre-design includes an estimate of the possible future channel profiles through the site; these are the estimated highest and lowest vertical adjustment profiles. The structure should be designed to satisfy design criteria when the bed is at any elevation within the range of vertical adjustment profiles as shown in Figure XII-6. For example, bed depth and channel width should be accommodated at the lowest potential profile and culvert capacity and debris passage should be accommodated at the highest potential profile.

There is no cookbook procedure for doing this assessment; it requires an understanding of channel characteristics and evolution and might require expertise beyond that in the design team. There is often uncertainty about what a future stable slope might be. A wide and conservative range of vertical adjustment profiles might be reduced with additional understanding of the channel. Seek additional information or expertise if needed to interpret the channel and predict future trends.

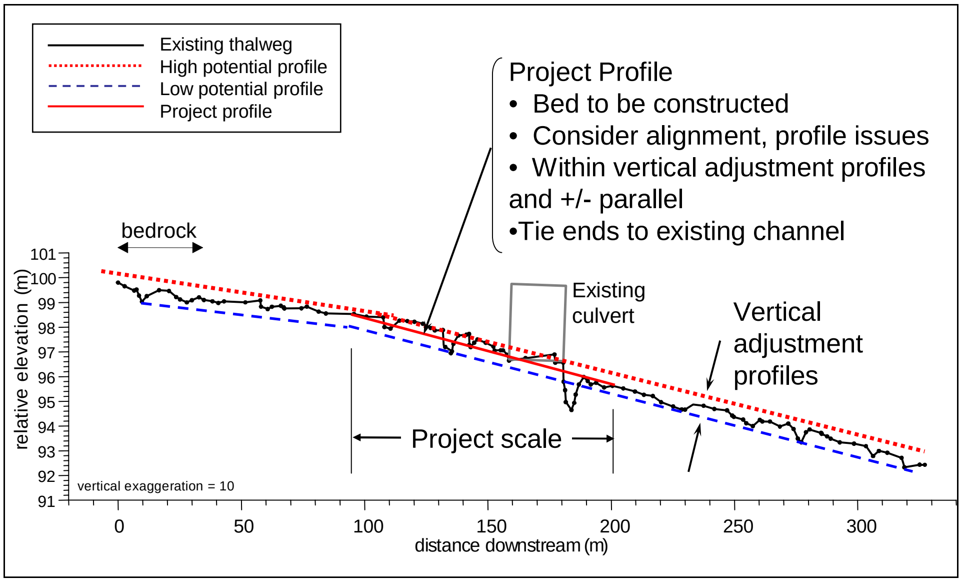


Figure XII-6. Possible project profile for a culvert replacement in a stable channel within range of vertical adjustment profiles (VAP) determined by site assessment.

Consider the following questions when developing vertical adjustment profiles:

- Is the channel profile controlled by temporary controls (e.g., beaver dam or debris jam) or permanent controls (e.g., bedrock or boulder channel)? Is the bed *mobile* or relatively immobile?
- What is the stage of the channel evolution and what will it look like in the future?
- Is the downstream channel incised or likely to incise? Investigate far enough downstream to identify a stable base level.
- Will land use practices affect the future channel profile by changing peak flow hydrology, sediment, and/or debris loads?
- Will channel changes in nearby reaches affect the channel profile?
- For culvert replacements, will replacement of the culvert affect the channel profile?

The resulting natural vertical adjustment profiles might not be acceptable. Headcut issues might affect this decision. In that case, a *forced profile* with profile control structures might be necessary. A forced profile is generally steeper than the otherwise stable slope of the channel constructed.

Scale of the Project

Generally, the scale of the project should reflect the scale of the problem. If an existing culvert is perched, the designer must determine whether the perch is due to local scour caused by the existing culvert, or whether the downstream channel has incised. Figure XII-7 shows the difference between the two conditions. Scour due solely to an undersized culvert in a *stable channel* is usually limited to a short distance below the culvert; the plunge pool is a local scour feature and the scale of the project can be local. The drop at the culvert outlet may be simply addressed by replacing the culvert with an appropriately sized culvert, filling the scour pool and allowing the accumulated sediment upstream of the culvert to scour and re-grade.

If the downstream channel is incised, the solution will be more complex and a solution of a comparable scale should be considered. The appropriate scale of the solution for an incised channel should consider the extent, status, and cause of the incision. Restoration of the incised channel will likely have the greatest overall benefit assuming it restores downstream habitats, protects upstream habitats, and is self-sustaining.

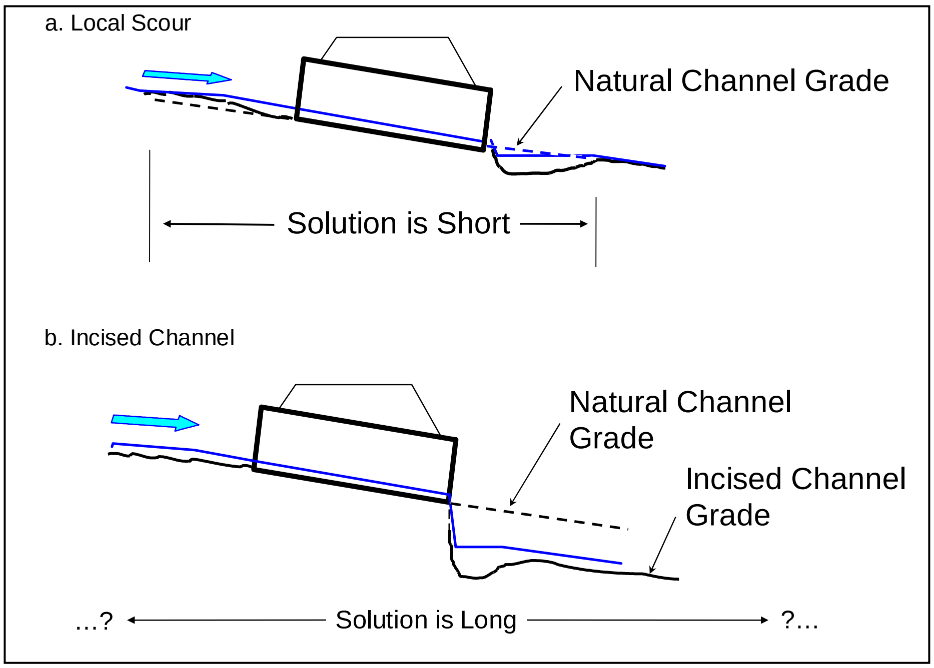


Figure XII-7. Comparison of a perched culvert caused by (a) local scour and (b) downstream channel incision.

Vertical Adjustment Profiles (VAP) in a Stable Channel

A stable channel is one that is neither *aggrading* nor *degrading* over time. For stream crossing design, channel stability is generally considered for the life of the crossing. At the very least, local streambed elevations can change due to local pool scour and fill, such as might occur during a flood.

Estimating the vertical adjustment range requires professional judgment, observation, and interpretation of natural channel conditions and evolution. Start with the surveyed longitudinal profile and characteristics of the channel. Evaluate any potential for downstream *base level* change, changes in incoming sediment loads, or other possible watershed changes that could affect vertical bed stability and elevation. Consider possible profile changes and stability of profile controls within the reach, such as loss or accumulation of debris, beaver dams, and other culverts or infrastructures that might be modified. Include limits of vertical changes such as soil and bedrock outcrops in the channel bed and floodplain elevations and locations and depths of any borings done for pre-design.

Any features or processes that may cause the channel to rise locally will affect the high adjustment profile. Debris accumulations can easily cause bed elevations to rise. In a depositional reach, natural aggradation should be considered. Sediment from a headcut, bank failures, or delivered from an upstream tributary may cause a streambed to aggrade.

Using that information, draw at least two profiles on the longitudinal profile drawing to show the range of vertical adjustment profiles (VAP's) through the site. The lower profile represents the lowest likely elevation of the streambed in the life of the structure and the upper profile is the highest likely profile. An example of a simple profile and vertical adjustment range is shown in Figure XII-6.

Draw the project profile considering the vertical adjustment range. The project profile is the stable profile that will be constructed or will initially develop. The project profile is ideally between the upper and lower vertical adjustment profiles and connects profile control features in the existing channel at the upstream and downstream ends of the project. It should extend at least as far upstream and downstream as the new culvert installation might affect the channel. If the culvert replacement will initiate an upstream headcut, the vertical adjustment profile should extend beyond the anticipated length of the headcut.

Profiles can be drawn in segments where a channel has distinct grade breaks. The high and low profiles might not be parallel where a feature will limit the possible channel elevation from going higher (e.g., floodplain elevation) or lower (e.g., bedrock). If it is uncertain how far the bed might move vertically (e.g., in a channel with a highly mobile bed and good potential for debris jam formation), the designer might increase the vertical adjustment range somewhat to offset the uncertainty and risk of error. If the designer is not confident predicting vertical adjustment range they should seek additional expertise and/or more assessment information. Additional assessments and/or expertise can reduce uncertainties. Design details, such as adding roughness elements, width, and bed depth, might reduce risk. Designers should document design assumptions with notes on the profiles.

Vertical Adjustment in Incised or Incising Channels

Construction or replacement of a culvert in an incised or incising channel is more complex. A channel incises when its bed scours and lowers over time either by natural process, by hydrologic changes in the watershed, by lowering of the *base level*, and/or by the lowering or removal of a control point in the channel. Figure XII-7(b) and Figure XII-8 show downstream channels that have incised so its profile is close to parallel to the upstream channel but it is offset at a lower elevation and the culvert is perched above.

Several project profiles should be evaluated in this case. In addition to considerations of the stable channel described above, it is necessary to understand the causes of channel incision, the sensitivity of the channel, and how it will evolve in the future. Consider how the condition of the upstream channel relates to project objectives.

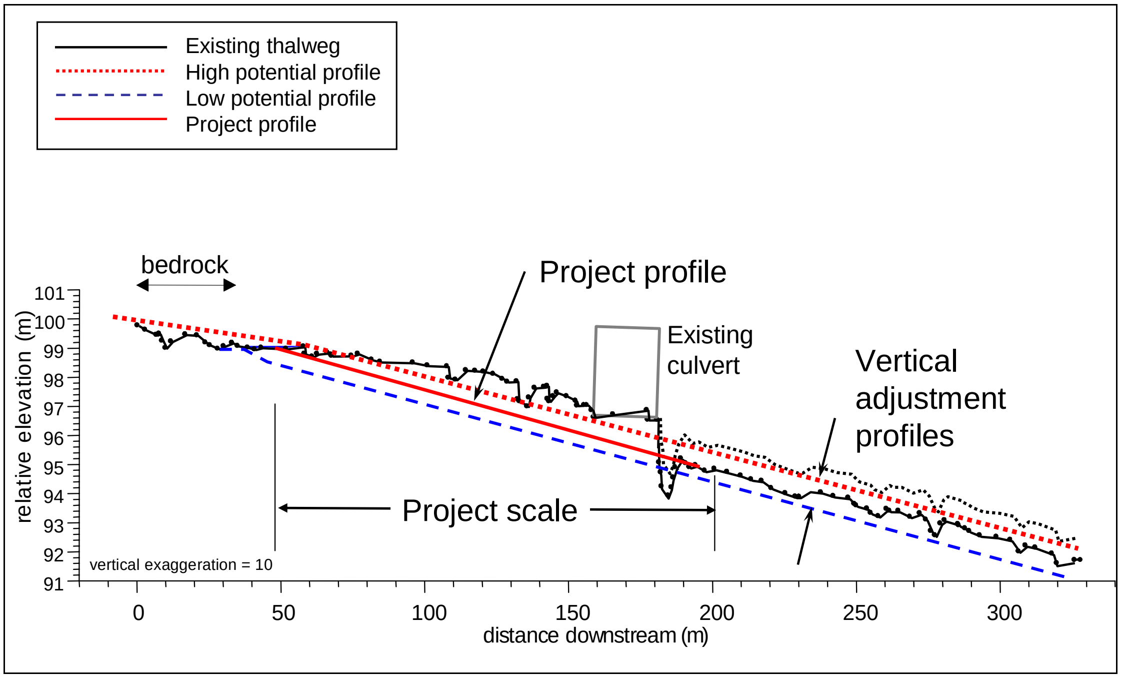


Figure XII-8. Possible project profile for a culvert replacement in channel with regional incision. Project profile is within the range of vertical adjustment profiles, which are based on the assumption of no culvert at the site.

A project profile to consider, and the ideal situation, is the stable profile that would be at the site if no culvert had ever been installed. The project profile should not be steeper than a natural reference reach in a similar setting in the same stream. If it is steeper, make sure the design will accommodate a lessening of the slope as the channel evolves.

To get that profile, the upstream channel might be allowed to incise or constructed at a lower elevation. There are significant risks that must be considered if a culvert is lowered and the incision is allowed to proceed upstream. A headcut profile might not be acceptable. Other considerations, such as construction limitations, other infrastructures, or protection of habitat might require limiting upstream headcutting. In these cases, the project profile might have to be located above or below the natural vertical adjustment range. If a *forced profile* with *profile control* structures is necessary, then immobile structures are needed to control the elevation and grade of the channel. A forced profile is shown in Figure XII-9.

Options for a forced profile are:

- Raise the downstream channel to a natural grade by rehabilitating it
- Steepen the downstream channel with profile controls
- Steepen the culvert
- Lower the culvert and steepen the upstream channel.

No single solution satisfies all situations and projects are often designed using a combination of two or more of these options. A general description of profile controls is included in Profile Control (page XII-54). The profile control strategy might be to permit a headcut to adjust the profile, but to control its extent with permanent profile controls, or limit its rate of migration using deformable structures. Temporary controls such as scattered, buried or temporary rock structures that are expected to fail over time mitigate some of the headcut impacts.

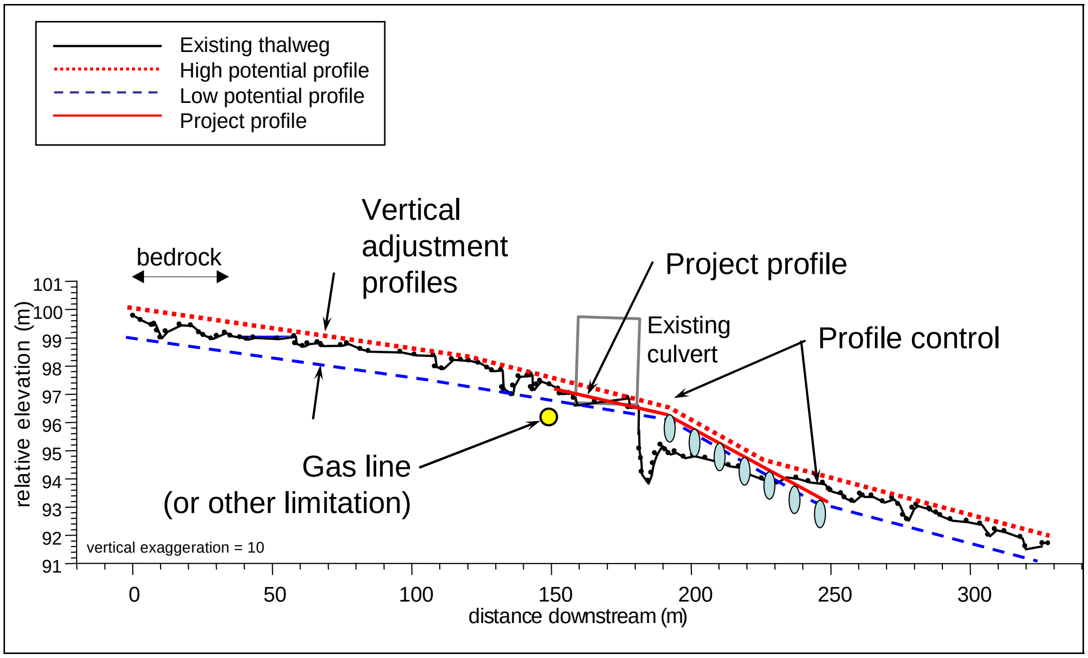


Figure XII-9. Possible project profile for a culvert replacement in a channel with regional incision and project limitations. Project profile is a forced channel using profile control structures due to site limitations.

Headcut Issues

Schumm (1977) described a channel evolution model, which is shown in a simplified version in Figure XII-10. During the initial stages of incision, the channel becomes deeper and narrower, the relative heights of the banks increase and the banks become steeper. Loss of floodplain connection and concentration of flows within the channel exacerbate the incision process. Reinforcement by root structure is decreased. Consequently, banks fail, and the channel then widens over a long period of time until the channel re-establishes its natural slope, floodplain, bankfull width and depth at the lower elevation (Schumm 1977). The entire process can take years, decades, or centuries (USFS 2008).

A channel may become incised locally by scour in response to the lowering or removal of a downstream culvert. The channel profile is often discontinuous and over-steepened where it transitions back to the unaffected channel upstream. That discontinuity is a headcut, which, as it erodes, migrates upstream and eventually incises the channel for some distance. The same situation occurs if an undersized culvert is replaced with a larger one, since the flood hydraulic profile is lowered by the reduction of the culvert constriction. The headcut in this situation is typically limited to the extent of the culvert influence.

Habitat impacts of channel incision can be extensive and prolonged. They can be mitigated by reconstruction of the channel either into a natural grade or steepened with hydraulic controls. Bates et al. (2003) and UFWS (2003) identified issues to consider when deciding whether to control a headcut or allow it to continue upstream when a culvert is removed or lowered and/or enlarged. The effects have to be weighed against other options, such as steepening a channel to artificially maintain the elevation of a culvert that is a *nickpoint*.

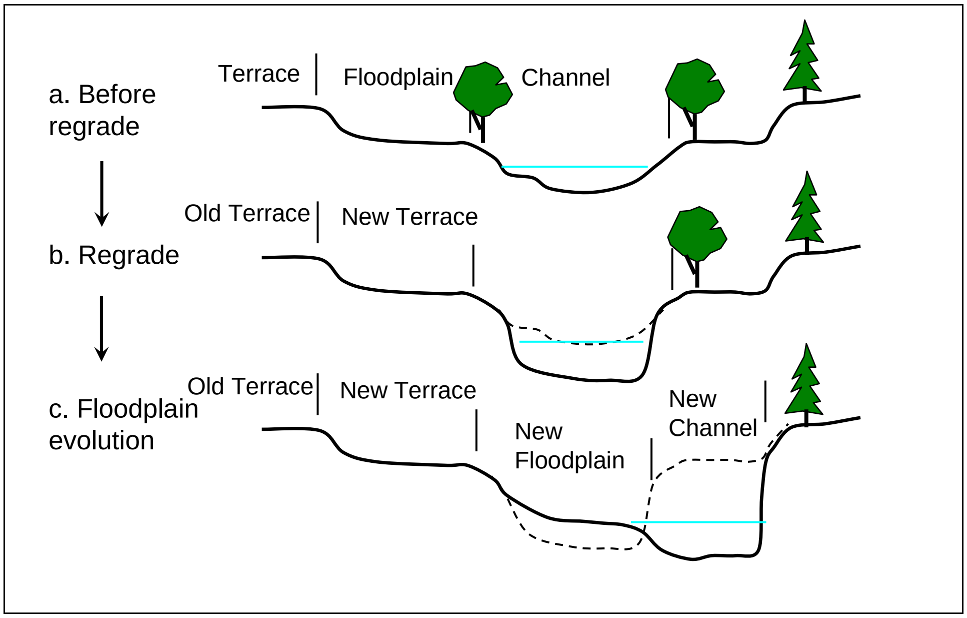


Figure XII-10. Channel evolution model based on Schumm (1977).

Extent of headcut - The distance a headcut can travel upstream depends on the channel slope, bed mobility, supply of sediment, and the presence of debris or other key features in the channel. The extent is usually less in armored or coarse-grained channels than in fine-grain beds. Sandy beds often headcut uniformly without increasing slope until they reach a grade control of debris or larger bed material. A headcut of just a foot can extend hundreds or thousands of feet upstream in a sand-bedded channel.

Condition of upstream channel and banks - If the upstream channel becomes incised, banks will become less stable as they are undermined. Banks that are already prone or are on the verge of failure are most vulnerable. A bank stability assessment can be used to identify this risk.

Habitat impacts of upstream channel incision - Allowing the headcut to travel upstream can have significant effects on aquatic and riparian habitats. As a channel incises it typically becomes confined and banks become vertical. Habitat diversity and channel stability are reduced because the stream cannot access its floodplain during high flows. The very habitat attempting to be restored for fish access might be impacted or lost.

The channel will eventually evolve back to a stable configuration, but it could take a long time, possibly a century. The evolutionary process is one of bank erosion as the channel widens and reestablishes a floodplain at a lower elevation, resulting in chronic discharge of sediment. Bedrock might become exposed if it is shallow, resulting in a loss of habitat. If no debris or sediment structure is left, sediment might not accumulate in which case recovery would be slow. The headcut can also cause enough downcutting to leave side channels perched and/or inaccessible.

Presence of fish or other organisms - A headcut can pose a short-term risk of loss of organisms that are in the bed or pools upstream of a culvert. The bed may scour at a lower flow than normal in a headcutting situation.

Habitat impacts to downstream channel from sediment release - The increased sediment released by a headcut will likely affect aquatic habitats downstream. In addition to the volume of sediment released, it will be released at flows lower than would normally transport that material so it might deposit in pools and other habitats.

Decrease in culvert and channel capacity due to initial slug of bed material - Allowing an uncontrolled headcut upstream of a culvert can mobilize a slug of material during a single flow event. As this material moves through the culvert and the downstream channel, it can accumulate and reduce the capacity of both. In a normal *bedload* regime, the material would transport through the reach, but in the case of a headcut, the bedload rate is high at lower flow. A loss of capacity can result in additional deposition and, in extreme cases, can fill the entire channel and plug the culvert.

The risk is highest where the upstream bed is mobile. Degradation should be controlled if the culvert and/or downstream channel cannot withstand much change in capacity, even for a short period of time. Similar limitations should be considered where structures downstream are at risk from a loss of channel capacity or where banks are at risk of erosion.

Utilities and structures - A headcut can jeopardize structures in the channel or on the banks. Be aware of utilities buried under or near the channel and the effects of increased bank erosion on structures near the channel.

Potential for fish passage barriers created within the degraded channel - Consider the risk of channel incision exposing passage barriers upstream. Buried logs, non-erodible materials, and infrastructure such as buried pipelines might be exposed by channel headcuts. Additionally, upstream culverts could become perched. As the channel headcuts to these features, they become the new *knickpoint* and fish passage barrier. Adding to the difficulty, these problems may occur where they are not visible from the project site, where access is more difficult, or on other properties.

Design Approach

The last task of the pre-design is to select the appropriate fish passage design approach or approaches. These approaches are discussed in Select the Design Approach (page XII-15).

The preferred choice, where applicable, is stream simulation. The low-slope design approach is a simplified version of stream simulation for low risk sites. Hydraulic designs, such as profile control methods, might be required in cases where stream simulation is not feasible or for retrofits of existing culverts. Baffling an existing culvert may be used in cases where replacement is not a feasible option. Fishways might be appropriate where site limitations are severe. They are designed by the hydraulic approach.

Figure XII-1 shows the types of stream crossing projects across the top and the range of passage solutions they might lead to across the bottom. Project objectives and limitations of the site the design approaches determine which line to track down and ultimately which approach can be used at a site.

GEOMORPHIC DESIGNS AT STREAM CROSSINGS

Stream Simulation

Stream simulation is a geomorphic approach for the design of culverts and open channels for passage of fish and other aquatic organisms. The objective is to create a natural channel (dimensions, slope, bed and banks) through the crossing to connect the channels above and below the crossing. Diverse hydraulic conditions, hiding and resting areas, and moist edge habitats that aquatic and semi-aquatic species might use are created at a wide range of flows.

The premise of the approach is that the stream simulation channel through the crossing presents no more of an obstacle to movement than the adjacent natural channel.

The intent is to set the stage so the simulated channel adjusts to accommodate a range of flood discharges and sediment/debris inputs and the channel evolves similarly to the natural channel it simulates. Bed material in the stream simulation channel is as mobile as the reference channel. Flows that transport sediment and debris and rework the channel should not be constrained or accelerated inside the crossing structure. Bed material sorting and distribution, and bedforms are therefore similar to the natural reach.

> Premise of stream simulation: A channel that simulates characteristics of the natural channel, will present no more of a challenge to movement of organisms than the natural channel.

The design is based on a natural reference reach near the crossing. Bankfull channel dimensions, channel slope, bed material, and *bedforms* are simulated. Bankfull flow is widely recognized as an index that represents channel-forming flows in alluvial rivers (Dunne and Leopold 1978; Leopold et al. 1964). Slope is recognized as a primary controlling factor of channel and bedform shapes (USFS 2008). Figure XII-11 shows an example of a stream simulation design with a bankfull channel width and banklines that mimic the adjacent channel and create diverse hydraulic conditions at all normal flows.

Natural stream channels are tremendously diverse and complex, and include some degree of randomness in their response to runoff events and land management. It is an art to “read” a stream in order to simulate it. Knowledge is continually expanding as more structures are built and tested by floods. Part XII represents the best set of methods at this time, but its limitations should be recognized.

Figure XII-11. Stream simulation culvert in Twenty-Six Mile Creek, Washington State.

A simplified stream simulation approach is the low-slope design. This design is limited to low-risk sites and the design is simplified to a culvert width and slope as functions of the natural channel width and slope. No reference reach is used in that case. A streambed is not necessarily built into the culvert though it can be. The application and design are further described in Stream Simulation Application (page XII-30) and Low-Slope Stream Simulation (page XII-41).

The difference between stream simulation and roughened channels (as described in Roughened Channels page XII-57) should be clear. Stream simulation channels mimic the natural channels near the crossing. It is as mobile as the reference channel. If the reference channel is immobile, the stream simulation channel is also immobile, though it resembles the characteristics of the reference reach. A steep roughened channel does not necessarily resemble any specific reach near the crossing.

Much of the stream simulation design process was initially developed by Washington Department of Fish and Wildlife (Bates et al. 2003) and has been expanded by USFS (2008).

Stream Simulation Application

Stream simulation can be applied to new and replacement culverts, but generally cannot be used in culvert retrofit projects since the culvert size is defined by the design process. Stream simulation is essentially a channel design. The approach can also be used to design other channels whether associated with a crossing or not.

Simulations of a channel placed inside a culvert are not exact replications of natural channels. Features like channel-spanning wood, embedded wood, bankline vegetation, cohesive soils, and floodplain functions cannot typically be created inside of crossing structures. These features usually reinforce the natural bed and provide roughness that slows flow and helps create a diversity of water depths and velocities needed for passage of aquatic species. Likewise, we cannot reproduce the roughness and diversity contributed by channel bends or the complexity of large features like debris jams inside of structures. Though they cannot be duplicated, some of these characteristics can be simulated with large rock, and sometimes with wood. Artificial banks constructed of rock sized to be immobile simulate banklines in the reference reach. The grade-stabilizing functions of embedded debris can also be simulated using permanent rock features.

There are occasions where the channel at the crossing is not connected to an upstream alluvial channel that can supply the size and volume of bed material needed to replenish the simulated channel. For example if a road fill creates a pond above the culvert, bedload will not be transported through the pond so the downstream culvert and channel reaches are not directly connected to a supply of bedload. Stream simulation may not be appropriate in such a case.

Low-slope designs are strictly limited to low risk sites; these are low gradient channels with short culverts. The premise of the low-slope design is if a culvert is installed in a low risk site and the culvert is large relative to the channel and an appropriate project layout has been established, it is a low risk, and the level of design can be reduced. The intended application of this design is for small private roads where the owner chooses not to invest in an engineered design but may be willing to, instead, oversize the culvert or crossing channel. The definition of a low-risk site, where a low-slope design can be applied, is a channel with slope of 1.0% or less and a culvert length of 75 feet or less. Use of the low-slope method does not preclude the need for a thorough pre-design and understanding of vertical adjustment potential and alignment issues. The design is described in Low-Slope Stream Simulation (page XII-41).

Stream Simulation Design Process

Each site will have a unique solution. There are many variables to consider in a design and no cookbook solution. The descriptions here are general. The designer should refer to more detailed design guidance such as USFS (2008).

The methods described here are more rigorous than are often necessary for simple sites. Other sites have unique challenges that can only be solved by applying an in-depth understanding of fluvial processes and how they relate to the crossing. Risky conditions such as a culvert that confines a floodplain or is steeper than the reference reach require the team to devote more time and care to the assessment and design effort and possibly to engage additional specialists in the design. There may be other methods of stream simulation analysis and design at specific sites.

Those methods are acceptable as long as the premise of stream simulation can be satisfied at least as well as it can by the methods described here.

Figure XII-12 shows the basic design steps for stream simulation. The first three steps in the design process are part of the pre-design, which was generally described in Pre-Design (page XII-4). They are revisited here because for the unique characteristics of this approach.

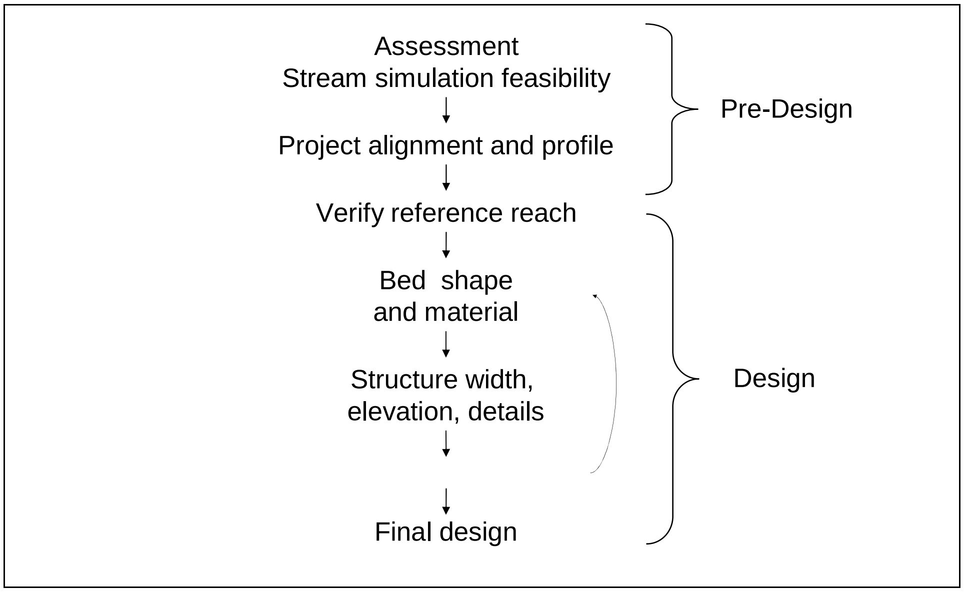


Figure XII-12. Stream Simulation Design Process Flow Chart.

A stream simulation design data form is provided in Appendix XII-A. It is intended to assist the designer in the design process and to document assumptions, data and their sources, and design conclusions.

Stream Simulation Site Assessment Needs

Site assessment has been described previously in general for culverts. There are some additional assessment needs for stream simulation. The stream simulation design is based on a specific reference reach near the crossing, which will be characterized in the assessment. In addition to the usual pre-design data needs, the following characteristics of the reference reach should be documented.

- Cross-section surveys including bankfull channel and floodprone area
- Floodprone width and characteristics to determine floodplain conveyance
- Bedforms and structure
- Bed material; pebble count and assessment of subsurface material or bulk bed material sample. Characterize colluvium, key features, debris, and bankline characteristics.

Specific techniques for doing these assessments are described further by USFS (2008).

Reference Reach

The reference reach is a specific identified length of channel near the crossing that serves as a template for the design of the stream simulation channel. To satisfy the premise of stream simulation, it must approximate the physical conditions, especially slope, of the project site and it must be self-sustaining when simulated inside a confined structure. This means that flows interacting with the bed and the structure walls will create and dynamically maintain streambed material sizes and patterns within the structure. In high flows, the simulated bed should mobilize, adjust and reform similarly to the natural channel; eroded material should be replaced by sediment transported from upstream. Setting the stage for this means establishing basic characteristics from the reference reach, such as gradient, bed and cross-section shape, bank configuration, and bed material size, key features, and arrangement.

The reference reach should have the following characteristics:

- Appropriate stage of channel evolution. Consider how the project reach is likely to change during the life of the structure before selecting a reference reach. What adjustments will occur when the existing structure is replaced by a continuous streambed?

- Near the project, ideally immediately upstream. Factors that control channel dimensions and structure (flow, debris, sediment) are then the same. If it is just upstream, it is the source of material that will replenish the project reach and it is continuous with the project reach.

- Outside of the influence of the existing structure.

- Channel gradient should be similar to the design gradient through the road-stream crossing.

- At least as long as the length of the road-stream crossing culvert or channel.

- Relatively straight. The roughness of bends must be simulated in a straight structure, usually using rock. This can increase turbulence and compromise the degree of simulation.

At new crossings, the undisturbed natural channel at the site is the reference reach.

Look at the longitudinal profile and consider the variability of slopes within the reach. There may be short punctuated steps that are steeper than the average gradient and that control the overall slope.

The slope of the reference reach should not be much different than needed for the project profile. If the channel is steepened too much the bed material must be so much larger than in the upstream reach that the material will not be replenished and the simulation will not be self-sustaining. Remember the premise of stream simulation is that the simulated channel is close enough to the natural one that organisms will move through it as easily. If the change of slope leads to a substantial change in channel shape or bed material character, that premise may not apply. While the design profile should approximate the stable slope connecting the upstream and downstream reaches, Bates et al. (2003) suggest the reference reach slope vary no more than 25% from the project profile slope. This a conservative suggestion; there are no data to support a specific criterion. A maximum *percent* change of slope is used, because a flatter channel is much more sensitive to a given absolute change than a steeper one.

Streambed Design

The simulated streambed is designed using the characteristics and dimensions of the reference reach. The following streambed elements are important to design of the stream simulation channel:

- Channel type; channel classifications as defined by Montgomery and Buffington (1997)
- Channel bankfull width, or active channel width if bankfull is not clear
- Channel slope
- Bed material size distribution
- Bedforms and cross-section shape
- Channel banklines, bank irregularities, margins, *key features*, floodplain
- Bed mobility.

Not all of these characteristics can be constructed. The framework and enough of the structure and materials are built so these characteristics will be developed and maintained by the hydraulic action of high stream flows.

The stream simulation bed material is a *well-graded* mix that approximates the reference reach particle-size distribution. It must include enough fines to prevent excess sub-surface flow. The simulation bed mix is specified based on the reference reach pebble count. Bunte and Abt (2001) and Harrelson et al. (1994) describe pebble count methods. Alternatively, a sieved bulk sample can be used if desired. Pebble counts are impractical for sand-bedded channels. A visual estimation of particle sizes is usually adequate in channels with dominant sizes of medium gravel and finer.

An essential component of stream simulation is bed mobility. Mobility here is the frequency of flow at which bed material is mobilized relative to the life of the crossing project. For example, a step-pool channel with key pieces that are mobile only at flows that occur once in 30 years is considered immobile. Chin (1998) and Grant et al (1990) show that step material moves only during infrequent floods, as infrequent as just during 50-100 year floods. The material of steps is expected to move so infrequently relative to the life of the project that it should be considered permanent and therefore designed as being immobile. At the other end of the mobility spectrum, the bed of a dune-ripple bed may be constantly mobile. The bed material might therefore be left to fill-in the culvert naturally since it is in constant supply and the risk of it not being initially installed is low.

As a framework for characterizing the reference, the channel classification system developed by Montgomery and Buffington (1997) is helpful. It focuses on the bedforms that control the functions and characteristics that are important.

Pool-Riffle and Plane Bed Channels

Channels characterized by an undulating bed with a sequence of bars, pools, and riffles are defined as *pool-riffle* channels by Montgomery and Buffington (1997). In contrast, they define channel beds without bedforms and with low width-to-depth ratios as *plane bed* channels. Designs for these two channel forms are the most basic. Design of the bed for these channel types is described below and will be the basis for design of other channel types.

The D_{95}, D_{84}, and D_{50} of the reference reach bed are used directly as the corresponding grain sizes of the stream simulation bed mix. The surface of the reference channel bed is therefore directly simulated. This means that, if the reference reach bed is armored, the large particle sizes will be over-represented in the rest of the mix below the surface. This is a safety factor for the simulated bed; if the bed scours, there is additional armor material below the surface and the resulting bed surface will become coarser and rougher. This is appropriate because the armored bed indicates a relatively low rate of bedload supply.

Pebble counts typically under-represent fines in the bed. However, the smaller grain sizes in the bed below the surface are very important for mobility and bed permeability. Mobility is affected by smaller particles that bind the bed together. A porous bed can allow substantial flow to move through it; the entire stream flow may go subsurface. The simulation bed mix must have enough fine sediment to fill the voids between the larger particles. Do not assume the stream will transport sufficient fines to seal an open-graded bed surface; it could take years to fill in the voids naturally. There are culvert situations in which the entire summer stream flow went subsurface for at least a decade after construction. The issue is especially critical in steep channels where the hydraulic slope can drive the flow subsurface and in spring-fed channels that do not experience frequent high flows or sediment transport. The smaller grain sizes are therefore sized based on the armor layer to create a dense mixture (see Sizing the Engineered Streambed Material page XII-67) for methods to size the material. USFS (2008) has additional detail on the technique.

Including fines in the bed mix commonly raises justifiable concerns about water quality and habitat impacts immediately after construction. Without special care, fine sediment in a freshly constructed bed will wash downstream during low or moderate stream flows that would not normally move the material. *Jetting* or *flooding* the fine material down into the bed during construction and/or placing a veneer of washed gravel over the surface can mitigate this.

Bed material is placed in the culvert with the expectation that subsequent flows will sort and distribute the material into a natural configuration. It is placed in a cross-section that includes a thalweg so there is some diversity and depth during initial flows.

When a bed of mobile material is recruited or placed in a culvert or other smooth-walled channel, the bed initially tends to flatten unnaturally. Then, because of the smooth walls, the flow often scours a trench along one or both walls. The streambed shown in Figure XII-13 is an example. Note the difference in character of the downstream channel and the channel within the culvert.

The bed is dominated by medium gravel and is quite mobile. The downstream bed has a diverse cross-section and is influenced by woody vegetation. The bed within the culvert is flat and shallow, and without character. It is also possibly a barrier to passage of adult fish at low flow. These effects can be prevented with banklines or other structures that create roughness and disrupt the flow along the culvert walls similar to natural banklines. They are equivalent to natural variations in stream banklines.

Figure XII-13. Deep Creek. Comparison of diverse bed created by woody vegetation that disrupts the flow and a flat shallow-flow bed within the culvert (Photo: Kozmo Bates).

Banklines in a low-slope design would be similar to the banklines described for stream simulation in Channel Cross-Section (page XII-37). Disrupters are single or groups of rock near the edges of the channel that create the bank diversity similar to natural banklines. If a bed is allowed to form naturally, disrupters should be large and high enough so they are exposed at the surface of the bed after it is deposited. The intent is to provide some disturbance so the stream will create bedforms naturally during the first freshets experienced by the project.

<u>Dune-Ripple Channels</u>

Dune-ripple channels are low gradient channels with sandy bed and bedforms as defined by Montgomery and Buffington (1997). The key to design of dune-ripple channels is the mobility of the fine-grained bed. Because the bed mobilizes and mixes during frequent moderate flows, a bed will readily form on its own. There may not be a need to place the bed material, except as needed to help maintain the initial channel cross-section shape and banklines. Pebble counts are impractical for sand-bedded channels. A visual estimation of particle sizes is usually adequate.

Step-Pool Channels

A step-pool channel is characterized by longitudinal steps formed by large clasts (cobbles or boulders) organized into discrete channel-spanning structures that separate pools as defined by Montgomery and Buffington (1997). Step-pool channels are more complex. Steps form when the largest particles in the bed congregate and support each other forming structures that are more resistant to movement than the individual pieces. Usually boulders form the framework of the steps, which support smaller bed material. In nature, step-pool bedforms can take decades to form so we cannot rely on step-pool features to form naturally in the lifespan of the project. Since they are critical for energy dissipation and channel stability, steps must be constructed. Steps should be designed to match those in the natural reference reach.

Likewise, it is not likely that steps would reform inside the culvert if the constructed steps are washed out. For this reason, steps made of large rock are designed with a bed stability model to be immobile. They are generally sized to be stable at the *stable bed design flow*, which is the flow at which the large rock forming the framework of the channel bed is sized to remain immobile. It might be the same as the *structural design flow* for the crossing (i.e., 100-year flow). The size of the large bed particles, width of the bed, and the size of the culvert all potentially affect stability. Immobile rocks placed in any streambed should be limited to banklines or be partially buried in the bed so the risk of them blocking movement of other material and creating a jam is minimized.

Except for the steps themselves, the step-pool channel bed is designed from a pebble count of the reference channel (see basic design process; Pool-Riffle and Plane Bed Channels page XII-34). Frequent high flows scour and replenish the material between steps as bedload moves through the system. The design of the steps can be approximated by a pebble count of the steps in the reference reach but it is then designed essentially the same as the engineered bed material of a roughened channel. The greatest difference is the channel shape, slope and spacing of key features of a stream simulation channel are based on the reference reach. Use the reference reach as a template and use the concepts described in Step-Pools (page XII-63).

Cascade Channels

Cascade channels are steep channels characterized by large roughness elements relative to the water depth and without repeating bedforms as defined by Montgomery and Buffington (1997). Cascade channels are steep and the largest bed particles are large relative to normal flow depths. Energy is dissipated by water flowing over and around individual rocks. Rocks that are key to bed structure and stability are immobile up to very high flows. Again, at these flows, shear stresses inside a pipe are higher than in an open channel. Bed stability would be critical in a simulation since, if the bed fails, the bare culvert would be unlikely to recover naturally. The channel is designed so individual rocks are stable up to the high *stable bed design flow*.

Like the step-pool channel, a cascade stream simulation is designed essentially the same as the engineered bed material of a roughened channel. Again, use the reference reach as a template and use the concepts described in Cascade and Pool (page XII-65).

Channel Cross-Section

A cross-section of the completed stream simulation channel is shown in Figure XII-14. The width of the stream simulation channel between the banklines is the same as the bankfull width of the reference reach. The culvert width may need to be greater than bankfull for several reasons discussed below.

The diversity, roughness, and shape of the channel and banklines are critical to satisfying passage objectives of some aquatic organisms. For example, weak swimmers and crawling species may need margins of slow, shallow water with eddies in which to rest. Channel edge diversity is necessary between low-flow and normal high-flow levels to accommodate the different movement capabilities of all aquatic species. Bankline diversity should be included in all stream simulation designs. Without root structure, cohesive soils, or the ability to scour into parent bed material, banklines will not form naturally inside the structure.

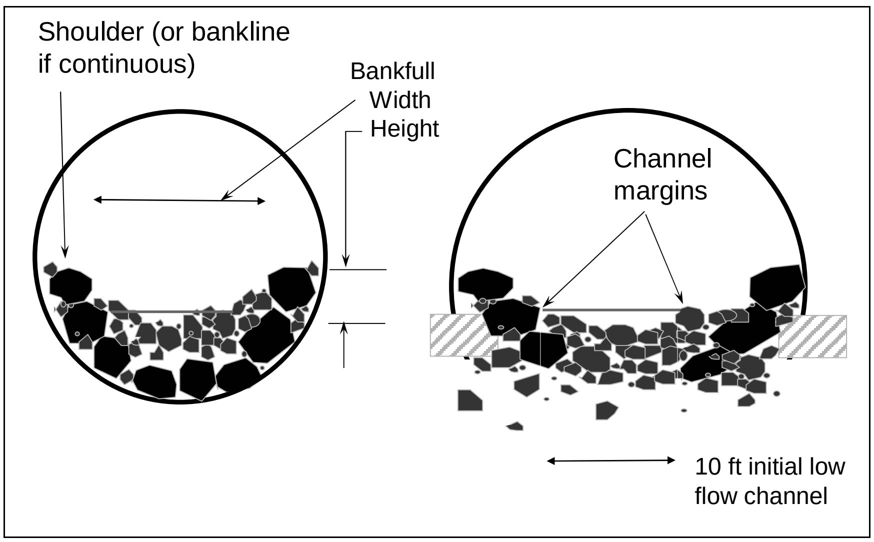


Figure XII-14. Stream simulation bed design with banklines or shoulders in round and bottomless pipes. Culverts span bankfull channel.

Features constructed on the margins simulate the reference channel banklines and edge diversity. Based on the complexity of the reference reach any of several structures might be added to the stream simulation bed. Use the reference reach bankline diversity, including frequency and size of wood or rock protrusions, as a guide to design the bankline/margin. The intent is to create a permanent bankline, so material large enough to be stable at the *stable bed design flow* is required (see Bankline Rock page XII-71).

Many streams have non-alluvial features such as large wood, embedded or jammed wood, and large boulders that may have fallen or slid into the stream or are glacial remnants. Woody debris in the reference reach might be in the form of small jams, buried wood that buttresses the bed and/or forms steps, or wood protruding from a bank. These features are often partially buried in the bed, they might block part of the channel cross-section, and then often play a significant role in the reference reach. Imitating the size and distribution of individual elements using large rock should simulate these functions. A cluster of rocks jutting out from the culvert wall can simulate a bank log in a natural stream. The cluster will provide some edge diversity, and will help prevent a low-flow trench being scoured next to the culvert wall. Figure XII-15 shows the cross-section, including *colluvial* boulders, in a stream simulation design. Note the similarity in channel shape and characteristics of the stream simulation channel within the culvert and the natural channel downstream.

Figure XII-15. Stream simulation channel in Stossel Creek culvert with natural shape, dimensions and key features.

In simple situations, bedform shapes (riffles and pools) are not constructed, but some temporary bed features are helpful to provide an initial thalweg and set the stage for channel margins to develop. In the simplest case, a V-shaped low-flow channel with a width up to about ten feet and lateral slope of 1:5 can be formed into the bed material that has been placed in the culvert. The V-shape is not intended to persist through flood events. High flows will redistribute the bed material naturally, constructing a diverse channel with a thalweg.

Structure Width

In the stream simulation design, the structure is sized by fitting it around the designed channel. It could be a culvert of various shapes or a bridge. Structure size might also be affected by stability, mobility, and/or flood capacity analyses.

The goal of stream simulation is that the simulated channel be self-sustaining and free to adjust similar to the natural channel. For the simulation bed characteristics to be self-sustaining, the hydraulic forces it experiences must be similar to the reference channel, especially at those flows that create and rearrange major bed structures. If the channel is constricted by the structure at those flows, the character of the bed will be changed; it may wash out, lose its structure, and/or become coarser. For these reasons the stream simulation channel has a width equal to the reference reach and has similar banklines and other key features that control channel and bed form. The bankfull cross-section or another similar parameter that represents channel-forming processes is used for this purpose. For this reason, *entrenchment* of the project reach is a critical parameter affecting culvert width. If a culvert is located in a channel within a wide active floodplain, over-bank flow will be forced laterally from the floodplain into the constriction of the culvert. The culvert may have to be wider so the bed simulates the reference reach that is affected by the floodplain.

The first estimate of culvert width is simply the width needed to span the bankfull channel. This is the minimum allowed culvert width for stream simulation. If the design includes banks, the culvert must be wide enough to span the bankfull bed plus the added width of bank material on both banks. Other considerations of culvert width are relative sizes of key pieces and their stability at high flows and construction and maintenance access.

> The first estimate of structure width is simply the width needed to span the channel.

Culvert Elevation and Height

The goal of setting a culvert elevation is to provide enough bed depth within the structure to avoid exposing the culvert floor or the footings, even in scour pools and when the bed profile is at its lowest potential elevation (lowest vertical adjustment profile). To set the elevation of the culvert invert or open-bottom arch footings, use these three parameters:

1. The low vertical adjustment profile (Project Profile Design page XII-20)
2. The depth of scour pools within that profile (Stream Simulation Site Assessment Needs page XII-31) and
3. A thickness of the bed so the material is well-integrated and able to structure itself.

The dimensions for setting a culvert elevation are shown in Figure XII-16. Start the sizing by setting the mid-point of the culvert rise or diameter at or above the high potential profile. If the culvert is any lower, the converging roof of the culvert will reduce the bed width. Then set the culvert floor elevation as if the bed is at the low potential profile. The required bed depth inside the pipe also depends on the size of the largest bed material. The minimum thickness of the bed over the culvert floor should be 1.5 times the diameter of the largest immobile particles in the bed or four times the size of the largest mobile material, whichever is greater. This is so the bed materials can form a mass and large particles do not have to set on the floor. For stream simulation beds with only small material, up to cobbles, the floor should still be buried by at least 20% of the rise of the culvert.

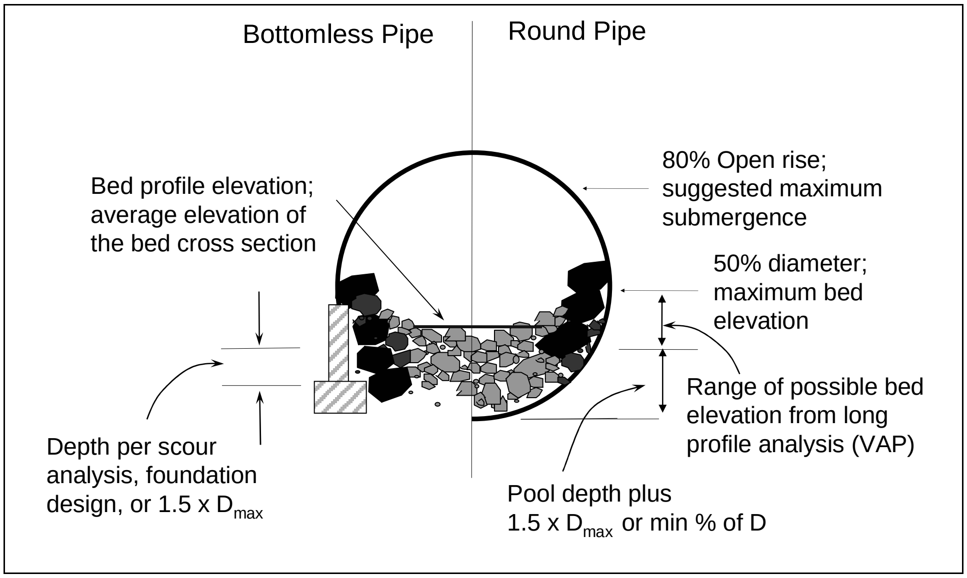


Figure XII-16. Stream Simulation Culvert Elevation.

Design of non-circular culverts will vary from this. Bottomless arches are typically built on stemwalls that are part of the footing. The elevation and design of the footing is determined by whichever is greater, depth needed for structural design of the foundation, the projected bed scour depth, or a burial of at least 1.5 times the diameter of the largest immobile particles in the bed as described above. The scour depth might be limited by bankline material if it is immobile. For an initial design bury the top of the footing two feet below the lowest expected channel profile. This should be verified in the final design. A thorough analysis is typically necessary (USDOT/FHWA 2001). FHWA describes scour methods and data (FHWA 2003). Where the consequences of failure are large, use a larger culvert or a deeper footing.

A second goal that affects culvert elevation is to maintain flood and debris capacity when the bed is at its high adjustment profile. This will determine the culvert height. The high bed design flow is the flow at which the any permanent features (key features, banklines, step structures) are stable and do not wash out of the culvert. The simulated bed is likely to fail if the culvert becomes pressurized during flood flows. Pressurized flow happens when the headwater depth is over the top of the culvert and there is substantial headloss (e.g., somewhat greater than the natural headloss in the reference reach of the same length) between the upstream and downstream water levels. For bed stability, and with a safety factor, the culvert inlet should not exceed 80% submergence during the stable bed design flow. The submergence is the distance from the bed, when at the high vertical adjustment profile, to the soffit of the culvert.

Select the bed design flow appropriate with the level of risk and consequences of failure of the bed. Consider bed mobility, the ability of the bed to restore itself, and equipment access for repair if necessary.

Bed Mobility and Stability Analysis

Mobile streambeds are designed so the reference reach stream simulation beds have "equal mobility." When the bed mobility's are equal, the bed shape, distribution of bed material, and bedforms are assumed to be similar and the goal of stream simulation is achieved. A mobility analysis is useful where the simulation differs somewhat from the reference reach (e.g., steeper or floodplain flow is confined into a culvert) and can also be used to help mitigate risks of pressurized pipe or of a long pipe. The mobility analysis is performed on the alluvial portion of bed; D_{84} is used as an index for bed mobility. USFS (2008) describes these risks further, including thresholds, methods, and background for the analysis. The goal is to have D_{84} as mobile in the stream simulation channel as in the reference reach. If the two channels have the same slope, size (cross-section), bed (bed distribution and bedforms), and confinement no analysis is needed.

Some stream simulation channel features such as banklines, steps, and rock clusters are intended to be permanent. A stability analysis is performed for those features at the stable bed design flow. Use the reference reach as a template and use the concepts described for roughened channels (Roughened Channels page XII-57) to size the stable bed and bank material.

Low-Slope Stream Simulation

Premise of low-slope: The design of an oversized culvert in a low risk site can be simplified.

The low-slope design is a simplified stream simulation design for use at low risk sites. Low risk sites are defined as short culverts in channels with low slopes. This approach is intended to simplify design and permitting for short crossings under residential driveways, farm roads, short public road crossings, and similar sites. The primary advantage of the low-slope approach to the culvert owner is to avoid surveying and engineering costs associated with fish passage design for other options. Special fish passage design expertise is not required. Accurate geomorphic interpretation of the channel profile (vertical adjustment potential) and layout (alignment) are still necessary though. The low-slope option requires few technical calculations for design of the culvert itself and results in a conservative but reasonable culvert size. The default dimensions do not guarantee culvert flood capacity, which still must be calculated.

The California low-slope option is defined by these criteria:

- The low-slope approach shall only be applied in low risk situations of low slope and short culvert length. Culvert length is limited to 75 feet and the natural channel slope is limited to no more than 1.0%.

- The bottom of the culvert is embedded 20% to 40% of the height of the culvert (diameter of a round culvert) when the bed is at any potential elevation during the life of the project (low to high vertical adjustment profile). Minimum footing depth is the critical dimension for bottomless structures in lieu of a culvert floor. A thorough pre-design is necessary, especially for culvert replacements.

- For culverts greater than 50 feet in length, the culvert and scour pool must be backfilled with material that has a similar gradation to the bed material in the adjacent channel. For culverts less than 50 feet in length the scour pool must be filled with bed material in the adjacent channel, but the bed can be allowed to from through natural recruitment inside the culvert.

- The width of the culvert at the streambed elevation must be at least 1.25 times the average natural channel bankfull width. This and the shape of the culvert determine the actual culvert structure width.

- The culvert and associated road fill must not constrict the active floodplain excessively such that frequent backwater affects the upstream channel or there is a risk of culvert or road failure.

Figure XII-17 shows the same definition of the low-slope design option.

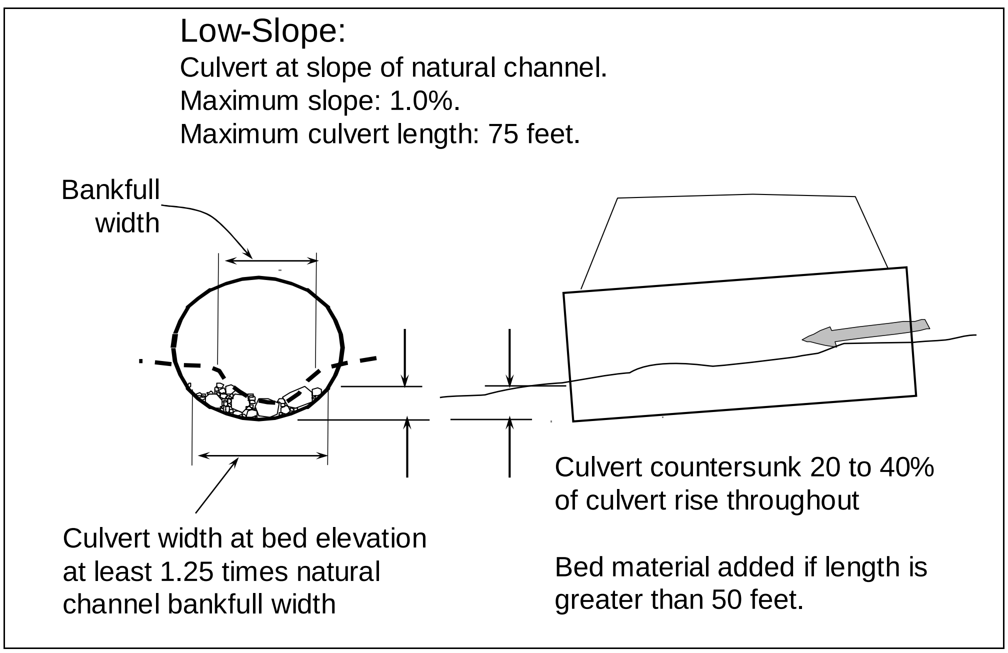


Figure XII-17. Graphic definition of low-slope design.

Low-Slope Application

This option is appropriate only for low risk situations with a low slope and short culvert length. The culvert height must be adequate to accommodate uncertainties of an unstable channel as aggradation or incision occurs. Because the application and design entirely depend on the future channel slope and elevation, a careful assessment of the potential channel elevation for the life of the project is essential (see Project Profile Design page XII-20).

It is anticipated that because the culvert bed is at least as large as the natural channel bed, material will deposit in the culvert. However, for culverts greater than 50 feet in length, there is increased risk of relying on material deposition, so material must be placed in the culvert to form a channel bed. The natural bed will allow a broad range of fish species and sizes to move through the culvert. This might not occur or might not be persistent in several situations. For example, a floodplain constriction can cause a culvert bed to be unstable or the naturally recruited streambed may be inadequate to meet the objectives of the project. The streambed in a culvert that is skewed significantly may not be stable as it is scoured by concentrated flow. A streambed or channel margins and banklines might not form immediately after construction but may be important for migration of aquatic organisms. The design might be modified to mitigate these issues or the designer may have to consider constructing the streambed as a stream simulation design.

The low-slope design option is usually only applied in new and replacement culverts. It can be used as a retrofit only in the unlikely situation that the culvert is already appropriately sized but the downstream channel has incised and left it perched. In this rare situation you may be able to use profile control or profile restoration to reestablish a downstream channel elevation that places the existing culvert at a suitable elevation for the low-slope approach.

Low-Slope Design Process

The low-slope design begins with the pre-design described in Pre-Design (page XII-4). From the pre-design the designer must understand the vertical adjustment range of the channel through the new culvert and be able to evaluate the effects of any headcut created by a culvert replacement, lowering, and/or enlargement.

From this information and the design criteria, the elevation of the culvert can be established and an initial estimate of the size of the culvert can be made.

The width of the culvert at the elevation where it meets the average elevation of the streambed at any cross-section is at least 1.25 times the average natural channel bankfull width. This and the shape of the culvert determine the actual culvert structure width. The floor of the culvert is embedded within the range of 20% to 40% of the culvert rise. If no bed is placed in the culvert, use the culvert width at the elevation equal to the lowest potential profile.

Bed material placed or naturally deposited inside the culvert may not be persistent if the culvert constricts the active floodplain too much. For example, consider a culvert designed in a channel with a bankfull width of 10 feet and a floodprone width of 100 feet. During a flood, flow from the floodplain will be constricted into the 10-foot culvert and will likely scour the bed. To design a culvert that will have a persistent bed, the culvert can be enlarged or additional culverts can be placed through the fill in the floodplain. The additional culverts in this case are not intended for normal flow conditions. They are intended to be active only during overbank flows.

If the low-slope culvert is 50 feet or less in length and built in a bed that is mobile, a streambed does not have to be constructed in the culvert. Bed material in a mobile streambed will quickly fill the culvert and form a natural bed.

If a scour pool exists downstream of a low-slope culvert that is replacing an undersized culvert, the pool should be filled as described for stream simulation culverts so the internal bed can develop.

Banklines in a low-slope design would be similar to the banklines described for stream simulation in Stream Simulation (page XII-28). Rocks should be scattered along the banklines to disrupt the flow and create some diversity in the hydraulics and the bed.

Finally, the flood capacity of the culvert must be verified, as it is for any culvert design. Capacity should be checked assuming the channel bed is at the highest vertical profile. The design should also meet or exceed other applicable local, state, or federal standards for hydraulic capacity, headwater depth, and other design parameters.

Geomorphic Considerations in the Design of Fords

This section provides an overview of the design considerations and elements essential for fords. A ford crossing is a road-stream crossing in which the drivable roadway is overtopped by stream flow anywhere from year-round to once every few years. Other common names for fords are low water crossings and Arizona crossings.

A traditional (un-vented) ford is built at the elevation of the streambed and places all of the stream’s flow over the roadway. A vented ford has an opening under the roadway surface, such as a culvert, that provides conveyance of normal flows and keeps the roadway dry most of the time. Whether vented or un-vented, fords frequently create barriers to fish and other aquatic organisms and interrupt transport of sediment and debris. Additionally, they often require frequent maintenance and repair that cause repeated disturbance to the adjacent stream channel. For passage and maintenance, they are very sensitive to any changes of elevation in the natural streambed, especially un-vented fords.

Fords are typically used in channels with low banks and relatively high width-depth ratios. A key advantage to the use of fords is they can be designed to avoid interrupting flow conveyance across a floodplain because the approaches to a ford do not need to be raised. Other advantages are if a ford fails, little to no sediment is released to the downstream channel and they are designed to allow debris and sediment to pass over the roadway. Because of these advantages, fords are best suited for roads that are not maintained frequently.

Fords are poorly suited for highly entrenched channels because of the difficulty of constructing the approaches, which must be steep and require a large amount of excavation into the bank. Entrenched channels are often better suited for other types of stream crossing structures that freely span the flood prone channel width.

The following is a summary of the different types of fords and the design features that can make them suitable for passage of fish and other aquatic organisms. Refer to the US Forest Service (2006) publication, titled *Low-Water Crossings: Geomorphic, Biological, and Engineering Design Considerations* for more information. The USFS publication provides descriptions of types of fords and their suitability to provide aquatic organism passage and maintain channel stability.

Un-Vented Fords

Un-vented fords can be problematic for fish passage if vehicles must cross the stream at the same flows that fish are expected to move upstream. Vehicles crossing through flowing water as shallow as one foot are at substantial risk of being swept off the roadbed. This is also the typical minimum water depth required for upstream passage of adult anadromous salmonids. Therefore, use of un-vented fords on fish bearing streams should be limited to intermittent streams where vehicles do not need to cross during fish passage flows.

Un-vented fords can be classified as unimproved or hardened. Unimproved fords have a roadbed consisting of native streambed material. Unimproved fords typically create suitable fish passage conditions, but often fail to provide adequate safety for vehicular traffic. They are also susceptible to scour damage.

Hardened fords have a stable driving surface of rock, concrete, asphalt, concrete blocks, planks, gabions, geocells, or a combination of these materials. A scour hole often forms downstream of improved fords because the surface of the roadbed is rigid and smoother than the natural channel. The acceleration of flow across the roadbed causes scour immediately downstream and a drop may form off the downstream edge of the ford. The drop creates a shallow water depth on the ford, which, with the drop, may limit fish passage. Like a culvert, if the downstream channel incises, the ford is likely to function as a knick point and a drop will form across the downstream end of the ford that can block fish passage.

Preventing a drop from forming over an un-vented ford with an improved roadbed often requires use of one or several profile control measures downstream of the crossing. This can be in the form of rock weirs downstream of the anticipated scour pool or construction of a roughened channel to prevent a scour pool from forming (see Profile Control page XII-54). The grade control should backwater the road surface and provide sufficient depth and suitable water velocities during fish passage flows.

Vented Fords

Vented fords, if properly sited, designed and constructed, can provide aquatic organism passage and not jeopardize a geomorphically stable channel. The vent is typically constructed using one or more concrete or metal culverts. The size of the vent is relative to the bankfull width, depth and area, and the ratio of the open-area of the vent to the bankfull area is referred to as the Vent-Area Ratio (Figure XII-18).

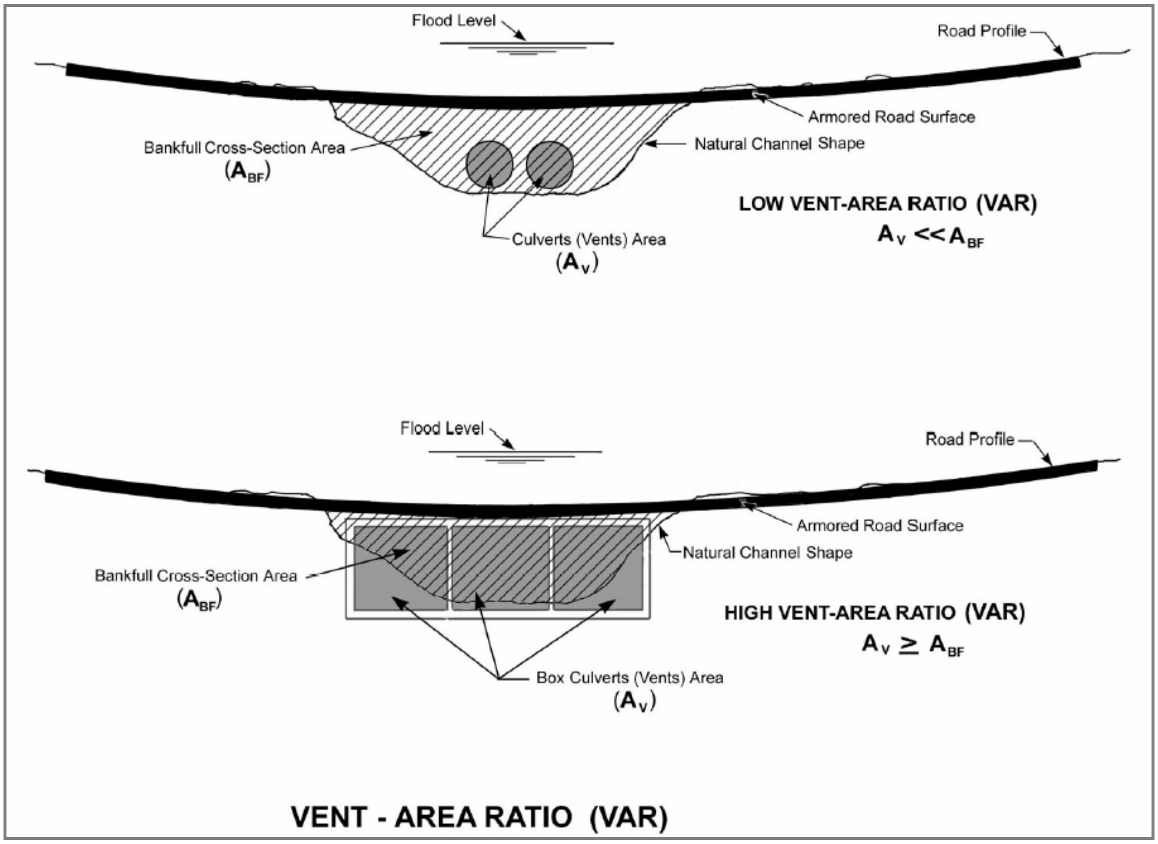


Figure XII-18. Definition sketch of the Vent-Area Ratio (VAR) for vented fords (USFS 2006).

A low vent-area ratio indicates that the crossing constricts the bankfull flow, leading to frequent overtopping and spill off the edge of the ford, typically forming a scour pool and a permanent drop downstream of the ford. Vented fords with low vent-area ratios frequently clog with sediment and debris. Once clogged, fish passage is blocked and the roadway becomes inundated even more frequently and at greater depths and the channel is affected.

To reduce clogging of the vent, the vent should be sized larger then the bankfull cross sectional area. The vent should span the bankfull channel width and the top (*soffit*) of the vent should be above bankfull depth (Figure XII-19). If multiple vents are required to achieve this, dividing wall thickness should be minimized and positioned away from the main flow path, which is often located near the thalweg. The wall separating multiple vents often catches debris and is a risk to fish passage and the structure. To reduce the risk of catching debris, the upstream edge of the wall should be adverse sloped to encourage debris to float up onto the crossing, and be rounded to eliminate sharp edges that are more likely to snag debris.

Once a vented ford creates a backwater, sediment may deposit and accumulate in the upstream channel. Reducing backwater at bankfull and higher flows can minimize this. In mobile bed channels, the headwater should not overtop the vent soffit until reaching a flow where the channel bed is fully mobile. This is generally above bankfull depth. The height of the roadway above the vent soffit should be minimized to reduce backwater effects and allow stream flow to overtop the road once the vent is at capacity. The flow blockage effect of guardrails and other flow obstructions should also be minimized.

Figure XII-19. A vented ford constructed with three embedded concrete box culverts that span the bankfull channel and convey the bankfull flow without overtopping (FishXing Case Studies 2008).

To maintain natural streambed substrate, the vent inverts should be embedded below the low potential streambed profile, as identified in the Pre-Design (page XII-3) and should be aligned with the approaching channel (Stream Crossing Layout: Alignment and Profile page XII-16). Rock banklines can be constructed along the edges to simulate the hydraulic roughness and diversity found along the banks of the adjacent channel. Rock used to form the banklines should be sized to be stable up to the stable bed design flow (e.g., 100-year flow). In mobile bed channels the bed within the vents can be formed by the natural recruitment of streambed material. Otherwise, it should be constructed within the vent. With these design elements, the design of bed within the vent is no different than other stream simulation designs.

Roadway Approaches

The roadway approaches to fords typically slope downward towards the stream. If left unpaved or if they drain into an unarmored ditch, they can become chronic sources of fine sediment to the stream.

Over time and use, the downstream end of an un-vented ford often subsides. When this happens the depth will increase, forcing vehicles to cross further upstream. This causes the approaches to widen, frequently leading to rutting and increased sediment delivery.

These problems can often be addressed by paving approaches, including best sediment management practices in drainage ditches, minimizing the length of the approach, and constructing the crossing as a vented ford to keep the roadway dry. Refer to Part X of the *California Salmonid Stream Habitat Restoration Manual* for more on reducing sediment inputs from road-stream crossings.

The road approaches should not be built up above the elevation of the floodplains, which would constrict the floodplain. Low road approaches is a basic advantage of using a ford.

Final Design and Construction Techniques

This section describes construction techniques and practices that are unique to stream simulation projects. They are primarily related to specification and construction of the streambed inside the culvert. Normal structural design, analysis of flood capacity, water management, excavation, and culvert placement practices are no different than other culvert installations and are therefore not described here.

Selecting the Style of Culvert

The stream simulation design up to this point has focused on design of the streambed and the overall dimensions of the culvert. The decision as to what style of culvert to use is part of the final design. A wide variety of structures may fit the project site and objectives; circular pipes, pipe arches, concrete or metal boxes, open-bottom concrete or metal arches, and many types of bridges. All have their specific advantages and disadvantages. Use the structure type that best fits the specific needs and objectives of the crossing.

While the design of a stream simulation structure is based primarily on accommodating natural stream function, other considerations that might affect product selection for the crossing are roadway geometry, failure risks, geotechnical considerations, construction limitations, cost, and others.

One-piece *embedded pipes* are usually used on small streams because of their low cost and generally simple installation. Actual width is limited to what can be manufactured and hauled to the site. There is large difference between embedded pipes and bottomless pipes. One-piece embedded pipes can be placed quickly as a single unit. Special equipment might be necessary to load bed material into it however or the means for placement of the material might limit the size of the pipe itself. Larger road-stream crossings may be constructed with a wide variety of structure types.

Bottomless pipes have the advantage that bed material can be placed from above before the culvert is attached to concrete footings and stemwalls. On the other hand, construction of those footings and delayed installation of the culvert structure result in other complications and a longer project duration and therefore possibly greater cost. A bottomless pipe might save excavation of bedrock and bottomless pipe footings can be placed to contour to bedrock.

A minimum depth of fill is generally needed over a culvert for structural purposes; it may vary from no fill (possibly for pre-cast concrete) to three feet or more. When fill heights are low, round and pipe-arch culverts may not allow sufficient cover over the structure. Consider using low profile and box structures, raising the fill height, or using a bridge.

Compared to culverts, channel-spanning bridges tend to have lower risks and higher longevity, and provide better passage for aquatic, semi-aquatic and terrestrial animals. Even with short spans they are often cost competitive with culverts. With increasing span, they become more economical than culverts. When they are close in cost to other structures, they are generally preferable. It is worth considering bridges in active flood plain locations and debris-flow or landslide-prone areas where high clearance is necessary.

Specifying Bed Material

An ideal bed mixture is based on the reference reach and may have to be modified for site conditions. The contract might specify a range of material sizes rather than specific sizes so there is some flexibility in procuring the material. Material might be specified that is within 5% larger and 5% smaller than the ideal gradation. For example, the rock intended to be the D_{84} in the streambed might be specified as being between the screen sizes that pass 79% to 89% of the mixture.

If possible, use standard rock sizes and mixtures that are commonly used in the area such as those commonly specified in local public works contracts. Mix portions of materials described by standard specifications to get the desired mixture. Samples of the bed mixture components should be inspected before material is hauled to the site or mixed. Specify the alluvial and key feature components separately so the key features are supplied and handled separately. For the alluvial material, a spreadsheet design can be used to combine various quantities of standard size materials until a plotted curve of the specified mix overlays a corresponding plot of the designed mix. USFS (2008) describes more detail for specifying bed material quality and mixtures.

Material in the original bed at the site might be suitable for at least a portion of the stream simulation bed. If the bed is removed for the placement of an embedded pipe, it will be mixed and loosened in the process. Compare the size of the material to the desired size distribution based on the analysis of a bulk sample. Additional material may have to be added to achieve the desired gradation.

Placing Bed Material

This section describes the hauling, sequence, and installation of bed material. Some of these practices differ greatly between a bottomless pipe and a full pipe, and, in fact the practice itself might be a determining factor in selection of the style of culvert.

Large cobbles and boulders should be hauled separately from small rock so the material does not get separated as it is hauled, stored, and loaded into the culvert. Haul it and store it at the site and mix each load to be carried into the culvert.

Backfill around the culvert before or concurrently with the placement of bed material so the culvert strength is developed before the bed material loading distorts the culvert. The exception to this is when bed material is placed against concrete stem walls in a bottomless pipe installation.

If possible, construct the bed entering from the upstream end and placing material starting at the downstream moving upstream. This helps pack the material as if it were sorted and placed by the stream. This is especially true for steeper channels; steps and other key features should always be built from the upstream side. A base of rock might be added on the floor of the culvert to protect it from any equipment used inside the culvert.

Key features should be embedded into the alluvial streambed. Place them individually over the first lifts of alluvial or base material and then place smaller material around them. Bankline rock should be placed into position rather than pushed. Bed material should be placed over and behind bank rocks to fill the gaps around them.

It is helpful to paint the bed profile on the inside of the pipe as guidance to the equipment operator as well as to see how the bed reacts after construction. Stable stream simulation beds typically loose about 20% of their depth due to consolidation and erosion of finer material when there is not substantial replenishment right away. Overfill the bed to account for any initial loss of depth.

Equipment used for installing streambed simulation material depends on the size of the structure and whether it is an embedded or bottomless pipe. Trail-building or garden equipment can be used for embedded culverts smaller than six feet high. A small loader or manual labor might be used for slightly higher culverts. Special materials conveyors and dump boxes mounted on rails have been used for mid-sized pipes. Be aware of air quality issues and safety regulations with gas-powered equipment operating in confined culverts.

Bed material should be placed rather than pushed so it does not separate and the structure is not damaged. Use rubber-tired equipment when possible. Material should be tamped in place. It generally does not have to be mechanically compacted. Form a thalweg in the bed to concentrate initial low flows. A thalweg formed with 5:1 side slopes and up to ten feet in width is generally adequate.

The final bed should be washed so the fines are pushed down into the bed. This can be done with a hose from a dewatering pump or with a wash of water from the bucket of an excavator. A veneer of washed gravel can be placed over finished bed to make it even cleaner.

USFS (2008) describes more details for placing bed material in stream simulation culverts.

OVERVIEW OF THE HYDRAULIC DESIGN APPROACH

Definition of the Hydraulic Design Approach

The hydraulic design approach has long been the standard fish passage design approach for culverts and *fishways*. Unlike stream simulation, the hydraulic design approach involves designing a structure for passage of targeted fish species and life stages by creating a hydraulic environment that is compatible with the fish's swimming and leaping abilities over a specified range of flows. The hydraulic conditions generally evaluated are water velocity, depth, turbulence, and drop height over weirs. The design objective is to achieve the desired hydraulic conditions at flows that the target fish are expected to move upstream. The range of stream flows is defined by the *low and high fish passage design flows*.

The hydraulic design approach focuses on providing passage of specific fish targeted species and life stages rather than providing unrestricted movement for the entire assemblage of fish and other aquatic organisms within the stream. This approach requires knowledge and understanding of the swimming and leaping abilities of the target fish and how they vary within the population, timing of upstream fish movement relative to season and stream flow, and behavioral issues that may affect passage. Because hydraulic designs have historically focused on passage of adult salmonids, there has been considerable research to guide development of design criteria for these fish. However, much less information is available for the hydraulic and hydrologic requirements for both juvenile salmonids and non-salmonid species.

Application of the hydraulic design approach is limited to situations where *ecological connectivity* is not a project objective. Some applications include:

- Retrofit of existing culverts with baffles
- Use of grade control structures, such as log weirs, rock weirs and roughened channels
- New or replacement culverts where physical limitations preclude use of other design options (i.e., stream simulation, bridges)
- Fishways, including fish ladders and roughened channels.

Although this design approach focuses on creating a suitable hydraulic environment for fish passage, considerations must also be given to the geomorphic impacts the design will have on the channel. Experience has found that culverts designed with the hydraulic design approach often fail to provide fish passage as intended due to unanticipated impacts to the downstream and upstream channel. For example, a culvert designed for passage of adult salmon or steelhead may still have outlet water velocities at high flows far greater than those found in the natural channel. As a result, a large scour pool may form that can cause the culvert to become *perched*, blocking fish.

Due to the shortcomings and limitations of the hydraulic design approach, it is generally not recommended for new or replacement culvert installations. When applying the hydraulic design approach to the retrofit of an existing stream crossing, it may not be possible to satisfy all fish passage design criteria. In these cases, fish passage improvements may be limited to a portion of the fish population.

Hydraulic Design Criteria

Projects that apply the hydraulic design approach for fish passage will often require, at a minimum, involvement of a fisheries biologist, hydrologist, and hydraulic engineer to establish appropriate design criteria and develop an acceptable hydraulic design. There can be significant errors and uncertainties associated with estimation of hydrology, hydraulics, and fish swimming speeds, which can be mitigated by making conservative assumptions in the design process. For example, a design based on the swimming abilities of the weaker individuals will improve passage for a greater portion of the population.

The design process begins with determining the fish species and life stages for which passage is desired. Once these target fish are identified, fish passage design flows and hydraulic criteria need to be established. For salmonids, these criteria should be based on the current CDFG criteria and NOAA Fisheries guidelines (CDFG 2002; NOAA 2001).

Fish Passage Design Flows

It is generally neither practical nor necessary to provide fish passage at all flows. For structures designed using the hydraulic approach, fish passage criteria should be satisfied within a range of *low and high passage design flows*. At the low passage design flow the objective is to provide sufficient water depth. At the high passage design flow the objective is to avoid excessive water velocities and turbulence.

When defining fish passage flows, the objective is to encompass the range of flows that fish typically move upstream based on an understanding of the life history of the target fish. For adult anadromous salmonids upstream movement is often associated with the timing of their spawning migration. For juvenile salmonids upstream movement may be associated with daily foraging or seasonal movement related to changing flow conditions, habitats and environmental stressors, such as overcrowding or declining water quality. The timing of movement may be seasonal or year-round.

CDFG (2002) criteria and NOAA (2001) guidelines recommend criteria for fish passage design flows for both salmonids and non-salmonids. Fish passage design flows should be selected with consideration for the hydrologic characteristics of the stream and sensitivity of the target fish to low-flow and high-flow delays in movement. The movement of some fish is more time sensitive than others. For example, adult salmon and steelhead often require higher flows to migrate upstream and spawn. If the fish encounters a culvert that presents a high-flow barrier, migration may be delayed for days. Such a delay can have a direct influence on the success of the fish to spawn, the location that it spawns, and the viability of its offspring. Conversely, a fish that moves daily to forage may only be minimally affected if upstream movement is blocked during high flows. Lang et al. (2004) discusses the considerations for developing fish passage design flows and explores the implications to migration delay when selecting design flows within the hydrologic regime of coastal northern California.

In coastal central and southern California, rainfall events are often more intense but less frequent than further north. The resulting flow patterns provide adult steelhead more limited opportunity to migrate up rivers and streams to spawn, warranting consideration of providing passage at higher flows than may be called for further north. A more appropriate high passage design flow for adult anadromous steelhead within these regions may be closer to the 2-year recurrence interval flow.

Water Velocity

Maximum cross-sectional average water velocity criteria for salmonids are provided in the CDFG (2002) criteria and NOAA (2001) guidelines. The water velocity criteria are conservative, and intended to provide passage for the smaller and weaker individuals within the population. The water velocity criteria are applied to the entire length of a culvert or other hydraulically designed structures that fish must swim through. The criteria generally do not apply to velocity over the crest of a baffle or weir because the distance over the crest is short.

Specific swimming performance data must be obtained when using the hydraulic design approach to provide passage of a non-salmonid species. The FishXing User Manual (USFS 2007) provides a well-referenced discussion on fish energetics and locomotion accompanied by a list of published studies on the swimming abilities of numerous fish species.

Hydraulic Drop Height

Whether a fish leaps over or swims up a hydraulic drop is based on physical and behavioral factors. The CDFG (2002) criteria and NOAA (2001) guidelines provide criteria for maximum hydraulic drop heights for passage of salmonids at culvert outlets. This is the vertical difference in water surface between the culvert outlet and downstream tailwater pool. Drops at culvert outlets should be avoided, but in cases of culvert retrofits, may be unavoidable. In these cases, the maximum hydraulic drop at a culvert outlet should not exceed the maximum drop heights listed in the CDFG criteria and NOAA Fisheries guidelines. To dissipate energy associated with the hydraulic drop and provide suitable conditions for salmonids to leap, depth of the receiving pool should meet CDFG criteria and NOAA Fisheries guidelines.

The hydraulic drop criteria also apply to drop structures. However, there is a distinct difference between drops at a culvert outlet and over a profile control weir. Unlike a culvert outlet, slower and deeper water is typically found both downstream and upstream of a weir, reducing the likelihood that the fish will be swept back downstream over the weir.

Boulder weirs create substantial hydraulic diversity (Ruttenberg 2007) resulting in better passage conditions than for more uniform profile control weirs. The diversity in drop heights, water velocities and depths, and flow patterns created by well-designed and constructed boulder weirs can provide good juvenile fish passage conditions. In some cases, they are allowed to have larger hydraulic drops than other types of weirs for juvenile salmonid passage.

For designs following the stream simulation approach the hydraulic drop criteria do not generally apply. Instead, the drop heights within the constructed channel should be similar to, but not exceed, those typically found in the adjacent natural channel.

For hydraulic designs that require passage of non-salmonid species, the leaping and swimming abilities of the target fish must be established. There are many non-salmonid species that do not leap and are unable to swim through steep hydraulic drops. If the leaping abilities of the target fish are unknown, hydraulic drops should be avoided.

Water Depth

Minimum water depth criteria are applied to culverts, roughened channels, and other hydraulically designed structures for fish passage. Water depth is the greatest depth in the channel or culvert cross section. Water depth criteria generally do not apply to depth over the crest of a baffle or weir because the distance over the crest is short. The CDFG (2002) criteria and NOAA (2001) guidelines provide minimum flow depth criteria for salmonids.

Minimum water depth criteria are generally intended to provide sufficient depth to fully submerge the fish (Powers and Orsborn 1985; Webb 1977). To ensure full submergence, water depth criteria is based on the body depth of the fish plus some additional depth to account for variability of fish within the population and other factors.

Examples of depth criteria for non-salmonids are given by the Vermont Department of Fish and Wildlife (VDFW 2007) and Maine DOT (MDOT 2002). Both recommend providing depths that are at least one and a half times the body depth of the fish. Minimum water depth requirements are typically based on the largest individual fish of the population. To estimate body depth, FishXing (USFS 2007) and FishBase (2008) provide relationships for body depth to total fish length for many species.

Turbulence

Turbulence is the rapid fluctuations in water velocity associated with energy dissipation and typically includes entrainment of air within the water column. Large amounts of turbulence can disorient and exhaust a fish, resulting in a passage barrier. Smaller fish, with their smaller mass and weaker swimming abilities, are more susceptible to turbulence. Although little research has been conducted regarding the effect of turbulence on juvenile salmonids, Powers (1997) documented a marked decrease in passage of juvenile coho salmon associated with increased turbulence along the walls of a corrugated metal culvert.

Avoiding excessive turbulence is generally a design consideration for pools below hydraulic drops, baffled culverts, and roughened channels. A common measure of turbulence in fish passage design is the Energy Dissipation Factor (EDF). This is the rate of energy dissipation within a volume of water. Although CDFG and NOAA Fisheries do no have specific EDF design criteria, this document provides some guidance and recommendations for evaluating turbulence in hydraulic design.

PROFILE CONTROL

Profile control covers techniques for steepening the channel profile. Approaches to controlling the channel profile can be used both downstream and upstream of replaced or removed barriers to control *headcutting* and channel *incision*, or to meet other channel and habitat restoration objectives. Profile control structures are also used to raise the downstream channel to the elevation of an existing culvert or other in-stream barrier to improve fish passage. See Project Profile Design (page XII-20) for examples of site conditions at stream crossings that warrant consideration of profile control in a *forced profile*.

Profile control options include one or a series of drop structures, roughened channels and profile restoration. Fishways can be considered an extreme example of profile control and are described in Fishways (page XII-107). Except in some cases of profile restoration, profile control involves constructing a length of channel steeper than its self-sustaining slope using *forcing features* constructed of materials that will remain stable. Saldi-Caromile et al. (2004) provide detailed description and design guidance for use of profile control structures.

Approaches for controlling the channel profile include:

- Profile restoration
- Roughened channels; rock ramps, mimicking natural steep channels
- Drop structures; rigid weirs, rock weirs and chutes, deformable drop structures.

These structures vary from semi-natural and diverse to rigid and uniform. They also vary in the hydraulic environment they create, the degree and certainty of passage provided, the range of applicable slopes, structural durability, and construction materials.

Siting of Profile Control Structures

When profile control structures fail, it is commonly by scouring either under or around the end of the structure. Keys to a good design include consideration of overall slope, planform and cross section geometry, embedment and bank keys, and ballasting of buoyant materials.

Profile control structures are best suited for relatively straight channel reaches. Placement of profile control structures within a meander or channel bend increases the risk of flanking, bank erosion, or scouring around the end of the structure. In un-entrenched channels and streams with erosive banks the elevated water level upstream of a profile control structure further increases the risk of channel migration and flanking. Lateral migration of the channel can lead to poor alignment with the structure, potentially creating adverse entrance or exit conditions for fish passage.

When placed in a reach containing a gradual bend, structures should be oriented and shaped to turn the flow away from the outside bank and towards the downstream channel. This can reduce erosion along the outside bank and decrease the risk of flanking.

Channel adjustment at the transition between the profile control structure and the downstream natural channel is an important and often overlooked part of the design. Extending the project past the last control structure will help prevent downstream scour and potential failure. Saldi-Caromile et al. (2004) and Mooney (2007) summarize methods and equations for predicting scour below various types of profile control structures.

Increased water depth, velocity and turbulence generated by the structure are often carried to the downstream channel, causing scour of the bed and banks. If not accounted for in the design, this scour can form an excessive drop at the end of the profile control reach, creating a fish barrier and increasing the risk of failure. A pool at the downstream end of the last structure is often needed to dissipate this energy and prevent downstream erosion. If no pool is available naturally below the profile control structure, it should be constructed or expected to develop. The profile control should be extended downstream to accommodate such a pool (Figure XII-20). In a stable channel, the downstream end of any profile control structure is often placed at or below the grade of the existing channel to accommodate a pool.

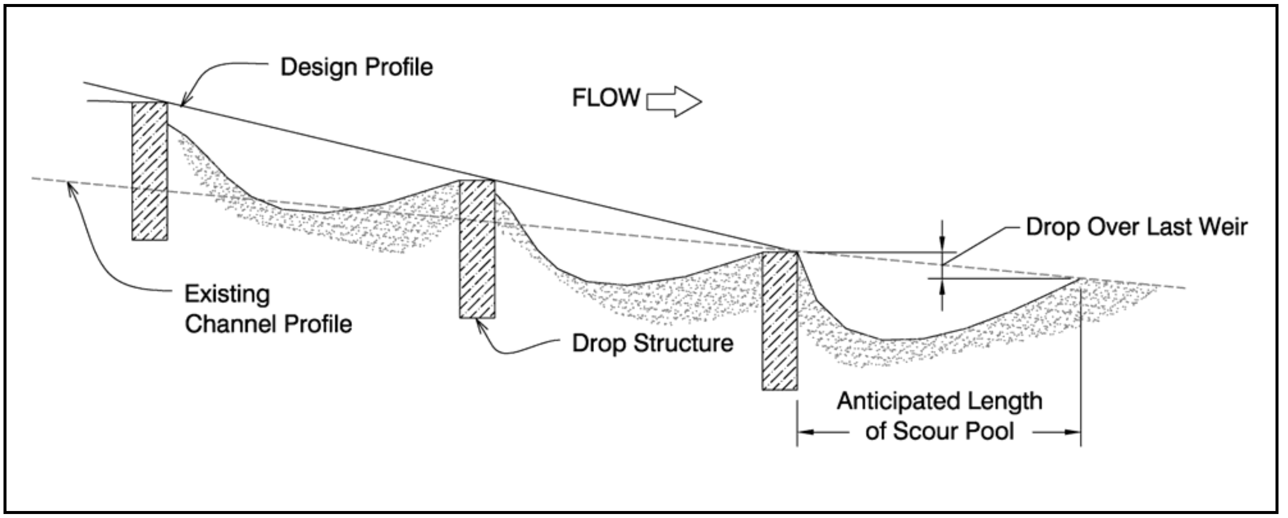


Figure XII-20. Downstream-most profile control structure is placed at or below existing channel grade to ensure the drop formed by the resulting scour pool does not become a barrier.

If the cross sectional shape of a profile control structure constricts flow more than the downstream channel, the drop at the downstream transition may increase with increasing flow. To account for this, the drop at the last structure should be less than the maximum drop for fish passage. A hydraulic analysis can assist in evaluating the drop height at the low and high fish passage flows.

If the channel is unstable with the potential for some downstream incision, the transition of the profile control structure should be designed based on the future bed elevation and the vertical adjustment potential. Identifying a downstream point in the channel that is stable and unlikely to experience future incision may assist in determining the ultimate stable channel profile. A geomorphic characterization of the downstream channel stability and potential for post-project channel incision should be conducted during the pre-design phase of the project (Pre-Design page XII-4).

Profile Restoration

The US Forest Service (USFS 2008) describes channel restoration as the re-establishment of structure, grade, and function to the stream with the goal of achieving a self-sustaining channel at an appropriate grade to meet fish passage and/or other objectives. Restoring the profile of the channel might include re-grading or realigning the channel to restore the historical profile, channel length, and meander pattern. Profile restoration, by definition is the most natural profile control approach. However, physical changes within the stream and watershed may prevent profile restoration from being self-sustaining.

Channel incision frequently leads to vertical drops at hard structures within the channel, such as culverts, bridge aprons, and pipeline crossings. Profile restoration should be considered for projects to address the effects of an incised channel. The opportunity for profile restoration should be identified in the pre-design phase. Benefits of this technique may go far beyond passage of aquatic organisms. Restoring the historic profile might restore in-stream, riparian and floodplain habitats, improve channel-floodplain interactions, reconnect side-channels, reverse bank erosion, and reduce sediment delivery from bank and bed erosion. It can also eliminate any effects of a headcut, if it were to be allowed to occur.

Profile restoration projects often need to extend a long distance downstream, requiring cooperation and involvement of multiple landowners. The larger project scale may slow implementation and make profile restoration the most expensive alternative. However, profile restoration is likely more self-sustaining than other options. Profile restoration might be accomplished over time by building structure and roughness into the channel as part of the project and then allowing natural sediment deposition to raise and reconstruct the channel.

There are a number of valuable design references for channel restoration. For an introduction to the process of channel restoration see FISRWG (2001). Specific details for design of channel restoration projects are included in Saldi-Caromile et al. (2004).

Roughened Channels

Roughened channels, sometimes referred to as nature-like fishways, are constructed channel reaches stabilized with an immobile framework of large rock mixed with smaller material. Roughened channels provide fish passage by controlling the channel profile and adding roughness and structure to it. By design, they create hydraulic diversity that emulates conditions found in steeper or confined natural channels. Unlike individual rock weirs used to control the channel profile, the bed framework forming a roughened channel creates a continuous stable channel structure that is able to flex and move slightly while continuing to function as intended. Unlike stream simulation, a roughened channel is designed with an immobile bed and is not necessarily based on a reference reach in the same channel. Roughened channels are designed using the hydraulic approach.

Roughened channels have a wide variety of fish passage applications. Most common are providing profile control in conjunction with existing or replacement stream crossings and passage over or around low-head dams and other types of drop structures.

They can be constructed inside or outside of culverts. When constructed inside culverts they are usually limited to replacement installations because existing culverts rarely have the necessary width and capacity to accommodate the additional bed material. A common application of roughened channels is where the channel has to be steeper than a reference reach so stream simulation cannot be used.

> Roughened channels should only be used at stream crossings when other more preferred approaches, such as stream simulation, are not feasible.

Common configurations of roughened channels include rock ramps spanning a part or the entire width of the channel, step-pool or cascade-pool sequences, and bypass channels around dams or drop structures. These are similar to the fishway layouts described in Fishway Layout (page XII-110). Although short segments may be steeper, overall slopes of roughened channels commonly range between 3% and 5%, which are within the range of channel slopes that salmonids traverse in natural systems.

When designed and constructed properly, the hydraulic diversity created by the bed and banks of a roughened channel creates a broad range of depths, velocities and turbulence within any given cross section and over a wide range of flows. This hydraulic environment provides many pathways for smaller and weaker swimming fish, including along the margins of the channel. Although roughened channels are treated as hydraulic designs aimed at passage of target fish (Calles and Greenberg 2005; Bates 2003), the hydraulic diversity allows for passage of weaker swimming non-target aquatic species. For example, studies of roughened channels in other regions have documented successful passage of minnow, chub, roach, larval stages of lamprey and a host of cyprinid species (Beatty et al. 2007; Calles and Greenberg 2007; Santos et al. 2005).

In addition to providing upstream and downstream passage of aquatic organisms, roughened channels are generally efficient at passing high flows, wood and sediment. Similar to stream simulation designs at stream crossings, roughened channels placed inside culverts can include banklines that provide a passage corridor for semi-aquatic and terrestrial animals.

Although roughened channels have been widely used in other regions for a number of years, they are relatively new to California, and the design methods outlined in Part XII have not been extensively tested. Implementation and effectiveness monitoring is especially important given the experimental nature associated with roughened channels. Through monitoring and experience, these design and implementation procedures will likely continually improve to better meet objectives.

Roughened Channels as Profile Control

Although many different types and configurations of roughened channels have been constructed, Part XII focuses primarily on design of full spanning roughened channels for profile control that mimic the morphology of natural channels with slopes similar to the designed project profile. Unlike stream simulation, a “nature-like” roughened channel has a different slope and morphology than the adjacent channel. Though the structural design of steep stream simulation channels may be the same as for roughened channels, roughened channel morphology is out of context with the adjacent channel, and not considered stream simulation.

While this section focuses on using roughened channels for profile control, the general design methods and procedures described may apply to other applications as well. Some of the methods described can apply to design of stream simulation crossings in naturally steep streams, as discussed in Geomorphic Designs at Stream Crossings (page XII-28). Other roughened channel applications, such as bypass channels around dams, are discussed in the Fishways (page XII-107).

Geomorphic Features and Channel Arrangements

The geomorphic characteristics of natural channel types, along with hydraulic fish passage design criteria for water depths and velocities, turbulence, hydraulic drops and minimum pool depths, can be used to guide design of a roughened channel. Montgomery and Buffington (1997) developed a channel classification system based partially on channel bed morphology. Based on their classifications, channels with slopes between 1.5% and 3% most frequently have a plane-bed morphology, which is characterized by a lack of repeating bedforms (i.e., pool-riffle). At the upper slope limit for plane-bed channels, the bed material is often cobble dominated mixed with large boulders, often referred to as a run or rapid.

Channel slopes between 3% and 6.5% are most likely to have step-pool morphology, with steeper channels having a cascade morphology. Both step-pool and cascade channels have bed and banks consisting of large material that is highly resistant to erosion. This large bed material forms structural diversity and governs geomorphic characteristics of step-pools and cascades, such as pool size and spacing and channel width and slope. The bed material in these high gradient streams is relatively immobile, with the largest bed material becoming mobile only during very infrequent (i.e., 50 to 100 year) flow events (Chin 1998; Grant et al. 1990).

A roughened channel can only approximate the characteristics of a plane-bed, step-pool or cascade channel. Individual rocks are expected to adjust position but the larger rocks are sized to be stable and not move out of the roughened channel reach. The bed material must remain fixed because, unlike stream simulation, if a rock within the roughened channel becomes mobile it will not be replaced by natural recruitment.

The *active channel* in a roughened channel lies between the banks, and is sometimes referred to as the channel bottom width. An active channel with gradually sloping triangular or trapezoidal cross sectional shape creates hydraulic diversity that persists with changes in flow and stage (Figure XII-21). These channel shapes concentrate lower flows to provide deeper water in the center, and shallow, slower flow along the margins that persists, even with changes in stage. This edge zone produces suitable conditions for smaller, weaker swimming fish such as juvenile salmonids and non-target aquatic species as well as a wet margin possibly for semi-aquatic and non-aquatic species. Trapezoidal channel shapes are generally used for larger streams because they have a greater capacity and require more flow than a triangular cross section at the same depth.

The active channel width should be similar to the width of the adjacent natural channel. Excessive concentration of flow towards the channel center can create an unstable channel bed. To maintain shallow flow along the margins for weaker swimming fish, it is best to design the active channel to become fully wetted at roughly the high passage design flow for resident trout (5% annual exceedance flow). Generally, a water depth of less than two feet deep is achieved when the active channel becomes fully wetted. Steep cross-channel slopes can cause an excessive concentration of flow, which can destabilize the bed material.

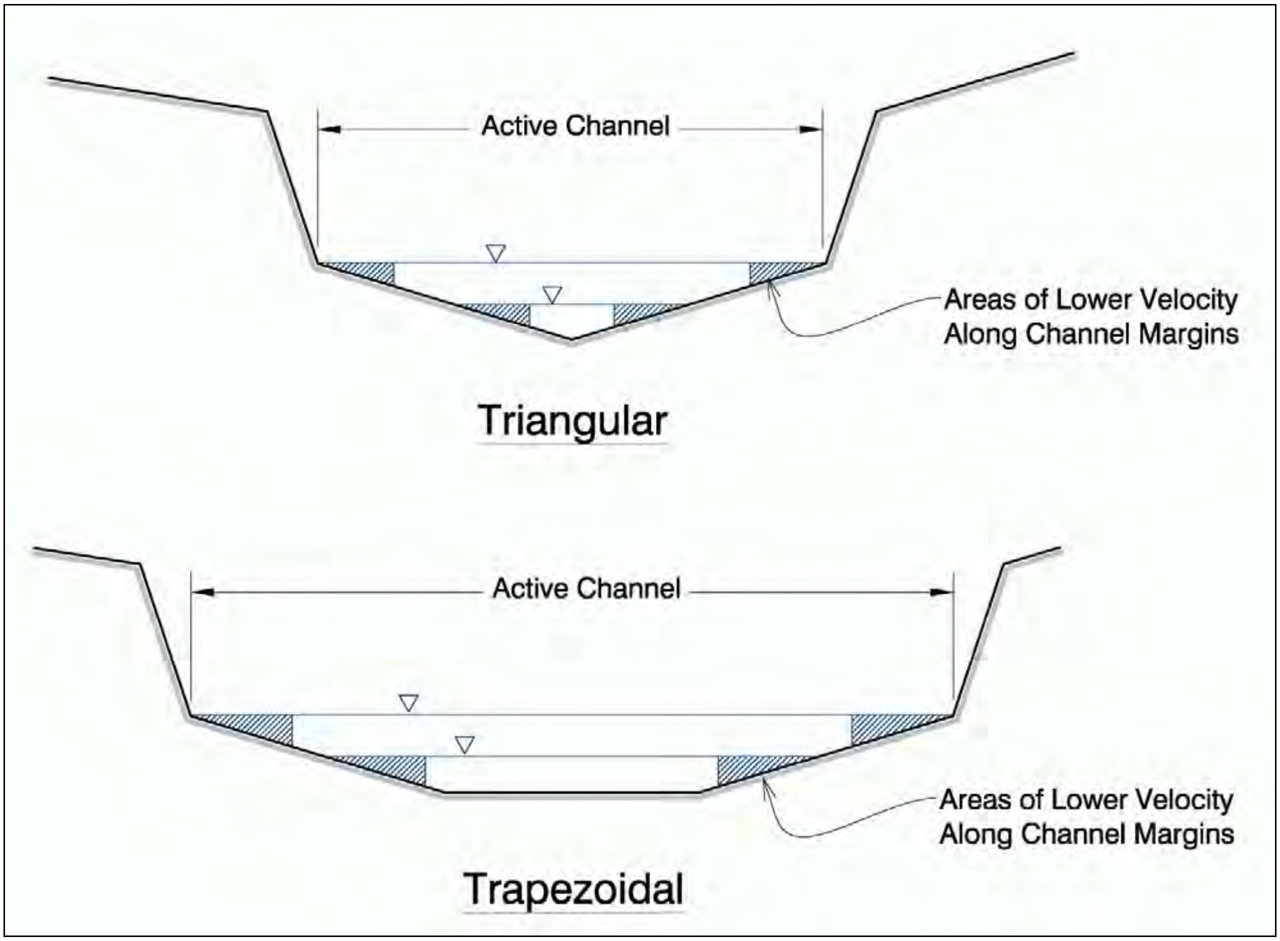


Figure XII-21. Triangular and trapezoidal shaped active channels provide slower water velocities and damp zones along the channel margins where smaller fish can swim through. A trapezoidal channel will require more flow to achieve the same depth as a triangular shaped channel.

<u>Streambed Material</u>

The bed material used in construction of a roughened channel is referred to as the *engineered streambed material* (Figure XII-22). Placed within the active channel, it consists of a *well-graded* mixture (diversified particle sizes) of material designed to be immobile up to the *stable bed design flow*, the flow threshold at which the large framework rock is designed to remain stable. When constructed as part of a new or replacement stream crossing, the stable bed design flow is frequently the same as the *structural design flow* for the crossing (e.g., 100 year flow). Unlike typical riprap sizing, engineered streambed material includes particle sizes ranging from large stable rock to fine sands and silts. The larger portion of rock ($\geq D_{50}$) is sized using standard riprap sizing methods for predicting stable particle sizes. Structure designed into the bed, such as steps, are built using the largest material in the gradation (D_{84} to D_{100}). Smaller material fills the voids between the larger rock and controls porosity to avoid excess subsurface flow. The bed mixture should include between 5% and 10% fines (sands and silts), similar to the bed material gradation in a natural channel. Sizing the Engineered Streambed Material (page XII-67) provides a suggested design procedure for developing the size, gradation, and thickness of the engineering streambed material, including the gradation of smaller particles ($\leq D_{50}$) in the mixture.

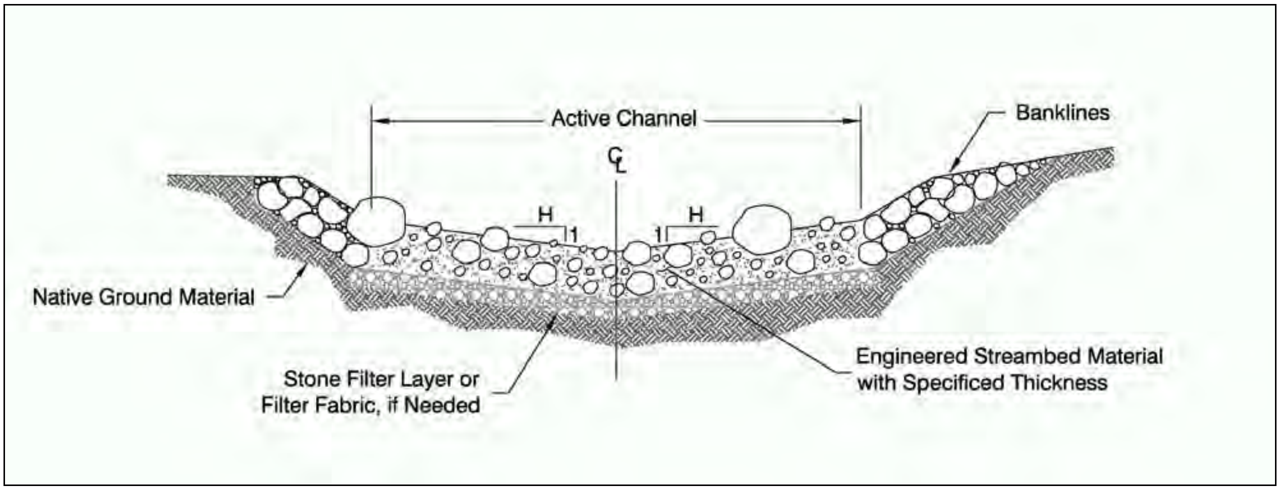


Figure XII-22. Typical cross section of a roughened channel with engineered streambed material and banklines.

Banklines

Banks of the roughened channel run along the edges of the active channel. As in natural step-pool and cascade type streams, banks are composed of material resistant to scour. The banks of the roughened channel should be well-graded, with both large immobile rocks as well as smaller material that fills the voids and prevents *piping*. Banklines should be irregular in shape to provide additional roughness and hydraulic complexity. Designs can include large rock embedded into the banks to create slight channel constrictions.

Banklines typically are composed of smaller rock than the active channel because the banks are subject to lower velocities. The toe of the bank typically experiences higher scouring forces than further up the bank. Therefore, the largest rock forming the bankline is often placed along the toe of the bank. Like naturally steep channels, banklines typically contain flows up to the 2-year flow, and often much higher flows. The height of armoring on the bankline should be adequate to prevent scour. This depends on site-specific factors, including water depth, velocities, shear stress on the banks, erosive potential of the native soils, *entrenchment* of the channel, and risk of flanking at the stable bed design flow. Bankline Rock (page XII-71) provides some guidance on sizing rock for banklines. Opportunities to use bioengineering techniques to limit the height of the bankline rock should be considered. Inter-planting the bank rock with vegetation should also be considered as a habitat mitigation feature (Fischenich 2001b) (McCullah and Gray 2005).

Bedform

The *bedform* morphology of the roughened channel profile can vary, depending on its length and slope, the characteristics of the adjacent natural channel, and project goals and objectives. In general, the more a roughened channel's slope and bed material diverges from the characteristics of the adjacent natural channel, the more risk and uncertainty involving channel stability and fish passage.

The following sections describe bedform morphology for different roughened channel types. They include rock ramps, chutes and pools, step-pools and cascade and pools. In general, when a roughened channel extends in length for roughly five or more channel widths, it is recommended that a large pool be added to break up the reach and aid in dissipating energy. Each reach of steep channel and pool combination is referred to as one sequence. Table XII-1 lists each channel type and their recommended slope ranges. There is not always a clear distinction among these bedforms in nature.

Bedform	Overall Roughened Channel Slope	Recommended Maximum Elevation Drop Across Roughened Channel
Rock Ramps	$\leq$4.0%	5 feet[1]
Chutes and Pools	$\leq$4.0%	2 feet per Sequence
Step-Pools	3.0-5%	5 feet per Sequence[2]
Cascade and Pool	4.0-6.5%	5 feet per Sequence

Table XII-1. Recommended range of overall design slopes and maximum elevation drops for various roughened channel bedforms.

[1] Larger drops across the roughened channel require breaking up the reach with large pools.
[2] A step-pool sequence may include multiple steps; four or five steps per sequence are common.

Much of the design guidance for roughened channels is based on the characteristics of natural channels. There is some risk in using a natural channel as a template for design of a channel that is intended to be stable, if not rigid. Natural channels have evolved over decades if not centuries and have been formed by a history of flow events likely including some extreme flows. Even the best design and construction practices cannot duplicate the structure and hydraulic sorting and particle done in nature. Consider the slope, spacing, and rock sizing describe as natural limits. Mitigate any risk and uncertainty by designing conservatively relative to those limits.

Rock Ramps

Rock ramps are continuous roughened channels constructed at a constant slope with no large structural bedforms (e.g., steps, pools). Rather, random large rocks (D_{50} to D_{100}) in the engineered streambed material create hydraulic roughness and diversity. Morphologically, rock ramps are similar to *plane-bed channels*, which lack repeating bedform patterns (Montgomery and Buffington 1997). The largest rocks are substantially smaller size than bankfull depth, which differentiates them from cascades. Rock ramps are often limited to slopes less than 4% and are best for overcoming elevation differences of 5 feet or less. Higher and longer rock ramps may be less stable due to the potential for increasing water velocities in the downstream direction. Additionally, the risk of creating an exhaustion barrier to fish increases as the ramp length increases. To overcome larger elevation differences, rock ramps can be interspersed with large pools to form a sequence of chutes and pools or small pools can be scattered within rock ramps.

Rock ramps and chutes rely on the swimming, rather than leaping, abilities of the fish, making them better suited for passage of fish species and life stages that have poor or no leaping abilities.

However, to achieve adequate water depth for fish passage, a sufficient amount of flow is required, which limits their application. In streams with very low base-flows, rock ramps and chutes may not be able to provide adequate water depth for fish passage during low flows. This concern is increased with increasing slope, channel width, and the likelihood of significant subsurface flow.

Chutes and Pools

A chute and pool channel consists of a short rock ramp subunit followed by an armored pool subunit. The bed structure of this repeating sequence dissipates energy through a combination of hydraulic roughness across the chute and the volume of the pool below the chute. Chutes and pools are recommended in lieu of rock ramps when the roughened channel is long or when the unit discharge (flow in channel divided by active channel width) is high. The recommended maximum overall slope for rock chutes and pools is 4% for small and moderate-sized streams, with the slope of the chutes greater than 4% and no slope across the pools. The drop across a ramp/pool sequence is typically limited to two feet to adequately dissipate the flow's energy. A small drop also typically causes each chute to submerge the crest of the next upstream chute during larger flows, drowning-out the lower portion of the chute. At high flows, greater than fish passage flows, the water surface slope across the chute becomes roughly equivalent to the overall slope of the chute-and-pool sequence rather than the steeper slope of the chute, thus reducing scouring forces on the chute.

The chute is typically constructed with a rock band at the upstream and downstream ends of the chute. A rock band consists of a row of large rock, two rocks deep, similar to a rock weir in design and construction (Rock Weirs and Rock Chutes page XII-83). Engineered streambed material (ESM) is placed between the rock bands. Both the bands and the ESM are V-shaped in cross section to concentrate flows towards the center of the channel and make for shallower and slower flow along the channel margins.

The bed of the pools typically consists of ESM, making them resistant to erosion and controlling the depth and length of the pool. Alternatively, the channel can remain unarmored between chutes, allowing pools to scour and form within the native ground. In this case, the chutes function as individual drop structures and the overall grade of the chute and pool sequence is typically limited to 2.5%. See Rock Chutes (page XII-88) for use of chutes as individual drop structures.

Step-Pools

A roughened channel can be designed to simulate a step-pool channel. Natural step-pool channels typically occur at channel slopes between 3.0% and 6.5%, but can be found in lower and higher sloping channels (Montgomery and Buffington 1997). Steps are ribs across the channel composed of boulders, logs, or bedrock. Water plunges over each step and into pools formed between steps. This bedform dissipates the stream's energy as water flows over the step and plunges into the receiving pool. The pools are armored and resistant to scour and erosion. Step-pool channels are generally highly confined and the stream banks are relatively rough and resistant to scour.

In design of a step-pool roughened channel for use as profile control, characteristics of natural step-pool channels should be emulated. For this application, focus on step-pool channels formed by boulders and large cobbles. Numerous studies have described spacing between steps or pools as exhibiting a rhythmic pattern related to channel width, slope, and particle size. These relationships, along with fish passage design criteria for hydraulic drops and minimum pool depths, can be used to guide design of a step-pool roughened channel. Figure XII-23 illustrates some common dimensions used to describe the step-pool bedform.

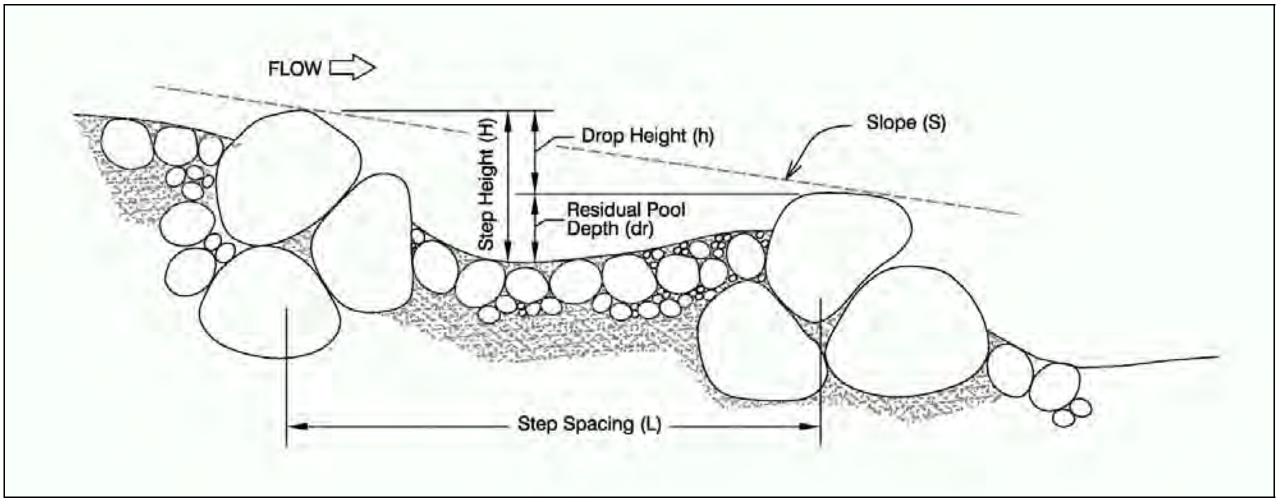


Figure XII-23. Dimensions used to describe a step-pool channel in profile.

Spacing between steps frequently ranges between 0.5 and 2 channel widths, with spacing becoming closer with increasing channel slope (Grant et al. 1990; Chin 1999; Chartrand and Whiting 2000). A relationship that is widely used to describe the rhythmic step-pool pattern, and that can be applied to the design of a step-pool roughened channel, is the ratio of H/L/S. The step height (H) is the sum of the drop between steps (h) and the residual pool depth (d_r). Zimmerman & Church (2001) reported that the ratio ranges between 1 and 5 for step-pool channels, and at slopes of 4% and less, generally between 2% and 5%.

The step height (H), as measured from the maximum depth of the pool to the top of the step, is closely related to the size of the particles forming the step (Chin 1999; Chartrand and Whiting 2000). Based on this work, the average or median rock size forming the step is roughly equal to the step height. Natural channels with steps composed of rocks on the order of one meter (3.3 feet) have been found to be extremely stable (Chin 1998). Additionally, the size of the larger rock forming the step is commonly between 0.5 and 1.0 times the bankfull channel depth, with bankfull depth measured at the step (Church and Zimmermann 2007; Montgomery and Buffington 1997).

The step-pool channel unit can be built at slopes between 3% and 5%. Because water often accelerates as it flows down this type of channel, the recommended maximum overall drop across a series of steps is 5 feet. If larger drops must be overcome, it is necessary to breakup steep step-pool reaches with large pools to dissipate accumulating energy.

<u>Use of Large Pools</u>: Grant et al. (1990) and others describe a step-pool channel composed of two subunits. One subunit is a series of tightly spaced boulder steps interspersed with small "pocket" pools (Figure XII-24). At the bottom of the series of steps is a large pool subunit. At high flows, water accelerates as it moves down the steps, and the large pool at the bottom of steps then

dissipates the flow's energy and slows the water. The large pool also provides holding habitat for fish during high flows, when the smaller pools are too turbulent.

Grant et al. (1990) found the spacing of the large pools, as defined in Figure XII-24, averaged between 2 and 4 channel widths, and the large pools with lengths of at least one channel width. The spacing between individual steps ranged between 0.4 and 0.8 channel widths, and the slope of steps subunit was between 5% and 6.5%. This type of channel sequence can be used to construct a roughened channel with an overall slope as steep as 5%. The large pool subunit should be constructed with no slope and the overall drop between the large pools should not exceed 5 feet. This repeating sequence of closely spaced steps with pocket pools followed by a large pool can aid in dissipating energy and should be considered when designing roughened channels that extend in length for five or more channel widths.

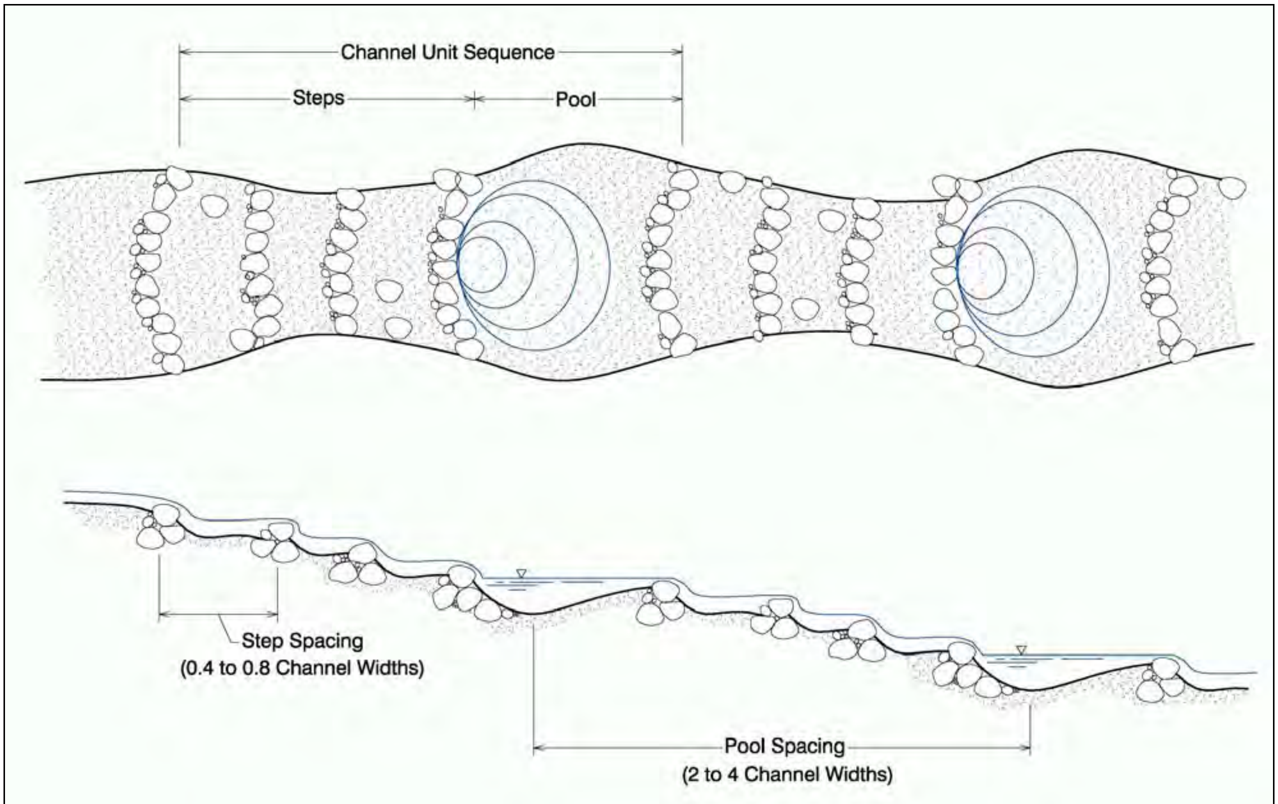


Figure XII-24. Step-pool channel sequence that includes larger pools every 2 to 4 channel widths, as described by Grant et al. (1990).

Cascade and Pool

Natural cascade channels are steep channels characterized by large roughness elements relative to the water depth and without repeating bedforms (Montgomery and Buffington 1997). They are most likely to have natural slopes greater than 6.5%, but have been observed in channels with slopes as low as 4.5%. Cascade channels contain small, partially channel-spanning pools spaced less than one channel width apart. The channel bottom is relatively flat. Large keystone rocks that are essentially immobile are found randomly throughout the active channel, with many of them located near the center of the channel. The size of the keystone rocks are close to or exceed the channel's bankfull depth. Their large size relative to the channel creates flow constrictions and retains smaller boulders and large cobbles to form complex steps at lower flows. The hydraulics of a cascade is characterized as jet-and-wake flow; water is constricted between, and flows over, the large bed material in the form of jets. The jet (supercritical flow) then enters the small receiving pool, forming a wake (hydraulic jump).

A cascade, as described above, can be used as bedforms for roughened channels. This type of bedform is best suited for profile control in stream reaches that are already steep (> 3%), and have relatively coarse bed material and confining banks.

> Constructed cascades are only suitable for relatively straight channel reaches that are highly confined, with floodplains that are small or nonexistent.

Given the steep slope and tendency for water to accelerate as it flows down a cascade, larger pools must be placed between short cascades to dissipate excess energy and provide holding areas for fish. The repeating cascade and pool sequence is very similar to the steps and pool sequence shown in Figure XII-24 and the unit sequence described by Grant et al. (1990). Pool spacing should not exceed 2 to 4 channel widths. To maintain suitable fish passage conditions, the cascades should not have a slope greater than 8% and the overall slope of the cascade and pool should not exceed 6.5%.

Unlike the channel spanning water surface drops created in a step-pool channel, the rocks in a cascade and pool roughened channel should create a complex series of smaller drops that effectively dissipate energy and provide fish with numerous pathways to swim upstream. Some approaches include creating constrictions with keystone rocks to create a hydraulic drop and backwater pool, or arranging rock structures to form multiple drops (Figure XII-25). During design and construction, care should be given to avoid creating situations where the drop criterion for fish passage is exceeded.

The cascade roughened channel is considered to be experimental. It is uncertain if young-of-the-year (YOY) salmonids will be able to ascend a constructed cascade, although a previous study found YOY coho ascending a 5.7% step-pool and cascade channel during summer low flows (Kahler et al. 2001). If passage of YOY or other weaker swimming fish species is a project objective, it may be necessary to develop a study plan to verify that adequate upstream passage is being provided.

At some sites there may also be concern for holding capacity for adults under low flows. If a cascade can not provide deep holding pools such an approach may not be appropriate for the site.

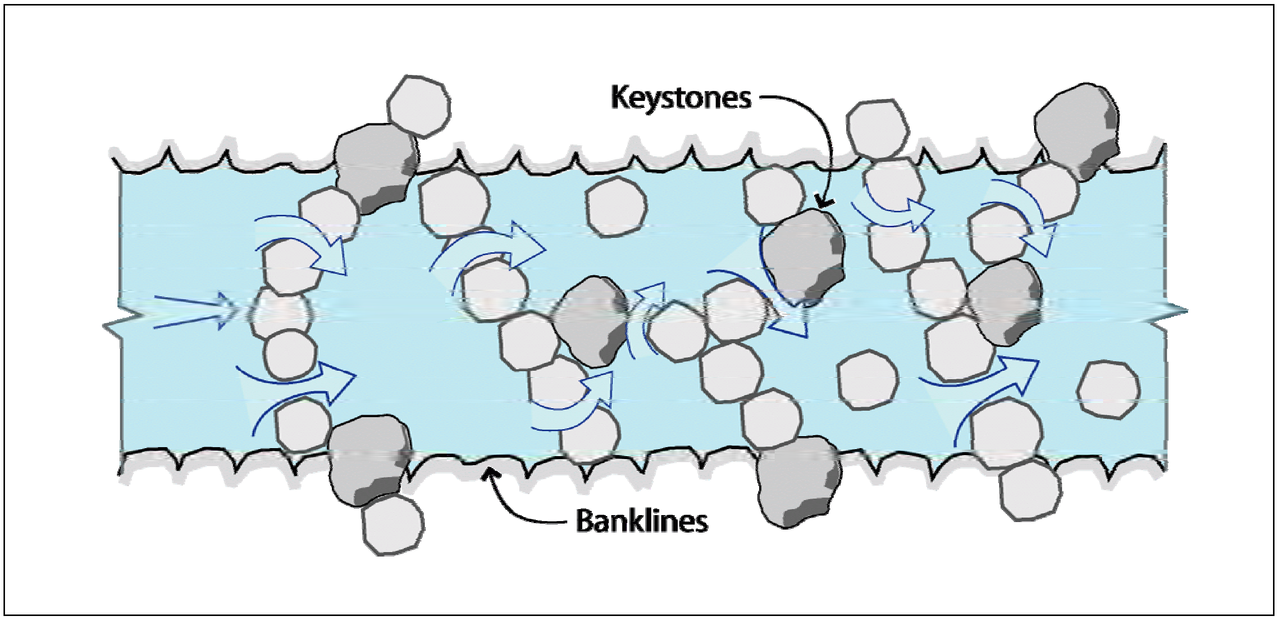


Figure XII-25. Cascade subunit of a cascade and pool channel. The cascade is a complex series of small steps form numerous pathways for fish to swim during lower flows while creating a rough cascade at higher flows.

Sizing the Engineered Streambed Material

Engineered streambed material that forms the bed of a roughened channel has two components: large rock that forms a framework and smaller material that fills the interstitial voids in that framework. The framework of larger rocks is the immobile component of the channel, and maintains the channel shape and profile. The framework rock is sized to be stable up to the *stable bed design flow*, with small adjustments in rock position expected at lower flows. Smaller interstitial materials fill the voids between the framework, minimizing the overall porosity of the streambed, maintaining surface flow, increasing stability and reducing the risk of *piping*. Together, they form a *well-graded* mixture with no gaps in the sediment gradation curve.

The following sections present a method for determining the size and gradation of both the framework and interstitial material that comprises the engineered streambed material. The bed sizing methods discussed applies to all types of roughened channels.

Framework Sizing Equations

This section presents a method for sizing the stable framework of the engineered streambed material (ESM). The framework is defined as the largest 50% of the ESM (D_{50} to D_{100}). There are numerous methods for sizing rock to remain stable in steep sloping channels (Mooney 2007; Maynord 1994; Abt et al. 1986; Abt et al. 1988; Abt and Johnson 1991; Ferro 1999; Costa 1983; Robinson 1998; ACOE 1994). These methods are primarily based on unit discharge in the channel, with many of them derived from shared data sets and yielding similar results. Differences among methods are primarily related to inclusion of coefficients for safety factors, rock thickness, gradation, angularity, and flow concentration.

The method described in this section uses the ACOE (1994) rock sizing equations as a foundation for developing the gradation of stable rock in a roughened channel design. The methods and equations for rock sizing provided in the *Hydraulic Design of Flood Control Channels* (ACOE 1994) are suitable for a wide range of applications and include sizing of rock for steep channels and chutes. It is important to review the original publication before applying methods outlined in this section.

ACOE (1994) presents the following equation for sizing rock for rock chutes with slopes greater than 2%:

$$D_{30-ACOE} = \frac{1.95 S^{0.555} (1.25 q)^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$ **Equation XII- 1**

Where:

- $D_{30\text{-ACOE}}$ — D_{30} stable particle size based on rock gradation provided in ACOE 1994 (ft)
- S — Hydraulic slope (ft/ft)
- q — unit discharge within the active channel at the stable bed design flow (cfs/ft)
- g — gravitational acceleration (32.2 ft/s^2)

Included in the equation is a flow concentration factor of 1.25 to account for failures induced by concentration of flow between individual grains. The equation was derived in a conditions of low unit discharge in straight riprap channels with slopes ranging from 2% to 20%. The riprap was angular and had a relatively uniform gradation, a layer thickness of 1.5D_{100} and banks with side slopes of 2.5H:1V.

Unit discharge (q) used in predicting the stable rock size for the channel bed is defined as the amount of flow within the channel ($Q_{Channel}$) at the stable bed design flow divided by the width of the active channel (b) (Figure XII-26). Overbank flow ($Q_{Overbank}$), if present, should be subtracted from the total flow for calculation of unit discharge. This will require a hydraulic analysis. For the initial design, a uniform flow cross sectional analysis is generally sufficient. A backwater analysis (i.e., HEC-RAS) may be necessary to finalize the design.

For the stability and associated hydraulic analyses, the overall roughened channel slope is generally used in the initial analysis. For roughened channels with compound slopes of chutes and large pools, the chutes are typically drowned-out during large flood events. The result is a water surface slope that approximates the overall channel slope. However, the highest shear stress on the channel may not be at the stable bed design flow, but rather at a lower flow when the water surface slope over the chutes is steeper. Before finalizing the design, a backwater analysis should be performed to validate the water surface slope and unit discharge used for sizing of the engineered streambed material.

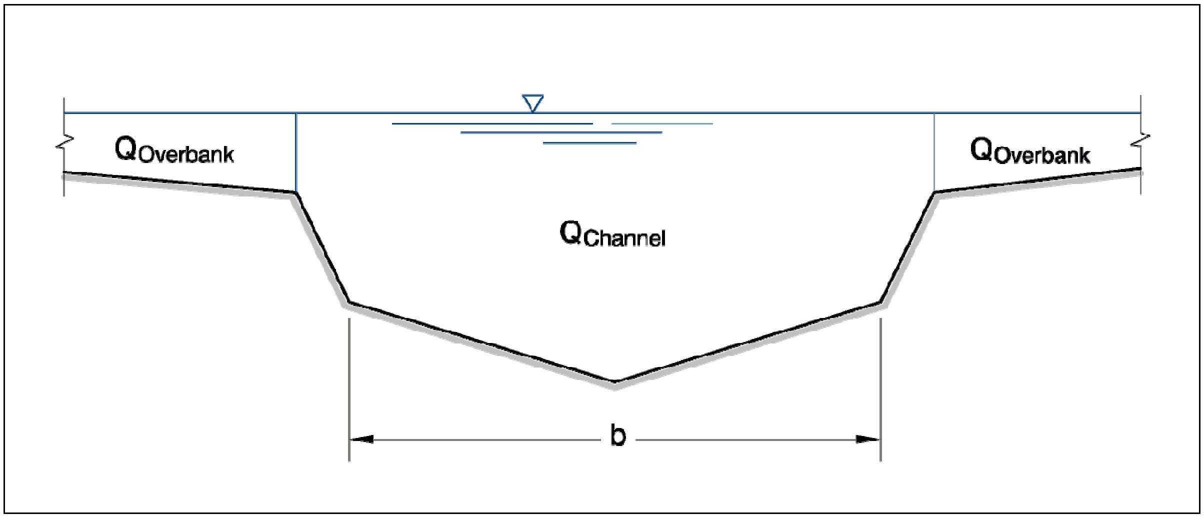


Figure XII-26. Unit discharge for analyzing particle stability is calculated using the flow within the active channel divided by the width of the active channel ($q = Q_{Channel}/b$). Overbank flow is not included.

The ACOE (1994) method produces a relatively uniform gradation, with D_{85}/D_{15} ratios ranging from 1.7 to 2.7. The result is a very porous mixture of similarly sized rocks, with voids composing as much as 30% to 35% of the volume (CalTrans 2006). The uniform gradation causes subsurface flow during low flows, creating unsuitable conditions for fish passage. Conversely, streambed material in a natural channel is characterized by a wide gradation of material sizes, with smaller material filling the voids between the larger particles. The ratio D_{85}/D_{15} in a natural steep channel is commonly between 8 and 14 (Bates et al. 2003; Montgomery and Buffington 1997; Grant 1990).

To achieve a stable bedform while filling the interstitial voids, Bates et al. (2003) recommends the $D_{30\text{-}ACOE}$ for a uniform riprap gradation be scaled by 1.5 to achieve a suitable D_{84} for the engineered streambed material (ESM) in a roughened channel:

$$D_{84\text{-}ESM} = 1.5\ D_{30\text{-}ACOE}$$

The $D_{50\text{-}ESM}$ (50 percentile particle in the ESM) and $D_{100\text{-}ESM}$ can then determined based on ratios derived from bed material within natural channels (Bates et al. 2003):

$$D_{50\text{-}ESM} = 0.4\ D_{84\text{-}ESM}$$

$$D_{100\text{-}ESM} = 2.5\ D_{84\text{-}ESM}$$

These ratios are within the ranges found in steep boulder and cobble bedded streams (Bathurst 1978, 1987, 1985; Thorne & Zevenbergen 1985; Jarrett 1984; Simons & Senturk 1992; and Limerinos 1970).

The ratios provided above for sizing the $D_{100\text{-}ESM}$ should be viewed as guidance, and may need to be decreased in some cases. In step-pool and cascade channels, as the D_{84} increases in size the D_{100} to D_{84} ratio has been observed to decrease. It is also important to avoid having rock that is disproportionately large relative to the channel width. Generally, the largest rock should not be greater in size than one-quarter of the active channel width. Otherwise, the channel may become constricted excessively, causing undesirable hydraulic conditions.

Filling Interstitial Voids to Control Porosity

The material smaller than D_{50} serves to fill the interstitial voids between the larger rocks. Material smaller than the D_{50} can be sized using a modified version of the Fuller-Thompson equation, as described in USFS (2008). This method is used to form a high-density mixture comprised of between 5% and 10% of fine particles (sands and silts) less than 2 mm in size to seal the bed and control permeability. The Fuller-Thompson equations rearranged to find the D_{16} and D_8 relative to the D_{50} are:

$$D_{16-ESM} = 0.32^{\frac{1}{n}} D_{50-ESM} \qquad \textbf{Equation XII- 2}$$

$$D_{8-ESM} = 0.16^{\frac{1}{n}} D_{50-ESM} \qquad \textbf{Equation XII- 3}$$

To develop the design particle-size distribution curve, an n value between 0.45 and 0.70 is recommended. These are standard values for high-density mixes. The n value selected should result in the $D_{8\text{-ESM}}$ to be approximately 2 mm. If it fails to, additional fines should be added to the mix to achieve the recommended 5 to 10% fines in the final mix.

Sizing of Rock Steps and other Large Rock Structures

For roughened channel steps, chutes or cascades, the larger rocks in the composite engineered streambed material, from $D_{84\text{-ESM}}$ to $D_{100\text{-ESM}}$ in size, are separated from the gradation and used to construct steps and other stable large rock features. The remainder of the material ($\leq D_{84\text{-ESM}}$) is used to form the bed between the steps. Although these large rock features are formed by material ranging in size ranging between the $D_{84\text{-ESM}}$ to $D_{100\text{-ESM}}$, the actual volume of material needed to construct these features should be calculated independently.

Thickness of Engineered Streambed Material

The framework ESM relies on the interlocking of the larger rocks for stability. It is recommended that the thickness of installed ESM be equal to the buried depth of the largest rock used in its construction. The thickness of the ESM between large rock features should be equal to the largest rock used in that section of channel, which is often the $D_{84\text{-ESM}}$. In a rock ramp, the largest rock is typically installed to protrude above the surface of the channel as much as one-third its height so it is effective hydraulically. In such cases, a suitable ESM design thickness is $0.67D_{100}$.

Many rock sizing methods have been found to be inappropriate for this application. Most rock sizing methods recommend a minimum material thickness of 1.5 to 2 times D_{50} or 1.0 to 1.5 times D_{100} of the installed rock. These methods use narrow gradations, with the D_{100} less than 50% larger than the D_{50}. However, the gradation of the ESM results in a D_{100} more than six times the size of the D_{50}, making these recommendations inappropriate for the ESM.

For constructed steps in a step-pool roughened channel, footer rocks are placed under the top rocks similar to the recommended design for rock drop structures (Footings of Rock Weirs page XII-84). This places the bottom of the footing rocks well below the bottom of the adjacent ESM (Figure XII-27).

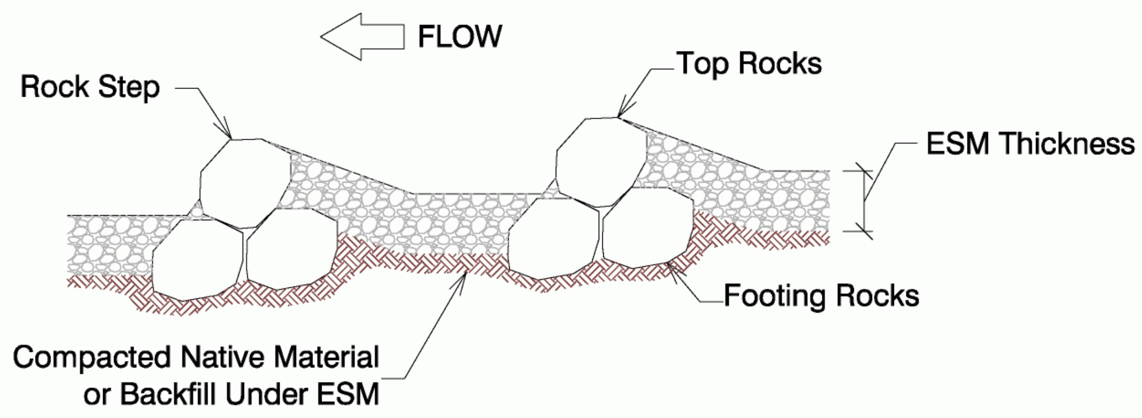


Figure XII-27. Typical thickness of ESM and rock steps in a step-pool roughened channel.

Bankline Rock

The banklines of a roughened channel should be resistant to scour and provide additional channel roughness. Observations of natural steep channels indicate that the composition of the banks is often similar to that of the channel bed materials. Material supplied to steep channels is typically from colluvial hillslope processes rather than the alluvial processes of channels with lower slopes.

The following methods for sizing bankline rock are based on sizing of rock for *riprap* revetments along waterways. Two methods are presented to allow for comparison of results. Both use average water velocity and side-slope of the revetment, but only one of them incorporates depth of flow. Both methods yield a D_{50} rock size that is substantially smaller than the D_{50} of the ESM, and should be viewed as a minimum rock size for the banklines. Rock must be stacked to achieve a steeply sloping bankline, which may necessitate larger rock than predicted with these equations. Rock angularity is important in this case.

Riprap revetments use a relatively uniform gradation, which results in large void spaces between the rocks. Roughened channel banklines use a wide gradation of material to fill these voids, which prevents piping and can accommodate revegetation. Using the calculated D_{50} for the banklines, the gradation of the bankline material is calculated using the methods outlined in Sizing the Engineered Streambed Material (page XII-67) for the Engineered Streambed Material (ESM).

CalTrans Stream Bank Rock Slope Protection (RSP)

The CalTrans Stream Bank Rock Slope Protection (RSP) Design Guidelines (CalTrans 2006) was developed to design rock slope protection along stream banks. The D_{50} rock weight is computed by the following equation:

$$W_{50} = \frac{0.00002 V_b^{6} SG}{\sin^3(\beta - \alpha)(SG-1)^3}$$ **Equation XII- 4**

Where:

W_{50} weight of the D_{50} rock (lbs)

V_b channel velocity to which bank is exposed (ft/s)

=V_c x 0.67 for parallel flows

= V_c x 1.33 for impinging flows (bends, flow convergence, divergence)

V_c Average cross sectional velocity (ft/s)

SG Specific gravity of rock (Typically 2.65)

b Shape factor constant equal to 70^o for broken rock

a Bank angle of RSP slope from horizontal (1.5H:1V slope = 33.7^o)

The rock weight is then used to determine the standard CalTrans rock size class forming the outer face of the RSP. Rock weights should always be rounded up to the higher size class. The higher velocity multiplier should be used to account for turbulent flow within roughened channels. Based on the specific weight of the rock, convert the rock weight to a diameter to obtain the D_{50} for the banklines.

HEC-11 Design of Riprap Revetment

The HEC-11 (FHWA 1989) method of riprap revetment was developed to design riprap revetment along waterways. The D_{50} rock size is computed by the following equation:

$$D_{50} = C \frac{0.001 V_{avg}^{3}}{d_{avg}^{1.5} K^{0.5}}$$ **Equation XII- 5**

Where:

D_{50} D_{50} rock diameter (ft)

C correction factor for flow stability (1.5-2.2 recommended for turbulent flow)

V_{avg} average main channel velocity (ft/s)

d_{avg} average flow depth (at design flow) in main channel (ft/s)

K slope factor

$$K = \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}}$$ **Equation XII- 6**

Where

θ bank angle (degrees) from horizontal, typically 1.5H:1V; slope = 33.7^{o}

ϕ riprap angle (degrees) of repose, typically 40^{o} (ACOE 1994)

Fish Passage Design of Roughened Channels

The type of fish passage analysis required depends on the roughened channel type due to the type of hydraulics created. Generally, roughened channel reaches are analyzed by the hydraulic approach (depth, velocity, turbulence, and hydraulic drop).

Rock Ramps, Chutes and Cascades

The hydraulic variables used to assess fish passage in rock ramps, chutes and cascades are water depth, velocity, and turbulence. Analyze the channel hydraulics at the critical fish passage design flows, which are usually the low and high fish passage design flows. When backwater effects are present at the high passage design flow, water velocities may be higher at a lower flow. Generally, a uniform flow cross sectional analysis is sufficient to evaluate fish passage hydraulics in these types of roughened channel types. The cross section should represent the channel, not a pool. The slope should be that of the ramp, chute, or cascade. A depth dependent roughness coefficient should be applied, as presented in Appendix XII-B. Compare the maximum channel depth, cross sectional average water velocity, and EDF to the fish passage criteria.

At a low fish passage design flow the maximum water depth in the channel cross-section should satisfy the minimum water depth criterion. At low flows, water depth is predominately controlled by constrictions as water flows between the large rocks protruding form the channel bed. At these flows, the *relative submergence* is generally beyond the range of flows that the depth dependent hydraulic roughness equations were developed (Appendix XII-B). Approaches to analyzing low-flow conditions include extrapolation of a roughness coefficient (using sound judgment) or evaluating the hydraulics of various constrictions based on the shape of the cross-section and distribution of large rocks to estimate water depths between constrictions.

At the high fish passage design flows water velocities and turbulence should be evaluated one of two ways; using the average cross sectional water velocity or the water velocity within a subsection of the cross section.

Use of a cross sectional average water velocity neglects the hydraulic diversity created by a roughened channel. Conditions along the margins of the channel are often suitable for passage, even when the average cross sectional velocity exceeds fish passage criteria. With sufficient water depth and wetted width in the channel, it is possible to divide the cross section into subsections, evaluate the hydraulics in segments near the channel margins and compare it to fish passage criteria. This can be performed with some cross section models, such as WinXS Pro (Hardy 2005), or using a backwater model, such as HEC-RAS (ACOE 2008). The average water depth, water velocity and turbulence in this channel subsection should meet the design criteria for the target fish. The width of a subsection should be no less than 4 feet.

To evaluate turbulence, the energy dissipation factor (EDF) is calculated at the high passage design flow using the equation for sloping channels (see Turbulence page XII-54 for EDF discussion):

$$EDF = \gamma VS$$ **Equation XII- 7**

where γ is the unit weight of water (62.4 lb/ft^3), V is the average water velocity (ft/s), and S is the hydraulic slope (ft/ft). Although there are no well-developed criteria for EDF in roughened channels, generally the EDF should not exceed 7 ft-lb/s/ft^3 for adult salmon and steelhead (Bates et al. 2003) within the entire channel, or channel subsection that fish may use for swimming upstream.

Insufficient depth, excessive velocity, and excessive turbulence can all be corrected by one or more of the following changes:

- Increase the cross-slope of channel to increase concentration of flow towards channel center
- Adjust the channel width
- Decrease the channel slope
- Increasing rock size in the ESM, thus increasing the hydraulic roughness.

Step-Pool Channels

The hydraulic variables used to assess fish passage in step-pool channels are the water surface drops over the steps, pool depths, and turbulence as EDF within the pools. In most situations, step-pool roughened channels maintain plunging flow conditions at fish passage flows. Hydraulics of the step pools are modeled assuming weir flow over each step. Generally, the hydraulics are modeled as sharp crested weirs. When the tailwater is above the crest of the step, the weir is partially submerged. Submergence should be accounted for in the analysis using the equation developed by Villemonte (1947), which is in Appendix XII-B, Equation XII-B-5.

If each step is constructed with the same crest-to-crest drop and the cross sectional shape of the steps is the same throughout the roughened channel, then the water surface drop will be the same over all of the steps. If the shape or crest-to-crest drop between steps varies, the water surface drops over the steps will differ. In such cases, the hydraulics of each individual step must be analyzed to determine if each water surface drop meets design criteria. For all step-pool roughened channels, the water surface drop over the last step should also be analyzed to ensure that it does not become excessive at the high fish passage flow. The last step is also affected by transitions (see Channel Transitions page XII-76).

At the low passage design flow the maximum pool depth should be compared to the minimum required depth. At the high passage design flow the EDF in the pool should be compared to the recommended EDF thresholds. EDF in the pool is calculated the same as for a pool and weir fishway (Turbulence page XII-54). For traditional pool-and weir fishways, a maximum EDF of 4.0 foot-pounds per second per cubic foot of volume is recommended for adult salmon and steelhead (Bell 1991) and 3.0 foot-pounds per second per cubic foot of volume for trout species (Larinier 1990). However, depending on the hydraulic diversity in the pool (i.e., bankline roughness), a step-pool roughened channel may provide fish passage at an EDF that is as much as 50% higher than these values (Bates pers. comm.). If the water surface drops vary from step to step or if pool size and shape varies, then the maximum pool depth and EDF in the pool must be calculated for each individual pool. Otherwise, the pool depth and EDF will be the same from pool to pool at a given flow.

Factors Influencing Longevity

In designing roughened channels and other types of profile control structures, it is important to recognize the potential mechanisms by which these structures can fail. Failure may be related to geomorphic or structural factors.

Geomorphic processes that can threaten a roughened channel or other types of profile control structures include downstream channel incision, insufficient supply of fine sediments, and lateral channel migration. Measures can be incorporated into the roughened channel design to address anticipated channel adjustments. A thorough geomorphic site assessment during the pre-design, as described in Alignment (page XII-16), will help identify and avoid these types of issues.

An insufficient supply of fine sediment can lead to long-term problems associated with the porosity of the roughened channel bed. When fines winnowed from the bed are not replenished by new fines, voids eventually form between the larger stable rocks. This results in piping and the subsequent loss of larger material – a process driven by the hydrostatic pressure created by the difference in head through the roughened channel. The loss of fines leads to excessive porosity and increased subsurface flow. This problem is most often associated with roughened channels at or around dams, within highly urbanized watersheds, or when the slope and size of the roughened channel bed material is much greater than the upstream channel.

Piping of the native material that underlies the engineered streambed material (ESM) can also cause structural failure. The risk of piping increases as the slope or the overall head differential through the roughened channel increases. Roughened channels constructed over fine-grained sandy substrates and/or without an adequate thickness of ESM are most susceptible. If piping is a risk at a project site, cohesive sediment may be added to the fines portion of the ESM, or the head differential minimized by over multiple roughened channel sections at an overall lower slope than originally planned. Finally, a granular filter blanket or geotextile fabric filter placed under the ESM can reduce the risk, but must be placed well below the potential scour depth. Based on the FHWA (1989) recommendations for riprap revetments, a filter may be considered beneath the ESM if the D_{15} of the ESM is more than five times the D_{85} of the native material. The wide gradation of material sizes in a well-designed ESM gives it similar characteristics to, and functionality of, a granular filter blanket. Because of the properties of the ESM, a granular filter blanket or geotextile fabric is rarely needed to control piping.

Structural failure can result from dislodging and the loss of large rock from the roughened channel or scour at the downstream end of the roughened channel that leads to rock movement and over-steepening of the channel. Proper sizing of the engineered streambed material and incorporation of transitions to dissipate energy at the top and bottom of the roughened channel will minimize the likelihood of failure by these mechanisms.

Channel Transitions

Adverse hydraulics at the transitions between the roughened channel and the natural channel or at slope breaks within the roughened channel can lead to poor fish passage conditions. Transition hydraulics at slope breaks and at the upstream and downstream ends of roughened channels should be analyzed using a backwater model. If the tailwater is too low, a drawdown in the water surface will develop. A drawdown causes water depth to decrease while increasing water velocities and turbulence in the downstream direction, potentially creating adverse fish passage conditions.

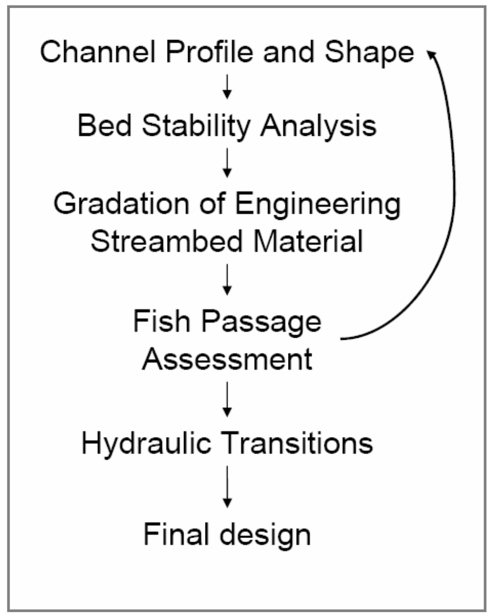
As flow enters a roughened channel there is often a drawdown and acceleration in water velocity, which can cause additional scouring forces. To reduce scour potential, an upstream transition should be included consisting of a gradual steepening and narrowing of the channel rather than an abrupt change in grade.

Roughened channels generally produce higher velocities than found in the adjacent natural channel. If close attention is not given to the transition between the roughened channel and the downstream natural channel, scour can occur in the channel at the downstream end. Downstream transitions are typically either a flat or reverse grade (forming a pool) section of roughened channel at the downstream end. The downstream end of the roughened channel can be buried into the downstream bed in anticipation that the channel may eventually scour and expose that part of the roughened channel.

Overview of the Design Process

The roughened channel design procedure involves an iterative process to develop channel shape, particle size, and hydraulic conditions for both stability and fish passage. The design begins with a project profile and a general cross sectional channel shape, followed by hydrologic and hydraulic calculations and a stability analysis to develop the gradation of the engineered streambed material. Fish passage conditions are then evaluated to ensure they meet design criteria. If fish passage criteria are not initially satisfied, the channel design will have to be modified and the previous steps repeated. Lastly, transitions at the upstream and downstream ends of the roughened channel should be designed.

Hydraulic geometry for the design cross-section and slope is determined for a range of flows including the stable bed design flow. A single cross section hydraulic analysis assuming uniform flow and assuming the water surface slope is equal to the overall slope of the reach is often adequate for the stability analysis.



Hydraulic roughness of a channel is directly dependent on the depth of flow relative to the size of the bed material. Appendix XII-B presents several depth dependent hydraulic roughness equations and their limits of application. Hydraulic roughness and the size of rock in the engineered streambed material are interdependent, requiring an iterative process to calculate a stable rock size.

Using the flow depth and hydraulic geometry, a stability analysis is conducted for the stable bed design flow. Particle stability is typically determined using standard riprap sizing methods based on unit discharge (flow rate in active channel/active channel width), as presented in Sizing the Engineered Streambed Material (page XII-67). The gradation of the engineered streambed material is determined from the stable rock size as predicted by the stability analysis. This rock size becomes the basis for determining the design gradation of the engineered streambed material. Material smaller than the D_{50} is sized using the Fuller-Thompson equation that was developed to achieve a low-porosity mixture.

Next, fish passage conditions are evaluated at the low and high fish passage design flows and at any other critical fish passage flows for each target species. For rock ramps, chutes and pools, and cascades, a single cross sectional analysis and depth dependent estimates of hydraulic roughness can be used to evaluate the water depth, velocity, and turbulence. The cross section should be representative of the roughened channel, and the slope of the chute, ramp, or cascade should be used for the analysis. Fish Passage Design of Roughened Channels (page XII-73) outlines the fish passage analysis for these channel types.

In step-pool roughened channels, the steps are assumed to maintain plunging flow conditions at fish passage flows. Fish passage conditions are evaluated assuming weir flow over each step, accounting for submergence when applicable. At each fish passage flow, calculate the water surface drop over each step, the maximum pool depth, and turbulence in the pool. Fish Passage Design of Roughened Channels (page XII-73) outlines the fish passage analysis process for step-pool channels.

Good judgment must be used when interpreting these results in terms of actual fish passage conditions. Additionally, depth, velocity, drops, and EDF in a roughened channel can be compared to those in the adjacent natural channel to understand how much more challenging passage of the roughened channel is compared to the natural channel. If fish passage conditions are not adequate, change the channel shape and/or slope to improve hydraulic conditions. The stability analysis and fish passage assessment must then be repeated.

Once the channel shape and engineered streambed material gradation have been determined, the gradation of the bankline material should be developed as described in Bankline Rock (page XII-71).

Next, the bed morphology should be developed. This includes determining the size, shape, and spacing of any rock structures, such as chutes, channel spanning steps, complex steps, or constriction rocks. These structures are composed of the largest of the engineered streambed material ($>D_{84}$).

Before finalizing the design, it may be necessary to complete a backwater analysis of the roughened channel at fish passage flows and the stable bed design flow to evaluate hydraulic transitions and the hydraulics at any other unique cross-sections.

Implementation of Roughened Channels

In general, construction of a roughened channel requires skilled equipment operators, a large quantity of rock and other imported material, and on-site construction guidance from persons familiar with design and construction of roughened channels. For the constructed roughened channel to be built and function as intended, regular guidance by the project designer is required during construction. Additionally, construction issues frequently arise that must be correctly addressed in a timely manner.

Construction of a roughened channel is typically done in the following sequence:

1. Excavate native material and/or backfill and compact material to the sub-grade elevations for installation of granulated filter blanket (if needed), banklines and ESM and material. Then excavate trenches for placement of steps, bands, or other rock structures that extend below the ESM or key into the banks.

2. It is typically best to work in sections, going from upstream to downstream so completed work does not backwater the current work area. If water is well controlled, working from downstream going up has the advantage of rock being placed against the downstream bed, which is closer to a natural condition of hydraulic sorting. Plan the sequence of construction so large equipment does not have to cross over completed structures or

bankline rock. If they do have to cross over existing structures, smaller fill material from the ESM can be used to protect the structures.

3. Place the footing row(s) and top row of rocks for steps, bands, or other rock structures.

4. Install bankline rock, including any keystone rocks that protrude from the bank. Individually place the larger rock in the bankline gradation. Use the smaller material to fill in the voids between the large rock. To compact the banklines, tamp in place followed by *jetting* or *flooding* to wash the finer material into remaining voids.

5. Install ESM in lifts across the active channel. The height of each lift should be greater than the D_{50} but less than the D_{84} of the ESM. Plan and specify the lifts and the large rock within each lift so the desired distribution of exposed rock is eventually achieved as described below.

    a. Begin each lift by individually placing the largest rocks in the lift (size greater than thickness of lift) throughout the channel bed in the proportions called out in the ESM gradation (Figure XII-28). This ensures the large rocks are positioned vertically and laterally throughout the ESM horizon. It also allows the large rocks to protrude above the finished grade to create hydraulic roughness and diversity. For stability, the rock should not protrude more than one-third of its height above the finished grade of the channel bed.

    b. Place the remaining material into the channel at a thickness equal to one lift. Mix in-place as necessary until the mixture is well-graded.

    c. Compact each lift by tamping, followed by jetting or flooding so fine material is worked into the lift. If water continues to rapidly infiltrate through the placed ESM, the bed is not adequately sealed. Add additional fine material to the top of the lift and then jet or flood the material into the bed. Repeat until the bed is adequately sealed. During final flooding of the top lift, an adequately sealed bed will maintain water flowing down-slope across the surface of the roughened channel.

The ESM is typically a mixture composed of different size classes of available material. The design gradation of the ESM can be achieved by mixing these materials in the correct proportions. The gradation of the different available materials may be available from the supplier. Otherwise, it can be verified by estimating with a pebble count (Harrelson et al. 1994) or a sieved bulk sample. Native streambed material excavated for the project can often be incorporated into the ESM mixture once the gradation of the material is established. In the end, a “recipe” is developed that describes the proportion of each material used in making the mixture.

If rounded rock is used for the construction of the engineered streambed material framework ($>D_{50}$) it should be adequately upsized during the design process. The ACOE (1994) equations were derived for angular rock. Experiments identified that when a riprap chute is comprised of rounded material, the stone begins to move at a flow about 40% lower than for angular rock (Abt et al. 1988; Abt & Johnson 1991).

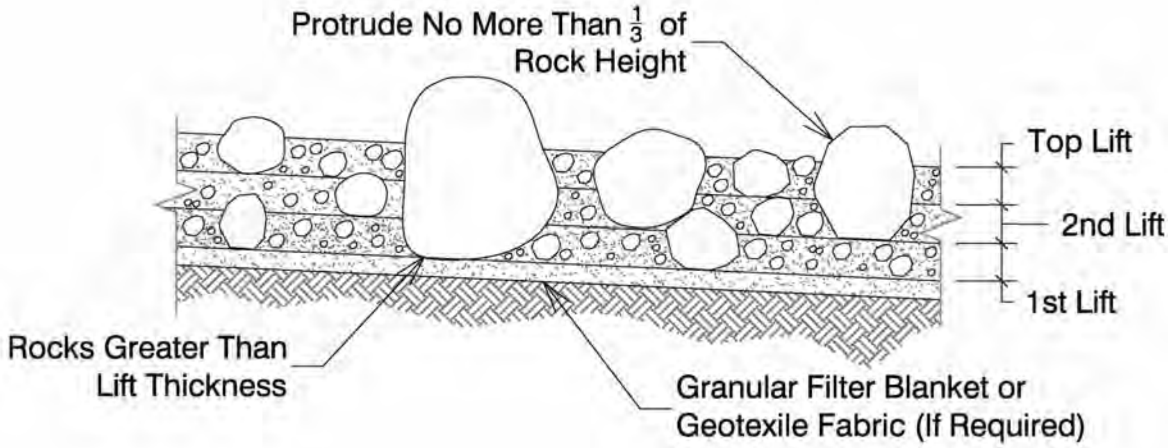


Figure XII-28. Placement of ESM in lifts. Begin each lift by individually placing rocks larger than the thickness of the lift, follow with placement and mixing of the remaining portion of the ESM.

Drop Structures for Controlling Channel Profile

Drop structures are individually constructed drops in the channel bed that span the entire channel to create a steeper profile than would naturally occur. They differ from roughened channels in that they are not a continuous structure throughout the project reach, but discrete individual structures with native streambed between. They are also referred to as weirs or sills. They are often constructed of rock or logs, but may be built with concrete, sheet pile, timber planks, or other types of construction materials. Some common uses of drop structures include improving fish passage at barriers such as perched culvert outlets, stabilizing the bed of an incising channel, raising the channel bed to restore the historical channel profile, or as a low dam to facilitate an in-stream water withdrawal.

Although a single drop structure is sometimes sufficient, a series of drop structures is generally required to meet fish passage project objectives. With a series of drop structures, the channel profile and water surface can be incrementally stepped-up to provide fish passage. When fish passage is required, each individual drop structure should comply with the maximum hydraulic drop criteria.

Unlike steps constructed in a roughened channel (see Roughened Channels as Profile Control page XII-58), each drop structure is typically independent from the next, with a distinct scour pool that forms between structures. The scour pool should be large enough to dissipate the energy of the drop and provide suitable conditions for fish to swim or leap over the structure. Shape of the drop structure, drop height, and competency of the streambed and banks all influence the width, length and depth of the receiving scour pool.

The longevity of drop structures depends on their structural integrity and the vertical and lateral stability of the channel. If one structure shifts or completely fails, the drop at the next upstream structure will increase, possibly creating a fish barrier. In some cases, failure of one drop structure can initiate a cascading failure of upstream structures.

Selecting the type of drop structure and construction materials is project specific. Influencing factors may include fish species and life stages requiring passage, slope of existing channel, stability of downstream channel, acceptable project length, construction work-window, site access for equipment and materials, availability of materials, level of construction experience and oversight, overall cost, and aesthetics.

Influence of Drop Structure Shape on Hydraulics

Drop structures generally function as weirs at most flows. The shape of a weir crest influences the flow patterns over the weir and the characteristics of the scour pool below the weir. Flow generally crosses perpendicular to the crest of a weir and is concentrated at any low point along the weir crest. The length and lateral slope of the weir crest governs the depth of water over the weir and the upstream backwater. Using these principles, the planform and cross sectional shape of a weir guides the flow patterns over the weir and the location and degree of downstream scour. A drop structure that is straight, perpendicular to the channel, and level across the channel tend to create a rectangular channel and a scour pool that spans the full width of the channel. A structure with a V-shape in plan view (pointing upstream) and/or in elevation across the crest (low in the center of the channel) tends to form a long and narrow scour holes in the center of the channel.

Slope and Spacing of Drop Structures

The slope of a design profile with drop structures is usually measured from crest to crest of the drop structures. Spacing of drop structures depends on drop height and design slope. As the slope of the design profile steepens, the spacing between drop structures must decrease to avoid exceeding the maximum drop criteria for fish passage. If the spacing of structures is too close, each scour pool will extend to the next downstream structure, thereby preventing deposition and formation of a pool tailout, as well as failing to adequately dissipate energy from the drop. When this occurs, it will be difficult to seal porous rock or log weirs, resulting in flow passing through the structure rather than over the crest. This can create a low-flow fish barrier and undermine the stability of the structure. Additionally, inadequate dissipation of energy in undersized pools can cause velocities and turbulence to increase, which may block fish passage, scour the channel bed and banks, and potentially cause failure of the next downstream drop structure.

For gravel and cobble bedded streams, drop structures should generally not be used to oversteepen the channel slope above 4% to 5% or they will become too closely spaced. In streams that do not experience large variations flows, such as spring-fed dominated streams, higher slopes may be sustainable.

Use of drop structures in low slope channels with fine-grain substrate (sands and silts) can be problematic due to the erosiveness of the streambed and banks and tendency for the structure to sink into the streambed. In these situations, a roughened channel (Roughened Channels page XII-57) may be a more appropriate method for controlling the channel profile. Roughened channels better control bed and bank scour and can be designed to withstand deformation while continuing to provide fish passage.

When using multiple drop structures in series, the drop height between structures is typically measured from crest to crest. This assumes that all of the structures have the same planform and cross sectional shape and dimensions. Variations in the structure can cause each to have different backwater characteristics, leading to differential drop heights and potentially creating a fish barrier at high flows. If drop structures have different shapes, a water surface profile should be developed for both the low and high fish passage design flows to evaluate the hydraulic drop over each structure.

If the bed between drop structures is erodible, the pools below each structure will generally scour to a sufficient size to dissipate the energy of the drop. Following the guidance for slope limitations and drop height will generally ensure that adequate pool volume is provided. However, in situations where the channel bed and banks are non-erodible (i.e., concrete, bedrock, or rock lined channel) the EDF for the pools at the high fish passage design flow should be checked to avoid creating a turbulence barrier. See Turbulence (page XII-54) for more information on evaluating turbulence in non-erodible pools below drops.

Upstream, Downstream, and Inside Culverts

Placement of drop structures within and around culverts should be done with extreme caution. When placed close to a culvert inlet, the hydraulic forces created by the drop can cause excessive scour at the inlet, sometimes resulting in scour of the bed through the entire culvert. Additionally, drop structures near a culvert inlet can decrease culvert capacity and increase the risk of debris plugging. As general guidance, avoid locating drop structures and their scour pools within the area of flow contraction upstream of a culvert inlet. HEC-RAS (ACOE 2008) provides guidance on determining the length of channel that experiences flow contraction. Provide a spacing that is greater than a long pool and tailout in the natural channel below a similar drop structure. Drop structures with a one-foot drop should be located at least 35 feet upstream of a culvert inlet (Bates et al. 2003) in a gravel-bedded channel.

When constructing a drop structure below an existing culvert, the structure should be placed at least 20 feet downstream of the outlet to maintain the outlet pool for energy dissipation. In cases where a new crossing is designed using stream simulation or low-slope approaches, no scour pool is expected and drop structures can be placed closer to the outlet.

Use of drop structures inside culverts is generally not recommended, unless the culvert is designed as a fishway (see Fishways page XII-107). A roughened channel is more suited for providing profile control inside new or replacement culverts. Rock weirs as part of a step-pool stream simulation channel can be placed inside culverts when applicable (see Stream Simulation page XII-28).

Keying into the Streambed and Banks

Keying drop structures sufficiently into the streambed and banks is essential for preventing undermining and flanking, or end-running (Figure XII-31). The crest of the weir at the banks should be placed high enough to concentrate flow towards the center of the weir. At the point that the weir intersects the stream banks, the top of the weir should be below bankfull elevation.

If flow plunges over the structure and towards the bank, the flow will tend to scour the bank and the structure key. A detail design for the treatment of this area is important to avoid erosion and over-steepening the bank, which can threaten structure support or sealing at the keys.

The structure extends into the bank in an excavated trench. The key typically extends at least as far into the banks as the banks are tall, or two foundation rock widths, whichever is greater but can be reduced where banks are not erosive because of armoring or competent native material. Cut-off walls of rock or logs buried into the stream banks and across over-bank areas and oriented perpendicular to the flow can be used in conjunction with the bank keys to further prevent flanking.

The key into the streambed should extend sufficiently below the predicted scour depth to prevent undermining of the structure and maintain the integrity of the structure. The scour depth increases with increasing drop across the structure and decreasing size of bed material in the channel. Fill any voids in or around the keys with high-density material and compact it to avoid seepage that can cause piping and failure.

Rock Weirs and Rock Chutes

Rock structures, which include rock weirs or chutes, can withstand small shifts of material and continue to function as intended. They are made of individual rocks stabilized by weight of the material as well as contact with other rocks. Because they can withstand small deformations and continue to provide fish passage, these types of drop structures are better suited than rigid weirs to withstand downstream channel adjustments.

Because of the inherent irregularities in the surface of rock structures, they generally provide increased hydraulic diversity and better passage performance in comparison to rigid weirs. They can also be easily adjusted by moving individual rocks by hand or with small equipment.

Rock structures are typically designed to maintain lower slopes than rigid weirs. Because of construction methods and the ability for the rock to shift, larger tolerances must be incorporated into the design of the shape and placement of rock structures. The gaps between rocks make them more permeable than rigid weirs, requiring additional care and consideration during design and construction to seal the weirs and provide suitable passage conditions during low flows. Sealing of rock structures is enhanced by providing sufficient spacing between successive structures so bed material accumulates upstream of each structure.

<u>Shape of Rock Weirs and Chutes</u>

Rock weirs can be shaped in both planform and in cross section to concentrate the flow towards the center of the channel and away from the banks, or to spread the flow relatively evenly across the entire channel width. Each pattern has advantages and disadvantages in terms of fish passage, structural stability, impacts to the adjacent channel, and overall design slope. The face of a rock weir can also be laid back in the stream-wise direction to spread the hydraulic drop over a longer distance. Laying back the face of the weir creating a chute rather than a distinct drop in the water surface, allowing fish to swim rather than leap over the structure.

Cross Sectional Shape of Rock Weirs

The crest of a rock weir should be shaped to concentrate low flows towards the center of the channel and away from the banks. Lowering the side-slope of the crest will decrease the backwater effect created by the weir. The side slope of the crest will depend on the channel width, shape of the weir, shape of the channel, height of the banks, and the desired backwater effect. Often it is preferable to have the weir crest closely resemble the cross sectional shape of the existing channel. To avoid excessive upstream backwater effects and downstream scour, side slope should not exceed 5H:1V, and should be less on wide streams (Figure XII-31). Weirs with relatively flat crests should include a low-flow notch for fish passage.

The ends of the weir should key sufficiently into the banks to prevent flanking. NRCS (2000) recommends that the rock extend at least four times the D_{100} rock size into each stream bank. If there is substantial over-bank flow during extreme high flows, the key may need to extend further.

Footings of Rock Weirs

Keying the weir sufficiently into the bottom of the channel can prevent undermining caused by scour; a common mode of failure for rock weirs. The rock must be stacked into at least two rows to key the foot of the weir below the potential scour depth. The bottom rocks are referred to as the footing rocks. The weir footing can be constructed with either one or two rows of footing rocks (Figure XII-29). Using two rows of footing rock can provide additional stability and better control for placement of the top rocks at the design elevation. Two rows of footing rocks are often used for stability when raising the elevation of the channel. However, to reduce materials one row of footing rocks below the row of top rocks may be used in situations where the new channel is cut into an existing channel bed. The footing rocks should be placed at the toe of the downstream slope so as not to prevent to formation of a jump pool. The top rocks should be carefully selected and individually placed with a minimum of voids. The upstream half of the top rock rests on the existing bed material rather than a second row of footing rock. Voids in the rock should be filled in lifts as the rock is placed. Material used to fill the voids should be washed into place and rodded into voids. After completion of the weir additional material should be spread and rodded into voids appearing after washing, and the process repeated until voids are filled.

Likewise, a chute should have a row of footing rocks and top rocks at the downstream end to buttress the material above it. Keep in mind that in a chute, the lower end is submerged at high flows.

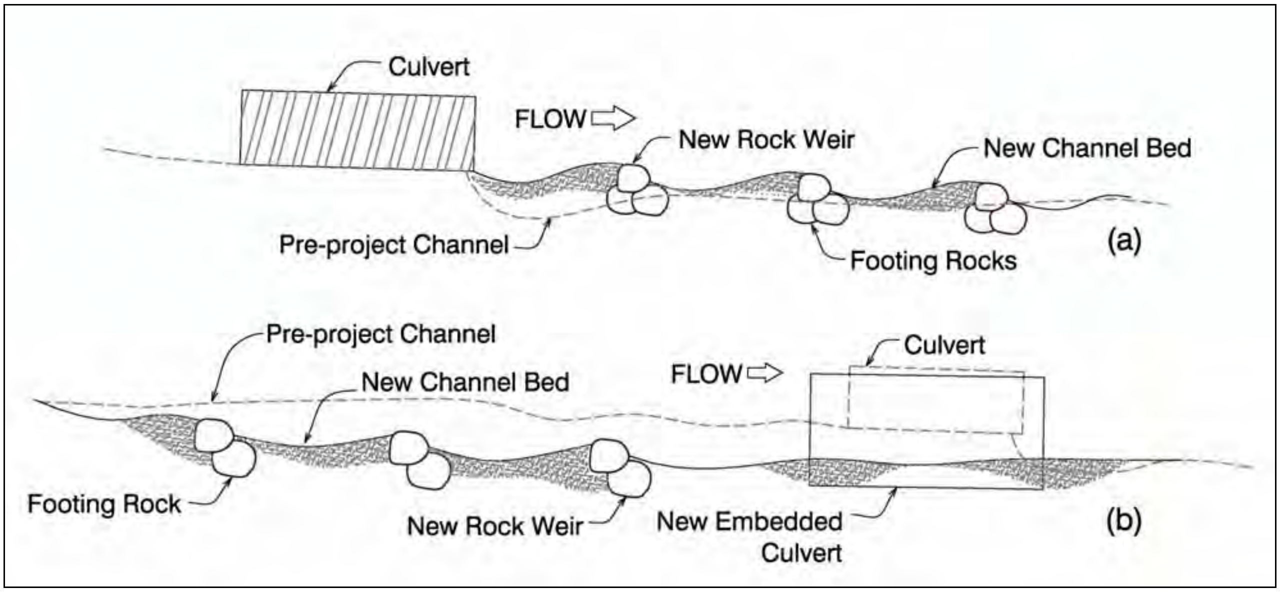


Figure XII-29. Examples of (a) using two rows of footing rocks for weirs that raise the existing channel bed below a perched culvert and (b) using a single row of footing rocks for lowering an existing channel profile to prevent headcutting upstream of a culvert replacement.

In lieu of a scour analysis, for gravel or cobble bedded streams, the largest rock size in the design gradation (D_{100}) can be used to determine the depth of the footing rock (see Rock Sizing for Rock Weirs and Rock Bands page XII-89). The bottom of the footing rock should be at least as deep as the D_{100} below the downstream weir crest or pool tail crest elevation (Figure XII-30). The depth of scour below a drop structure in a gravel-bedded stream is commonly two and a half times the drop of the weir (Saldi-Caromile et al. 2004).

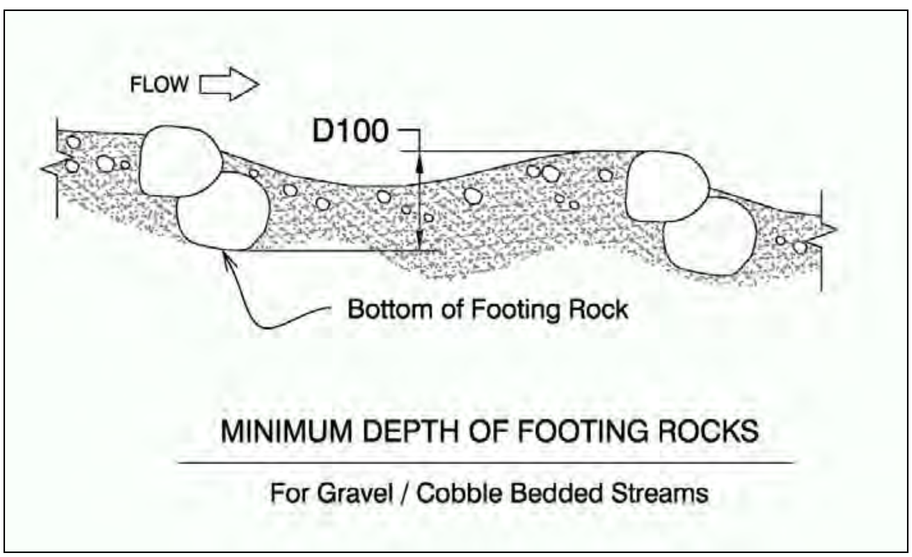


Figure XII-30. In lieu of a scour analysis, the minimum depth of the footing rock can be estimated from the D_{100}. The D_{100} is the largest rock size used to construct the weir, as determined from the rock sizing analysis.

If the rocks keyed into the bank are exposed due to bank scour, they may become an active part of the rock weir. For this reason, the rock keyed into the banks should have footing rock and be roughly the same size as the rock used in the channel portion of the weir.

Arch and Chevron Rock Weirs

Weirs in the planform shape of an arch or chevron, with the apex pointing upstream, concentrate flow towards the center of the channel (Figure XII-31). This shape of weir tends to scour a long and deep pool in the center of the channel while directing flow away from the downstream banks. A depositional area along the channel margins may be created, reducing the risk of bank scour.

To span a wide stream or river may require the use of W-shaped weirs, also referred to as labyrinth weirs. These are composed of two or more chevron shaped weirs placed together to span the channel. The weir shape will create a diverse channel bed in the downstream channel rather than a uniform, flat channel. The weir crests at the apex of each weir cycle in a labyrinth weir can be placed at different elevations to concentrate low flows into a single low flow notch rather than splitting it between multiple low flow notches.

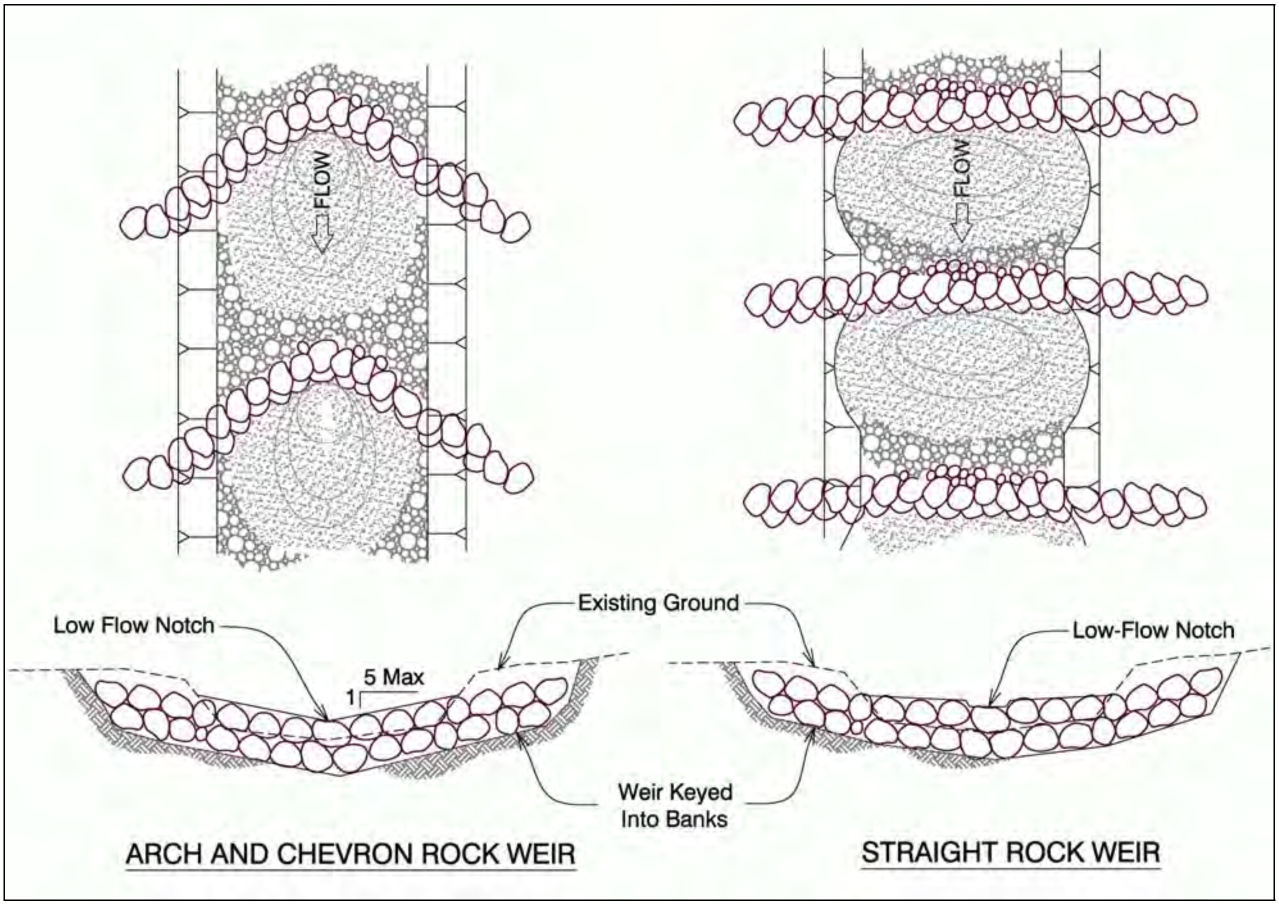


Figure XII-31. Examples of arch shaped rock weir and straight rock weir in planform and cross section.

These upstream pointing rock weirs gain strength through their arch shape (Figure XII-32). The forces exerted onto the weir by the stream flow pushes the rocks against each other, transferring the forces into the banks. The apex of the weir should have an angle between 90 and 120 degrees. The sharper the angle, the more flow is concentrated towards the center of the channel, creating a longer and deeper scour pool with an increased risk of undermining. Bates et al. (2003) suggests a maximum overall grade (measured from crest to crest) of 3% for sharply angled arch and chevron rock weirs. The crest elevation of the weir should slope down towards the apex to concentrate flow away from the banks and towards the center of the channel.

Straight Rock Weirs

Straight rock weirs span the channel perpendicular to the flow (Figure XII-31). The crest can be level or sloped. The more level the crest, the more flow is spread across the entire weir, limiting its backwater effect. By spreading-out the flow, the concentration of scour is reduced. The resulting scour pool below a straight weir is typically shallow and wide, spanning the entire channel. The stream wise length of the pool is relatively short. Because the weir does not direct flow away from the channel margins, bank erosion should be anticipated immediately downstream of straight weirs.

Figure XII-32. Arch-shaped rock weirs produce diverse hydraulics across the crest while concentrating flow towards the channel center. Photo courtesy of Rob Sampson.

To reduce the velocities along the banks, the crest should have a gentle side slope towards the center of the channel. Additionally, it should have a distinct notch near the center of the channel to concentrate low-flows for fish passage.

Because a straight weir lacks the inherent strength provided by the arch shape, the rock may need to be larger to remain stable. Additionally, achieving good rock placement during construction of straight weirs is essential, including ensuring excellent rock-to-rock contact.

Straight rock weirs with level crests can be placed at closer spacing than arch or chevron weirs because their scour pools are generally shorter in length. Bates et al. (2003) suggests a maximum overall grade (measured from crest to crest) of 5% for straight rock weirs.

Rock Chutes

A rock chute is a short, steep, semi-rigid section of constructed channel. They mimic chutes that occur in natural channels but are designed to be permanent. When the pool below a rock chute is armored with engineered streambed material (ESM), it is considered a chutes and pools roughened channel and the recommended maximum slope from chute to chute is 4%. When the pool is not armored below the chute, it is considered an individual drop structure, and the recommended maximum overall slope from chute to chute is 2.5%, but may be steeper in course bedded streams.

A chute has a sloping face of 5% to 10%. Because of their sloping face of the rock chute, they can be built with a larger overall drop than an individual weir. The maximum recommended drop through a rock chute is one foot. They are constructed in a series with the spacing between chutes sufficient to dissipate the energy within the pools.

The rock bands define the ends of the chute and are designed like rock weirs (Figure XII-33). They are constructed with a cross-sectional V-configuration to concentrate low flow in the center and to provide a diversity of hydraulic conditions at all flows. ESM is placed between the rock bands (see Sizing the Engineered Streambed Material page XII-67). The plan view shape is concave with the opening pointing downstream so flows are concentrated towards the center of the channel. Refer to Chutes and Pools (page XII-63) for details regarding design of the rock chutes.

The pool length and depth between chutes should be sufficient to dissipate any excess energy coming off the chute. A scour analysis can assist in estimating the appropriate pool depth. It may be prudent to excavate the pool to achieve the desired depth rather than allowing it to scour. Otherwise, the energy from initial high flows may not be adequately dissipated in the pool below the chute, potentially scouring and mobilizing the next downstream chute.

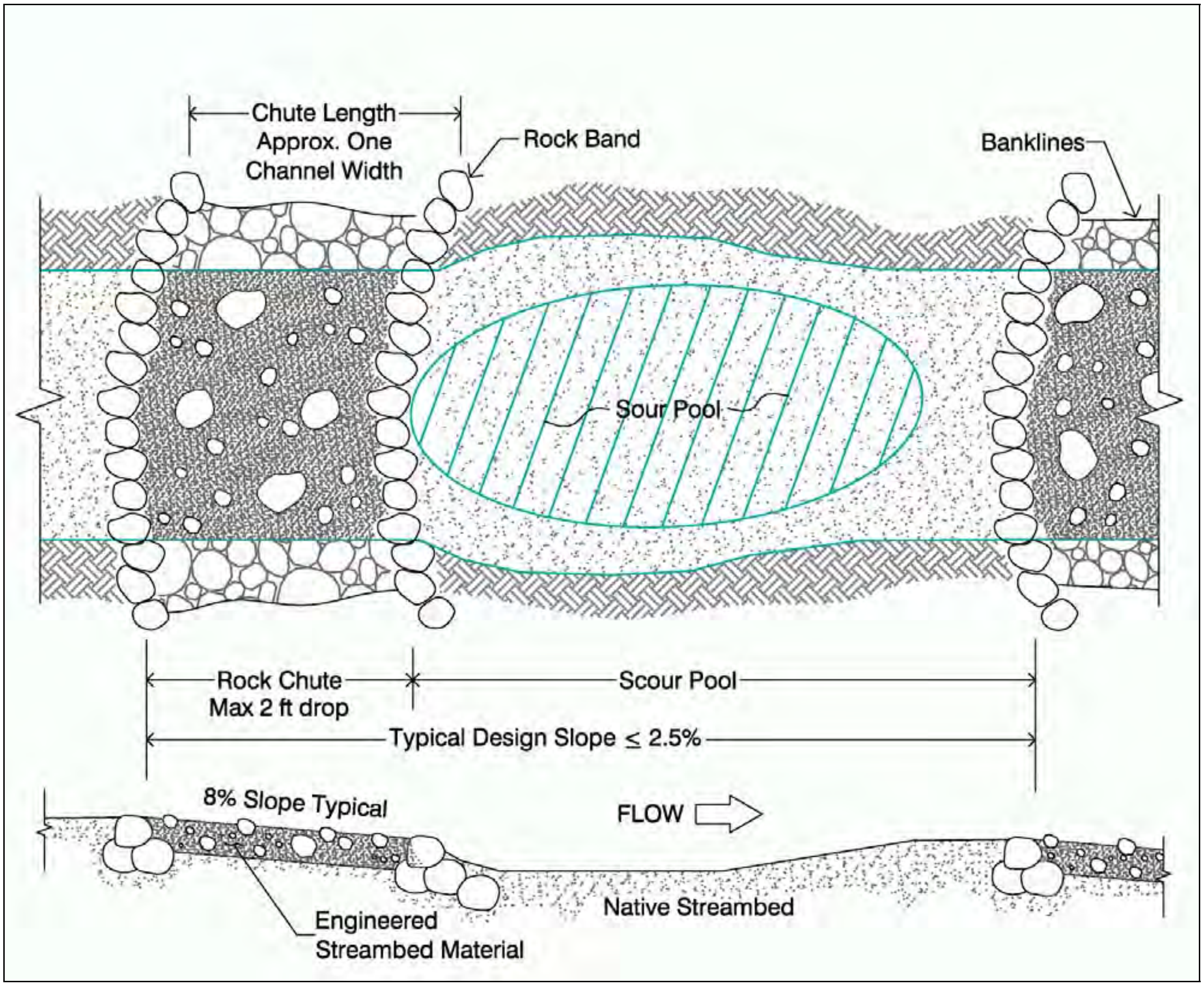


Figure XII-33. Typical chute with unarmored pool in plan and section.

Rock Sizing for Rock Weirs and Rock Bands

Rocks comprising a rock weir or the rock bands in a chute should be large. Larger rocks are less easily moved by flows, less prone to failure due to scour, and take less time to install. In general, guidelines recommend minimum rock sizes of 2 to 3 feet (NRCS 2000; FHWA 1979; Thomas 2000), and larger in streams with unit discharges greater than about 15 cfs/ft.

The size of rock should not be disproportionately large relative to the channel width. The weir should be comprised of a number of rocks to ensure that they interlock and voids are filled, thus increasing stability and impermeability. Avoid using any individual rock that is greater than one-third the channel width.

Stability depends on the size of the rock, the interlocking of the rock, and planform shape of the weir. Riprap sizing methods are based on a blanket of rock placed parallel to the flow, where the stability of the individual rocks relies largely on the interlocking created by the blanket-like placement. As a result, the stable rock sizes determined using standard riprap sizing procedures are too small for rock weirs.

NRCS (2000) recommends sizing rock for rock weirs by first computing the stable median rock size using the Far West States (FWS) Lane Method riprap sizing method (NRCS 1996) and then increasing the results by scaling factors to obtain an appropriate size of rock for the weirs. The FWS Lane Method for riprap is a follows:

$$D_{75-riprap} = \frac{3.5wDS}{CK}$$ **Equation XII- 8**

Where

$D_{75\text{-riprap}}$ D_{75} riprap size in inches

w channel top width at the design flow (feet)

D maximum depth of flow in channel (feet)

S channel slope (feet/feet)

C coefficient for channel curvature. Ranges from 0.6 to 1 with a value of 1 for straight channels.

K side slope coefficient. Typically ranges from 0.53 to 0.87 for installed rock slope revetments of 1.5H:1V to 3H:1V, respectively.

The FWS Lane Method yields a D_{75} riprap size in inches. The K side slope coefficient significantly changes the computed rock size. A value of 1.0 has been used by Fripp et al. (1998) because the rock is placed flat on the streambed.

The $D_{75\text{-riprap}}$ is then scaled to obtain the $D_{50\text{-riprap}}$ based on standard riprap gradation. A common scaling factor is (NRCS 1996):

$$D_{75\text{-Riprap}} = 1.2D_{50\text{-Riprap}}$$

To determine the rock gradation for rock weirs, the $D_{50\text{-Riprap}}$ is then modified as follows:

$$D_{50\text{-Weir}} = 2 \text{ x } D_{50\text{-Riprap}}$$

$$D_{100\text{-Weir}} = 4 \text{ x } D_{50\text{-Riprap}}$$

$$D_{min\text{-Weir}} = 0.75 \text{ x } D_{50\text{-Riprap}}$$

NRCS recommends that the rock be well graded between the D_{50} and D_{100} sizes, with the larger rock forming the surface of the weir and the smaller rock filling the voids between the larger rock.

Rock Selection and Placement

It is best to use angular rock due to its ability to lock tightly together and resist movement. Rounded rock can be used, but the size must be increased. Rock size should be measured as the average of the three dimensions (length, width, thickness). The least dimension of an individual rock should not be less than one-third the greatest dimension. Rock used in weirs should be uniformly sound, durable and free from cracks, seams, and other defects that can increase its deterioration.

Construction of rock weirs and other types of rock structures require a skilled equipment operator and an attention to details. Elevation of placed rocks should be regularly checked, and rock position should be adjusted to achieve the design elevation. All large rocks used in structures and in the channel should be individually placed by hand and/or machine and secured in desired position by machine tamping of rock and surrounding support material. Large rocks forming the rock weir should be placed tightly together to minimize gaps, and each rock should have a minimum of three contact points with adjacent rocks. When constructing, it is useful to hand select individual rocks that best fit. Fill all voids with smaller material in layers as the rock is placed to minimize permeability. After completion of the weir, fill material should be tamped further into place and material spread into any voids that appear. This process should be repeated until voids are filled.

<u>Cabling Rock</u>

The rock size used in rock weirs should be sufficient to resist movement at the design flow. If properly sized rock is not available, cabling smaller rocks may be necessary to create adequate mass. Cabling may prevent a semi-rigid rock weir from being able to adjust over time. Cables have been known to catch debris, which can cause rocks to move. The steel cables can also create a public hazard by forming a leg-trap for people in the water and by causing lacerations when frayed.

Cabling of rock in weirs may be appropriate in situations of limited site access, where sufficiently large rock or heavy equipment large enough to handle the rock cannot access the site. If smaller rock must be used, cabling can add stability and longevity to the weir (see *California Salmonid Stream Habitat Restoration Manual* Part VII Figure VII-3).

<u>Sealing of Rock Weirs</u>

To reduce the risk of flow passing through the weir rather than over the crest, and to add stability, spaces or voids between the large rocks should be minimized. During construction, rocks should be placed close together to minimize the size and number of voids. Voids should be filled with smaller rock specifically selected to fill niches and native bed material and tamped in place. Through time, deposition against the upstream face of the weir will keep the weir sealed. In some situations, clay packed into the spaces between rocks has been used successfully to provide a long-term seal. The additional effort of using clay to fill voids may be warranted in cases where there is an insufficient supply of bedload to maintain a sealed weir.

Deformable Drop Structures

Deformable drop structures are designed to provide temporary bed stability and where gradual channel incision is acceptable. Typically constructed of rock, and to a lesser extent large woody debris, this type of drop structure is allowed to deform through time by means of downstream scour and movement of individual rocks. The drop structure may begin as a rock weir, deforming into a chute and then a steep roughened riffle. In each transformation the drop height decreases and fish passage is maintained.

Deformable drop structures have been used successfully to slow channel incision upstream of culvert replacements. In certain cases, slowing upstream incision can be desirable to prevent a rapid sediment release that could degrade aquatic habitat, overwhelm the culvert or severely decrease downstream channel capacity. Slow channel incision may also provide an opportunity for vegetation to stabilize stream banks as they steepen in response to the channel bed lowering.

Design of deformable drop structures is done by sizing the rock to withstand relatively low design flows or by minimizing the depth rock is keyed into the streambed, or both. Avoid using rock sized much larger than the maximum drop height to reduce the risk of creating an excessive drop as the structure deforms. Because of variability and uncertainty of hydraulics, soils, and the structure, it is not possible to accurately predict the flow at which any structure will begin to deform.

Rigid Weirs

Rigid weirs are fixed non-deformable structures that cross the entire channel to create a series of small drops to permanently control the channel profile. Their rigidity is the primary difference between them and rock weirs. They are commonly made of logs, sheet piling, concrete, or other durable materials. A benefit of rigid weirs is that they can often be built at a steeper grade than roughened channels and rock weirs, thus minimizing the project footprint. They are easier to seal and can be designed to concentrate flows so they perform well even at very low flow.

A series of rigid weirs is commonly limited to slopes of 5% or less. At these slopes, bed material is naturally deposited on the upstream side of each structure, improving sealing and stability. Steeper slopes may necessitate a formal fishway with flow control.

Weirs commonly have distinct water surface drops. They should include variability in cross section to create diversity in hydraulic conditions at the weir and in the channel downstream. They have the advantage that the cross-section can be finely controlled. They can include a hydraulically designed notch to concentrate very low flows, which can be advantageous for low-flow passage.

Horizontal weirs tend to create pools that are trapezoidal and uniform in cross section. Weirs that dip toward the middle of the channel and have a V-shaped planform pointing upstream tend to concentrate the thalweg in the center of the channel and create more complexity and diversity than horizontal weirs perpendicular to the channel. Trade-offs include that V-shaped weirs are more complicated to build and may have to be built at a lower slope. If they are built of logs, any exposed portions of the logs will deteriorate more quickly than if submerged. An example of rigid V-shaped weirs is shown in Figure XII-34 at Goldsborough Dam removal project.

Poorly designed or constructed weirs commonly fail by scour either under or around the end of the structure. Keys to a good design include overall slope, planform and profile geometry, embedment and bank keys, and ballasting of buoyant materials.

Figure XII-34. Goldsborough Dam Removal Project. An example of V-shaped rigid weirs.

Concrete and Sheet-Pile Weirs

Concrete and sheet-pile weirs can be manufactured precisely with a varied cross-section similar to the natural channel, and a crest shape that is specifically designed for fish passage. Sheet-pile weirs might be effective where foundation conditions are poor. Sheet-pile weirs can be solid sheet-piles or H-piles with wood or pre-cast concrete lagging between them. Prefabricated structures can reduce construction time and are useful where excavation and access is difficult. Special equipment, such as cranes or pile drivers are typically needed for installation.

Weir crests can lack the variety of passageways found in rock structures but the diversity can be enhanced by adding variability to the crest. Boulders might be embedded in the crest or a weir can buttress additional boulders in the upstream channel to create structures similar to chutes. In this case, the weir itself replaces the footer boulders in a chute.

Concrete and sheet-pile weirs can be built at a steeper overall slope than log weirs when the structures are more deeply embedded into the streambed. In comparison to logs or rock, these materials can provide a good seal without relying on deposition along the upstream face of the weir. As the profile slope increases, the structure effectively becomes a fishway and those design criteria must be applied. Saldi-Caromile et al. 2004, describes additional details of rigid drops structures.

Log Weirs

Log weirs are unique within the category of rigid weirs. They span the channel instead of being buried vertically like sheet-pile and other structures, they deteriorate more quickly than steel and concrete structures, and they are buoyant. Slope limitations previously described are especially important for log weirs because they can fail by being undermined if placed on too steep a slope.

There are a variety of designs of log weirs: stacked logs in a horizontal weir, weirs angled in planform to direct flow, and V-weirs and X-weirs to concentrate flow. Simple, straight, double-log sills are the most secure and the easiest to construct. These require the least overall channel length and are often the least costly of the rigid weirs if large logs are available. At low flow, horizontal logs have a thin uniform sheet spill. Without a notch, they can block any fish that does not leap.

Weirs that dip toward the middle of the channel and have a V-shaped planform pointing upstream tend to concentrate the thalweg towards the center of the channel. This creates more channel complexity and diversity than horizontal weirs perpendicular to the channel. Trade-offs include that they are more complicated to build and may have to be built on at lower slopes. If they are built of logs, any exposed portions of the logs will deteriorate more quickly than if they are entirely and permanently submerged.

Log weirs designed and built well commonly survive extreme flow events. Keys to a good design, in addition to those described for drop structures in general, are to use two stacked logs with diameters of 16 to 30 inches so the bottom log is deeper than the expected scour hole. Scour holes below horizontal weirs in gravel beds are typically two to two and a half times the drop of the weir. The logs should be pinned and cabled together with the upper log slightly downstream of the lower one so the water spills clear of the lower log. Logs should be notched during low flow to create a chute for those flow conditions.

The logs should be ballasted from below by cabling to a buried anchor block rather than by depending on riprap stacked on the ends of the logs. The buried ballast will also allow the ends to be protected with bioengineering techniques rather than riprap. Figure XII-35 shows a series of log weirs with the banks entirely protected with large wood. The weirs are ballasted from below as described above. No riprap was used on the project. Design details, sketches, and various log configurations are described by Saldi-Caromile et al. (2004).

Figure XII-35. Schoolyard Creek bank protection with large wood. No riprap was used on the project. Constructed 2000.

BAFFLE RETROFITS OF STREAM CROSSINGS

The most effective solution for creating unhindered fish passage at a barrier culvert is to replace it with a new crossing structure designed for using the stream simulation approach, combined with profile control if necessary. In situations where replacements are not feasible or justifiable, retrofitting a culvert with baffles may be a practical approach to provide incremental passage improvements. Baffles are a series of flow obstructions placed inside of culverts to improve fish passage by increasing water depth at lower flows and decreasing water velocity at higher flows. In comparison to weirs, baffles are short relative to the depth of flow and hydraulic drops between baffles are small. Baffles can also be used in flumes and other structures that function hydraulically like culverts.

Overview of Baffle Hydraulics

Baffles are designed to function in two different hydraulic regimes: plunging and streaming. Most baffles function as weirs at lower flows. Water plunges over each discrete baffle into pools formed between the baffles, similar to a pool and weir fishway (see Pool and Weir Hydraulics page XII-113).

As the flow and depth over the baffle increases, the water begins to stream, or skim, across the baffles rather than plunge over each baffle. In streaming flow, the baffles function together as hydraulic roughness that dissipates energy through turbulence. This effectively reduces the average cross-sectional water velocity and increases water depth. Baffles may also provide areas of low velocity where fish may escape from higher velocities. The flow at which the regime transitions between plunging and streaming is discussed in Pool-and-Chute Fishways (page XII-121).

Turbulence, measured in terms of the Energy Dissipation Factor (EDF), is important in the design of baffles. At low flows water plunges over each baffle and energy is dissipated through turbulence within the receiving pool. At higher flows, baffles act as large roughness elements that slow water velocities and dissipate the flow's energy through turbulence throughout the culvert.

Refer to Appendix XII-C for guidance on analyzing baffle hydraulics and evaluating turbulence in a baffled culvert.

Limitations of Baffles

When retrofitting a culvert with baffles, it is important to understand their limitations. Baffles rarely provide fish passage conditions equivalent to a crossing designed specifically for passage. In addition, baffles obstruct flow through the culvert, creating hydraulic conditions favorable to fish but that may affect culvert performance. Important limitations and concerns with baffle installations include reducing hydraulic capacity, debris and sediment trapping, suitability for juvenile and weak swimming fish passage and the possibility for unstable hydraulics. After attempting a retrofit design, these concerns may lead to the necessity for a different design approach, such as culvert replacement.

Baffles have the potential to substantially increase the culvert's headwater depth and reduce the hydraulic capacity of the culvert. Measures that improve the hydraulic efficiency of the inlet, such as adding wingwalls or mitering the culvert inlet, can slightly reduce the impact of baffles on hydraulic capacity. In some cases, the height and placement of the first baffle downstream from the inlet can be designed to reduce its influence on headwater depth and hydraulic capacity.

Baffles are prone to catching and becoming clogged with debris, which may create a blockage to fish, impair the hydraulic performance of the culvert, and jeopardize the entire crossing. Contemporary baffle designs attempt to accommodate debris passage, but some increased level of debris trapping is inevitable. Regular inspection of baffled culverts is required. Debris within a baffled culvert must be cleared in a timely manner to minimize the duration of any blockage to fish passage and to prevent further accumulation of debris. Because debris problems generally arise during high flows, debris removal is often required during those higher flows when access and working conditions are difficult. This is especially important because many fish populations migrate at those same high flows.

The pools between baffles may also trap and become filled with sediment. This can reduce the roughness and negate the fish passage improvements intended by the baffles. It may not be possible to maintain the intended roughness in baffled culverts where large gravel and cobble bedload is present. In severe cases, sediment accumulation creates a hydraulically flat and smooth bed of sediment along the culvert floor that results in conditions similar to before the placement of the baffles but with reduced hydraulic capacity.

There is little data to guide baffle design for passage of juvenile salmonids and non-salmonid species. Passage of juvenile salmonids is likely limited to relatively low discharges with plunging flow conditions, during which the baffles function as low weirs. Under streaming flow conditions, the average cross sectional water velocity in a baffled culvert may be within the swimming abilities of juvenile salmonids or other weaker swimming fish, but the turbulence generated by the baffles is believed to present a passage barrier.

Baffles are generally not recommended for culvert slopes greater than three percent. At steeper slopes, it becomes difficult to achieve streaming flow, and unstable hydraulic conditions and excessive turbulence are likely to arise. If the culvert is large enough, retrofitting with a weir-type fishway may meet fish passage objectives on steeper slopes. Otherwise, culvert replacement could be the only solution capable of meeting fish passage objectives.

Baffle Design

Appropriate baffle designs vary with the shape, size, and material of the existing culvert and site constraints. Baffle design starts by identifying an appropriate baffle type and materials for the culvert of interest. The hydraulic design approach is then applied to arrive at a preferred baffle configuration (geometry, height, and spacing). This approach requires identification of target species and life stages to establish fish passage design criteria and design flows, as outlined in Hydraulic Design Criteria (page XII-51). Special hydraulic conditions at the culvert inlet and outlet transitions must be considered. The baffle configuration that best meets these criteria is selected as the preferred retrofit design. Culvert hydraulic capacity and risks of accumulating sediment and debris must be evaluated.

The hydraulics of baffles are complex and difficult to model numerically. As a result, baffle hydraulics are best evaluated using results from scaled physical models. Only a limited number of baffle shapes, sizes, and spacing have been evaluated using physical models. The majority of these experiments have considered only the hydraulic performance of the baffles; very few baffle configurations have been evaluated biologically (Ead et al 2002; Gregory 2004; Rajaratnam 1990; Shoemaker 1956). The development of turbulence and its effect on passage have not been studied. As a result, design of baffles requires considerable engineering judgment from someone with extensive experience or expertise in hydraulic engineering. Appendix XII-C provides specific design equations and procedures for use in design of baffle retrofits.

Types of Baffles

There are numerous types and configurations of baffles constructed of varying materials. Selection of the baffle type will often be determined or constrained by the culvert shape, size, material, capacity, and condition. Contemporary baffle types have evolved from experiences with earlier baffles. For many years Washington (offset) baffles were the recommended baffle type. However, field experience has shown these baffles are highly prone to clogging with debris and sediment and they are believed to create hydraulics unsuitable for passage of juvenile salmonids and other weaker swimming fish. They are also difficult to install in circular culverts.

Baffles containing narrow notches or slots are generally not recommended due to their susceptibility of plugging by debris or large bedload. Baffles with notches that alternate from side to side are also not recommended. At higher flows, the alternating notches can create undesirable hydraulics and smaller fish that swim in the slower water along the edges may be unable to escape the higher velocities created by this alternating flow pattern. Additionally, each change in direction of the main flow increases the risk that the baffles will capture debris.

Generally, baffles that create diverse hydraulic conditions at fish passage flows and that open upward, such as a V-shape, are recommended.

Circular and Pipe-Arch Culverts

Corner baffles and weir baffles are recommended for use in circular culverts (Figure XII-36). The dimensions shown in the figure are parameters in the hydraulic design and are defined in Appendix XII-C. Corner baffles are shaped to concentrate the majority of flow and floating debris towards the low side of the baffle while providing slower water along the opposite side of the culvert for fish to swim through. Weir baffles are for wider and steeper culverts with a shape that is a composite of two corner baffles with a V-shaped notch or a small horizontal weir plate in the middle.

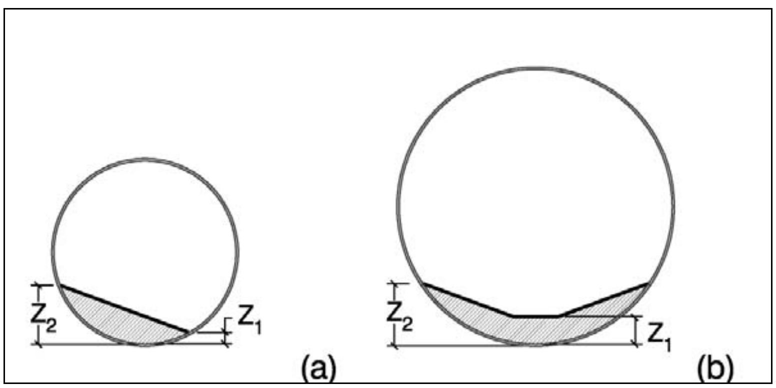


Figure XII-36. Cross sectional view of (a) corner baffles and (b) weir baffles for circular culverts.

Corner and weir baffles are typically constructed of steel. The metal baffles may be anchored or welded to the culvert or to a steel hoop wedged between corrugations. Baffles should fit snuggly against the culvert to prevent water from flowing under, rather than over, the baffle. The cross sectional shape of circular metal culverts is often deformed by loading and settling, requiring each baffle to be fitted individually. When concrete lining of the culvert invert is part of the project, the concrete can be used to secure and seal the baffles, but the concrete thickness must be accounted for in the baffle design.

Other baffle designs may be acceptable if shown to be as effective as corner or weir baffles in satisfying fish passage objectives.

Flat Bottom Culverts

The most common fish passage limitation in box culverts and other structures with flat floors is inadequate water depth. Considerable flow is required to achieve fish passage depth criteria. In these types of structures, correction of low water depth at lower flows often remedies excessive velocities at higher flows.

Angled baffles are recommended for retrofitting box culverts and other structures with flat floor (Figure XII-37). Angled baffles can be constructed of steel, wood or concrete and are anchored to the culvert floor. In plan view, the baffle is skewed 60 degrees relative to the direction of flow. The baffle is tapered so the upstream end is low. The baffle skew and tapered crest are designed to concentrate flow and promote debris passage along one side of the culvert while providing slower water for fish passage on the opposite side. The exact shape of the baffle crest is selected to provide sufficient water depth for each targeted fish species and life stage at its low passage design flow.

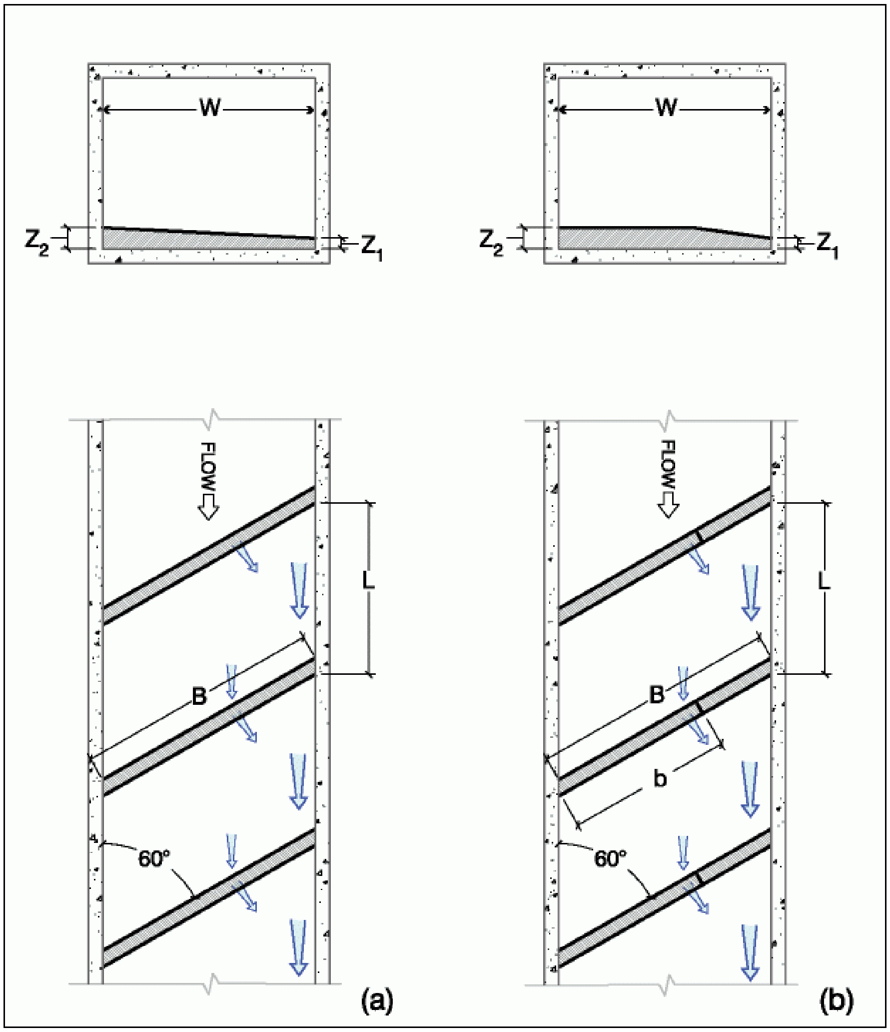


Figure XII-37. Section and plan view of angled baffles in a box culvert with (a) full tapered and (b) partial tapered crests.

Baffle Height and Spacing

For corner and weir baffles, the height of the notch above the culvert *invert* (Z_1 in Figure XII-36) and baffle spacing (L) are set to meet depth criteria at the low passage design flow and to provide sufficient roughness to satisfy velocity criteria at the high passage design flow.

In general, baffle spacing should be no less than 5 feet and should be set so there is at least 0.2 feet of drop between each baffle. Closer spacing or less drop increase the risk of sedimentation in a gravel-bedded stream. More drop would be required to scour larger bed material. Closer spacing may also fail to provide sufficient velocity shelter for fish to rest. In steeper culverts, taller baffles and closer baffle spacing might be required. In streams with large debris or sediment loads, goals associated with fish passage and structural risks may have to be compromised.

Water depth is always calculated between the baffles rather than on the baffle crest. At low flows, when baffles function as weirs, the minimum depth between two baffles occurs immediately downstream of each baffle. At higher flows, when water is streaming, the water surface slope matches the culvert slope and water depth is relatively uniform, though turbulent, between baffles. Like water depth, water velocity is calculated using the wetted area between the baffles rather than along the baffle crest.

For corner baffles and weir baffles, the high end of the baffle (Z_2) is typically set so the baffle is almost fully submerged at the highest fish passage design flow. The intent is to maintain a low-velocity and low-turbulence passage corridor along the edge of the culvert at fish passage flows.

For angled baffles the design usually strives to have the water depth just fill the notch and fully wet the baffle (water depth = Z_2) at the low passage design flow for the largest target fish, such as adult salmon or steelhead. This results in a minimum baffle height required to meet depth criteria.

Other Design Considerations

Adding baffles to a culvert requires attention to details beyond those addressed by the fish passage design criteria. These can include *hydraulic transitions* at the culvert inlet and outlet, providing sufficient *flow control*, minimizing sedimentation, and considering *fish attraction*.

Inlet Transition

An abrupt *drawdown* in the water surface as it enters the culvert may occur in situations where the culvert width is much narrower than the wetted width in the upstream channel, or the water velocity in the culvert is substantially greater than in the upstream channel (Figure XII-38). The overall drop in the water surface as it enters the culvert is the *inlet head loss*. The transition consists of a *flow contraction* followed by an expansion. In severe cases, this hydraulic transition can create a combined velocity and turbulence barrier to fish. Although there are no fish passage design criteria for maximum inlet head loss, it is recommended to avoid an inlet head loss exceeding 0.2 feet for juvenile salmonids and 0.5 feet for adult salmonids.

The inlet head loss can be calculated using standard methods associated with determining the headwater depth for a culvert (FHWA HDS-5 2005). The amount of head loss at the inlet is influenced by the water velocities in the upstream channel and in the culvert, the degree to which the culvert inlet constricts the approaching stream flow (relative size and alignment), and the shape of the inlet (i.e., projecting, headwall, wingwall, or mitered). In design of a baffle retrofit excessive inlet head loss can be corrected by further reducing the water velocity in the culvert or modifying the culvert inlet to make it more hydraulically efficient, such as adding wingwalls or other transitions.

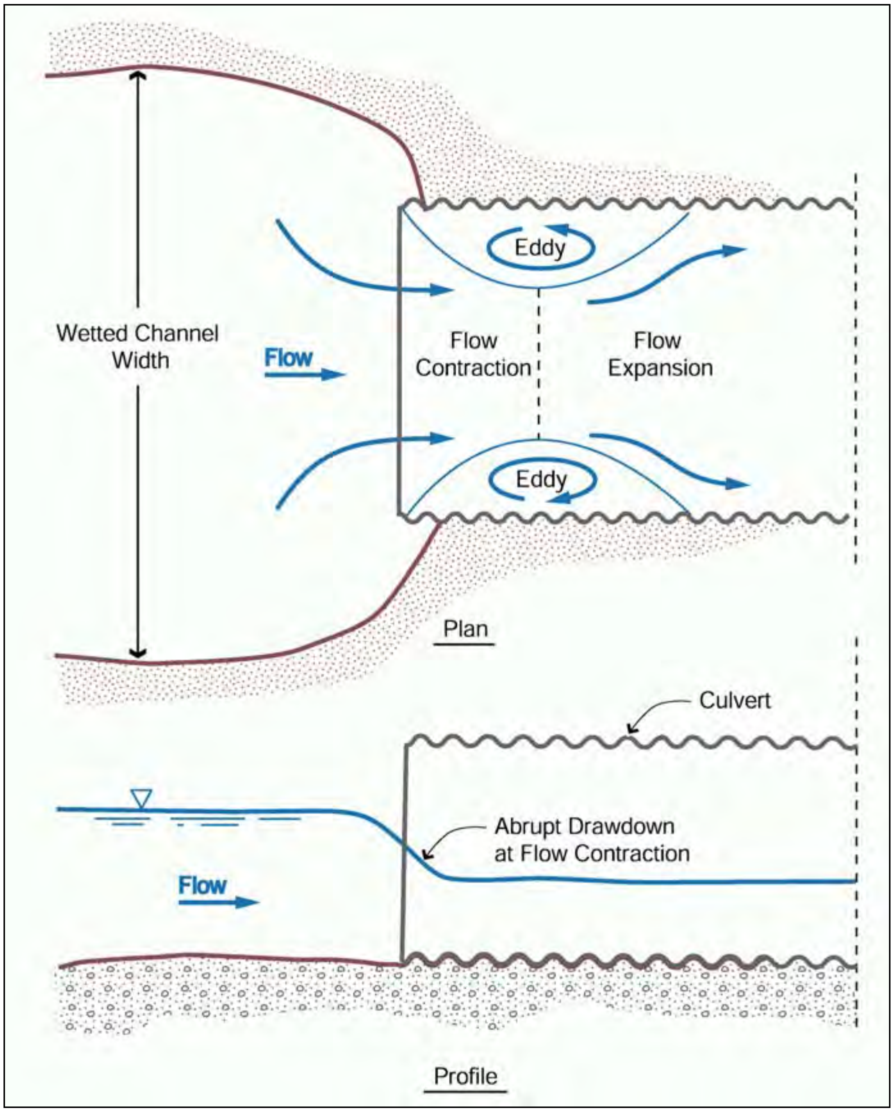


Figure XII-38. Contraction and acceleration of the stream flow as it enters a culvert can form a steep drawdown in the water surface. In certain cases, this drawdown may hinder fish passage due to excessive velocity and turbulence.

Outlet Transition

Designing a baffle retrofit requires attention to the hydraulic transition at the outlet at both the low and high passage design flows. Because baffles raise the water level within a culvert they will often create a hydraulic drop at the culvert outlet or increase the height of an existing drop. Even if there is no hydraulic drop at the outlet at low flows, a drop can form as flows increase and depth within the culvert increases more rapidly than in the *tailwater*. The result can be a substantial hydraulic drop at the culvert outlet during the high fish passage flow, creating a leap or velocity barrier, or both (Figure XII-39). Preventing a hydraulic drop at the outlet often requires adding weirs or other profile controls to the downstream channel to increase the tailwater level (see Profile Control page XII-54). If an outlet drop is unavoidable, the last baffle should be placed at the outlet and shaped like a notched weir to concentrate flow and provide good hydraulic conditions for fish to leap (see Weir Crests page XII-117). This last baffle may need to be taller than the other baffles to reduce the drawdown and acceleration in water velocity as flow approaches the freefall at the outlet. This may solve the drawdown and velocity effect but may create a leap barrier.

Figure XII-39. With increasing flow the water surface in the baffled culvert rises more than the tailwater pool, and a small hydraulic drop becomes much larger. The drop at high flow also causes water to drawdown and acceleration as flow approaches the culvert outlet, potentially creating a velocity barrier.

Dividing Walls for Wide Culverts, Multiple Culverts, and Aprons

In wide culverts, it may be necessary or desirable to baffle only one side of the culvert to achieve the desired hydraulic conditions for fish passage or minimize reduction in flow capacity due to the baffles. In these cases, a dividing wall running the length of the culvert separates the baffled and un-baffled sides (Figure XII-40a). Similarly, it may be necessary to use dividing walls on inlet and outlet aprons to confine the flow, especially at crossings with multiple culverts (Figure XII-40b).

Baffles in divided culverts frequently experience problems with excessive sedimentation. This problem can be due in part to concentration of high flows into the un-baffled section, leaving insufficient flow in the baffled portion of the culvert to scour the sediment. This is exacerbated when a dividing wall becomes overtopped at relatively low flows. Once the dividing wall is overtopped, the flow, water depth, velocity, and turbulence in the baffled section do not effectively increase with increasing stream flow (Figure XII-41a). If there is insufficient scouring forces, sediment will deposit and remain trapped between the baffles. To avoid this, a low-flow sill at the inlet of the un-baffled side might be needed to force sufficient flow into the baffled portion. The dividing wall should be high enough to contain flows that generate velocities and turbulence sufficient to scour and transport sediment (Figure XII-41b). In many cases this can be done be designing the wall height to prevent overtopping at flows less than bankfull flow. The low-flow sill might reduce the culvert capacity. The sill is often located at least one to two culvert widths downstream of the inlet to reduce the potential for debris clogging and minimize the effect of the sill on inlet control and culvert capacity.

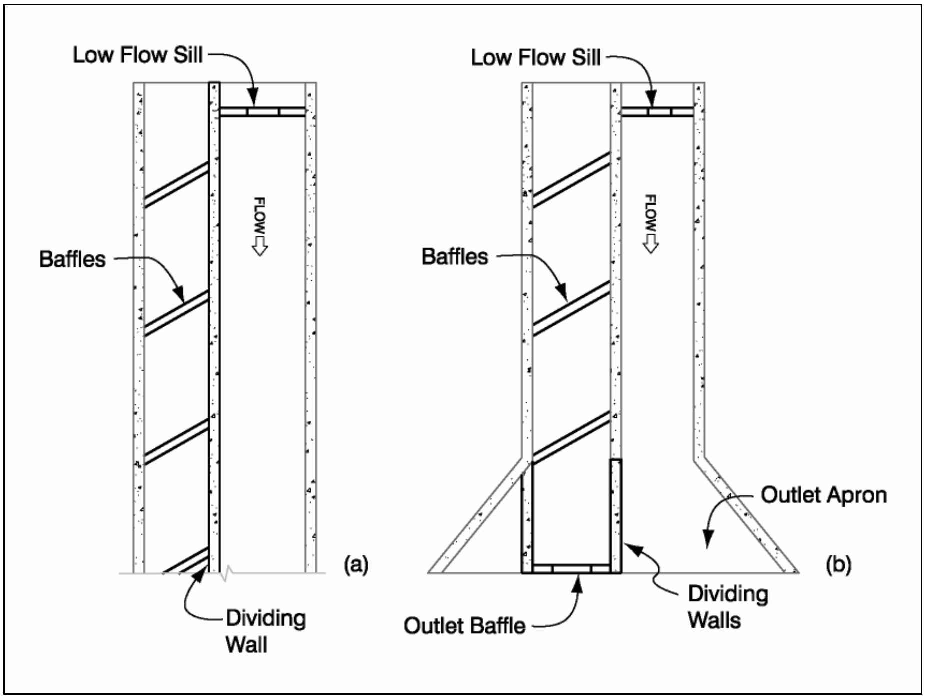


Figure XII-40. Dividing walls used (a) to baffle one side of a wide culvert and (b) to confine the flow on an outlet apron. The low-flow sill provides flow control to concentrate lower flows into the baffled section.

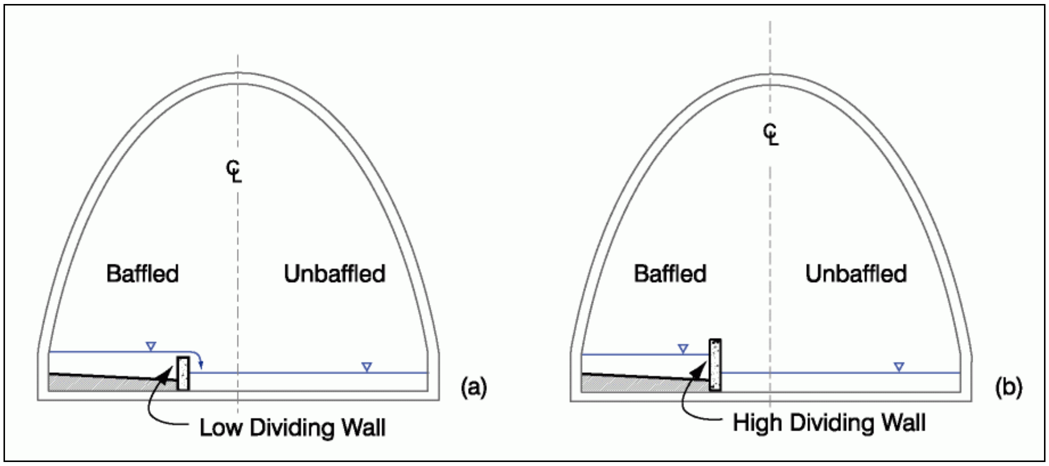


Figure XII-41. Section views of a wide culvert with (a) low and (b) high dividing walls that separate the baffled and un-baffled sections. Before overtopping the dividing wall, the baffled section should contain enough flow to generate sediment scouring forces.

Special attention is required at the downstream junction of the flows in the baffled and un-baffled sections. This junction should not create hydraulic conditions that may prevent fish from finding or successfully entering the entrance to the baffled section. Fish will be attracted to the un-baffled section if the flow is high. Refer to Fishway Entrance (page XII-111), for a description of conditions that aid in attracting fish to the entrance. In some cases, fish may swim through the un-baffled portion of the culvert. To help ease passage over the low-flow sill, the downstream face of the sill can be sloped and/or the sill can be notched.

Summary of Hydraulic Design Process

The hydraulic design of baffles in a culvert requires selection of the preferred baffle type and configuration that best satisfies fish passage criteria for the target species while meeting project constraints. The design process often requires several iterations before identifying a preferred baffle configuration. Due to site constraints and conflicting goals associated with retrofitting an existing culvert, it may not be possible to meet all design criteria and guidance. In such cases, it is important to have well defined project objectives that are acceptable to the reviewing agencies, weigh the impact of each decision on passage performance, and document the decision process. A design data form for hydraulic designs is included in Appendix XII-A and can be used for documentation of the process. In the end, the acceptability of the design relies on the degree to which it satisfies the project goals.

The design process begins with determining the target species and hydraulic design criteria and low and high passage design flows appropriate for them. Then select the baffle shape (corner, weir, or angled) appropriate for the culvert type. Next, determine the baffle configuration (height, spacing, and geometry) that meets minimum water depth criteria at the low passage design flows. Also, check the EDF at the transition from plunging to streaming flow to ensure the pools between the baffles are not excessively turbulent. Once a baffle configuration that satisfies minimum depth requirements has been determined, check that it satisfies maximum water velocity and EDF criteria at the high passage design flow. If not, velocity and turbulence can be reduced by increasing the baffle height or decreasing the baffle spacing, or some combination of the two. If only a portion of the stream flow will be conveyed through the baffled section, flow control and dividing walls need to be designed in conjunction with design of the baffles.

Once a preferred baffle configuration is selected, check that turbulence and scouring forces are sufficient to avoid excessive sedimentation between the baffles. This should be done at a flow when the upstream bed material begins to mobilize, which may be approximated in a natural stable channel using the bankfull flow. If sedimentation appears likely, increasing baffle spacing or lowering baffle height may reduce sedimentation risk.

Once the baffle arrangement is determined, the hydraulic drop at the inlet and outlet transitions should be evaluated at the low and high fish passage flows. Excessive inlet head loss may warrant changes to the baffle arrangement or modifications to the culvert inlet to improve entrance efficiency. Excessive drop at the outlet may be addressed with profile control measures (Profile

Control page XII-54) in the downstream channel. If an outlet drop at fish passage flows is unavoidable, an outlet baffle that creates a good hydraulic transition for fish to swim or leap into the culvert should be included. This baffle will function similar to a fishway weir (see Pool and Weir Fishways page XII- 113), for desirable weir shape characteristics for fish passage.

Once the culvert retrofit design has been completed, the hydraulic capacity of the baffled culvert needs to be evaluated. Determine the *structural design flow* for the culvert (e.g., 100-year flow), which is the flow that the maximum allowable headwater occurs. Check the hydraulic capacity of the baffled culvert to ensure it meets project constraints. If the baffled culvert is *outlet controlled* at the structural design flow, the baffles will likely reduce the culvert capacity. If the retrofit culvert lacks sufficient capacity, options are limited. It may be possible to increase incrementally hydraulic capacity by moving the first baffle downstream from the inlet, modifying the culvert inlet to improve hydraulic efficiency, or adding an overflow culvert. Meeting culvert capacity objectives may require reducing the baffle height and/or spacing, thus reducing the effectiveness of the fish passage design.

A step-by step design procedure for design of culvert baffles is provided in Appendix XII-C along with additional guidance, references, and equations for baffle hydraulics.

Final Design and Construction Techniques for Baffles

Once the hydraulic design of the baffle has been completed, the next step is to determine the baffle material and method of securing.

Materials for Baffles

Baffles are commonly constructed of wood, concrete, steel, plastic, and composites. The selection of baffle material is often governed by how the baffles will be attached, the culvert shape, material and condition, site access for construction, and the stream's sediment and debris loads.

Wood has been used for baffles for a long time. Tight-grained redwood is preferable due to its resistance to rot associated with recurring wetting and drying. Although lumber is less resistant to abrasion than steel and concrete, redwood baffles installed in numerous culverts on high bedload streams still function more than 30 years after construction. With suitable redwood becoming difficult to obtain, the use of recycled plastic lumber and other wood-plastic composites is becoming more common.

Lumber is generally easy to hand-carry and place into a culvert, making it well suited for difficult to access culverts. Baffles can also be constructed using several smaller pieces of lumber bolted together. It can be cut on-site to conform to the culvert shape, making it well suited for use in metal culverts, which typically have a varied cross sectional shape due to loading and settlement.

A characteristic of redwood is that it swells when wet. This helps ensure a tight fit along the culvert floor and walls. If using synthetic lumber, it may be necessary use a rubber gasket or grout between the culvert and the baffle to achieve a watertight seal.

Reinforced cast-in-place concrete is often used in concrete culverts. Like wood baffles, the wooden forms can be cut to match the shape of the culvert floor. Concrete is susceptible to abrasion and impact from large bedload and debris. Angle iron can be placed on the upstream face of the concrete baffle to increase its durability and longevity. Additionally, higher strength concrete and other admixtures can increase strength and durability.

Baffles in circular culverts are frequently fabricated from steel. Steel baffles are highly durable but can be difficult to install. Because steel baffles are generally prefabricated, care must be made to measure the culvert cross section at each baffle location to ensure the each baffle fits snuggly against the culvert. A gasket or grout between the metal baffle and culvert is sometimes required to achieve a good seal.

Anchoring Baffles

In reinforced concrete culverts, baffles are most commonly attached to the culvert by bolting or doweling and into the floor and the walls of the culvert. Lumber and metal baffles can be secured into holes drilled in the concrete floor using long threaded rods or bolts embedded with epoxy or grout.

Baffles are commonly secured to metal culverts using “L” bolts or expansion bolts. The bolts travel through holes drilled through the culvert wall. Another method is welding the baffles to the metal culvert using gussets.

Another technique for securing baffles in corrugated metal culverts is to use prefabricated steel baffles welded onto expandable hoop-rings (Bates et al. 2003). The rings are expanded into the corrugation by an arrangement of nuts and threaded rings similar to turnbuckles. Each baffle should be fitted for its exact location due to the varied cross sectional shape of an individual culvert.

There are several approaches to addressing situations in which the strength of the culvert floor, whether concrete or metal, is inadequate to carry the lateral or pullout load exerted by the baffles. These include adding a reinforced concrete lining along the invert, slip-lining in circular culverts, and use of helical anchors that extend into the soils underneath the culvert. Pressure grouting the void exposed by a hole drilled through the culvert floor might provide reinforcement for an anchor bolt.

Adding a reinforced concrete lining along the culvert invert is a common practice for rehabilitating deteriorated metal culverts and box culverts with exposed rebar. The baffles can be installed at the same time the culvert is being concrete lined, using the reinforced lining to secure them in-place.

Slip-lining is another approach to rehabilitate deteriorated circular culverts. The liner should be a metal pipe rather than plastic when adding baffles. Corner or weir baffles can then be welded into the new metal pipe before installation.

Helical anchors that extend into the soils beneath the culvert invert have been used to secure baffles in both concrete and metal culverts. The anchors are designed to transfer lateral loads from the baffle to the soil rather than to the culvert. A geotechnical investigation may be required to determine the feasibility of using helical anchors at a specific site.

FISHWAYS

Common fishways used at culverts and low dams in California are discussed below. This is only intended to be an introduction to general concepts and application of various fishway styles. It is not intended to have sufficient detail to guide a final design. Other options such as lowering or removing a dam or other barrier should be considered but are not described.

Formal fishways are not the preferred fish passage solution at culverts and low dams. Solutions with diverse hydraulic conditions and passage corridors, such as stream simulation, roughened channels and boulder weirs, are preferred over formal fishways because they provide passage for a broader range of species, often over a broader range of flows.

Fishways are designed primarily based on hydraulic criteria such as flow, velocity, turbulence, and drop height. Figure XII-42 shows the layout of a typical bypass fishway, one of several fishway styles, and common components and nomenclature used for fishways. Other pool-style fishways would have a similar general layout.

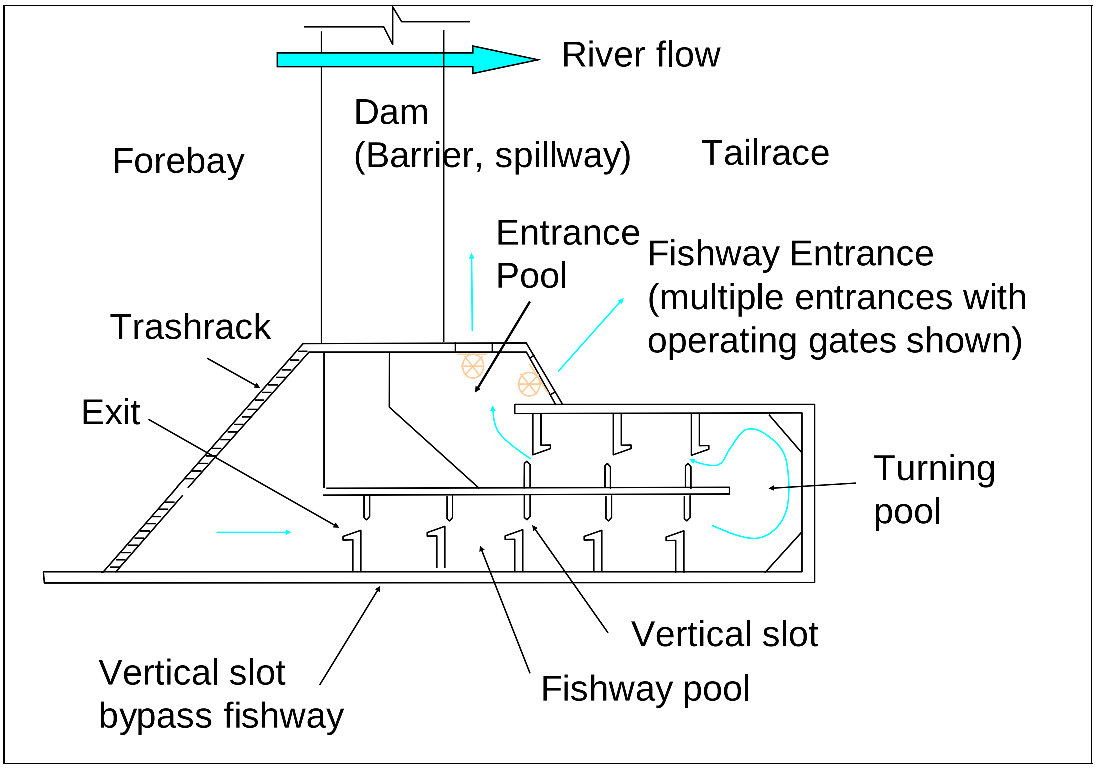


Figure XII-42. Vertical slot fishway with typical fishway nomenclature.

Entrances and exits refer to the fish entrances and exits as they move upstream. *Tailrace* and *forebay* (or *headwater*) are the areas downstream and upstream of the entrance and exit respectively. The entrance pool is the first pool inside the entrance. Auxiliary water systems supply additional water to the entrance pool to help attract fish to the entrance. *Flow control* is the system that controls the rate of flow to the fishway as the river flow changes.

Only fishways at culverts and low dams are discussed in Part XII. Concepts and details such as operating entrance gates, multiple entrances, auxiliary water systems, trap and haul systems, mechanical flow control systems, which are used in larger facilities are not described.

Six fishway styles are described:

- Pool style fishways
  - Simple pool and weir
  - Ice Harbor
  - Pool-and-chute
  - Vertical slot
- Roughened channel fishways
- Denil and Alaska steeppass fishways.

Most of these fishway styles can be used at a variety of locations - at dams, downstream of culverts, and within culverts. Specific applications and limitations are described with the descriptions of each style. The appropriate choice of a particular fishway style for a site depends on a number of variables including:

- Project goals including species and age classes to be passed
- Scale of system and project; dam height, channel, hydrology
- Degree of *flow control* available
- Dependability of operation and maintenance
- Debris, bedload, and ice considerations
- Capital, operation, and maintenance costs.

Fishway Pre-Design

Pre-design is a project step that accounts for characteristics of the stream and inter-relationship of the barrier, the stream, and the target species. It includes understandings of project hydrology, hydraulics, sediment, debris, target species, and fishway layout. Pre-design is generally described in Pre-Design (page XII-4). Additional elements of pre-design that are unique to fishways are described below.

A fishway might span the entire channel or be located adjacent to the channel and take only a portion of the flow. For full-spanning fishways, the project and fishway profiles are a primary focus of site assessment as it was for culverts. For bypass fishways, the fishway entrance and exit locations and hydraulic conditions are primary foci.

The pre-design should provide a framework for designers and interested parties to make decisions requiring trade-offs about fishway style, fishway flow and flow control, entrance and exit conditions, and maintenance and operational expectations.

Pre-Design Site Assessment

In addition to the general site assessment needs described in Pre-Design (page XII-4), these data are often necessary and unique to fishway designs:

- Document bathymetry of any scour or holding areas below the barrier.
- Develop continuous flow gaging, peak flow gaging, basin correlations, and hydrologic regressions. Accuracy of flow estimates for fishway design are important where flow control is required.
- Develop stage-discharge rating curves at the tailrace and forebay of the barrier.
- Document circulation patterns in the tailrace that might affect movement of fish for the range of fish passage flows. Videos are good for documenting flow patterns and flood conditions.
- Document observations of fish accumulating or leaping at the barrier.
- Detailed geotechnical information might be needed for more complex structures.
- Hydrology.

Fishway Layout

A fishway layout can be either full channel width, partial width, or a bypass. Figure XII-43 shows schematics of the three layouts for the example of roughened channel designs. These layouts apply to most fishways regardless of the style.

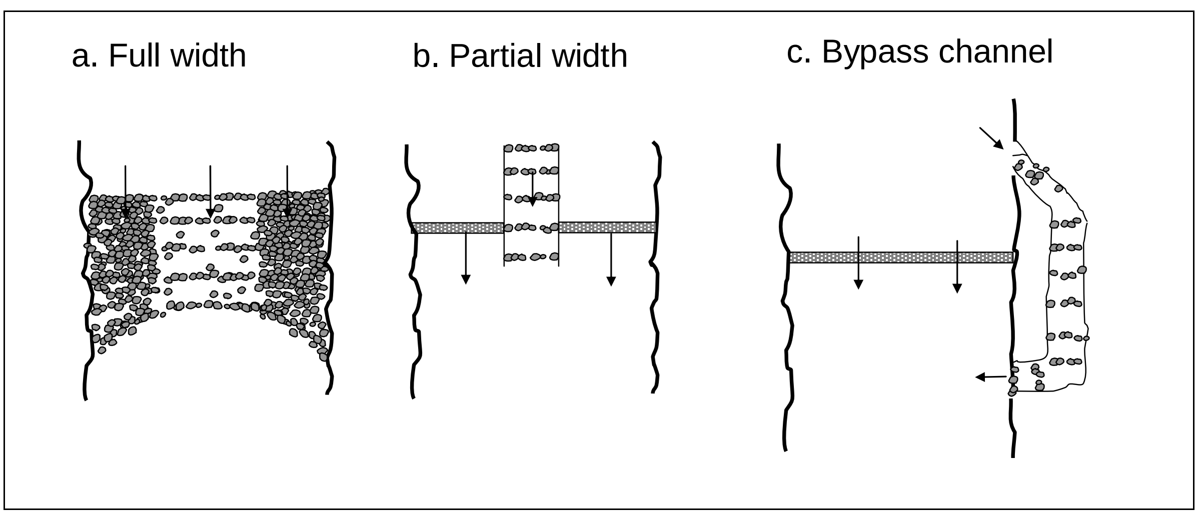


Figure XII-43. Fishway layouts (a) Full width, (b) Partial width, and (c) Bypass fishways.

A full width fishway (Figure XII-43a) has the advantage that it spans the channel so fish have no problem finding it. It normally has no flow control. *Flow control* is a system that meters the flow into a fishway and the hydraulic head and/or depth at the entrance, exit, or other locations as the stream flow changes. Full width fishways are limited in the width and slope of the channel in which it can be applied. It works well downstream of culverts and in incised channels. The fishway might consist of a roughened channel or independent weirs as described in Profile Control (page XII-54).

A partial width fishway, as shown in Figure XII-43b, can be applied to a wider channel. It might be on a bankline or in the center of the channel. The fishway shown in the figure has the disadvantage of being located mid-channel and thereby having poor access for maintenance and operations. On the other hand, the fishway entrance is more accessible by fish approaching from either side of the channel. It also has the disadvantage that, unless the fishway is constructed through the dam and partially upstream of the barrier as shown in the figure, the fishway entrance might be located downstream of the barrier. A basic principle of fishway design is to locate the fishway entrance near the barrier and not downstream of it, so fish are not forced to move back downstream to find it. If the fishway is moved upstream as in the figure, flow control is difficult because the upstream fishway walls might be overtopped at some high flow.

The bypass fishway is isolated from the channel (Figure XII-43c). It might be away from the dam as shown or built into the bank. A primary key to successful fish passage is attracting fish into the fishway, which can also be the greatest challenge in the design of a bypass fishway. The advantages of a bypass fishway are that it can be built and maintained in the dry and out of the channel, it has the smallest footprint, and the entrance can be located at the optimum location, such as at barrier. Fishway flow control devices and debris racks are easiest to include and operate in a bypass layout. A bypass fishway is generally smaller than other styles and the entrance can be hard for fish to find.

Fishway Entrance

Fishway entrances and entrance pools have several purposes. Complex hydraulic settings might require complicated entrance pool designs with multiple entrances equipped operating gates, attraction jets, and auxiliary water systems. The design of fishway entrances for small dams and culverts should consider, as appropriate, the functions and concepts described below. These apply to partial width and bypass fishways. In the case of full-channel fishways, the entire channel is the entrance.

The most obvious, and necessary, purpose of fishway entrance pools is to provide fish access to the fishway. Fishway entrance hydraulics are designed to attract fish. The jet of water leaving the fishway entrance is an extension of the fishway into the tailrace and serves to guide fish to the fishway. The further the entrance jet penetrates the tailrace, the further the path is carried.

As described previously for partial-width fishways, the location of the fishway entrance should be at the upstream-most point of fish passage. Take into account the locations where fish hold before attempting to pass the barrier, and routes by which they will approach the barrier and fishway. All of these hydraulic considerations can change through the range of passage design flows. Redundant entrances can be provided if the proper fishway entrance locations are not well identified. Be aware of eddies and local flow conditions, especially at high flows. "Upstream" to a migrating fish means swimming into the approaching flow. Fish that must approach fishway entrances located in an eddy, may have to swim downstream or across the direction of flow to get to it. A fishway that is built on a bankline can create eddies that make the entrance difficult to find.

Field observations, time-stamped photos and videos, and sketches of flow patterns above and below the barrier should be made, especially for high flows. Physical model studies might be required for complex tailwater conditions. Observations of fish location and orientation when attempting to pass a barrier are additional valuable information.

There are no specific fishway entrance flow criteria. For fishways at dams, the entrance flow must be adequate to compete with spillway or powerhouse discharge flow for fish attraction. Site conditions, especially tailwater hydraulics and channel width, determine entrance flow requirements. Ultimately, the fishway entrance flow may determine the scale or style of fishway used. The scale of the river setting gives some insight into requirements for entrance flow. Bates (1992) described entrance flows as typically three to ten percent of the stream flow at the high fish passage design flow. NOAA guidelines recommend a minimum of five percent.

The greater the momentum of the jet from the entrance, the further it reaches into the tailwater and the more successfully it can guide fish to the entrance. A fishway entrance jet is optimized when it has the following characteristics:

- Streaming, rather than plunging flow, plunging flow creates a boil, not a jet.
- Head differential is high but not so high that it creates a velocity barrier for the burst swimming ability of target species.
- Entrance jet is not dissipated by high-energy flow such as turbulence from a spillway or turbine.
- The entrance and entrance pool interior are well lit to ambient light levels.
- Jet is concentrated. A concentrated jet penetrates further than a thin jet of the same cross-section area and flow.

Optimum entrance conditions for adult salmonids are typically a barrier to juvenile fish.

The fishway entrance head differential should be maintained throughout the passage design flow range. An entrance head differential of one foot is commonly applied to fishways for adult salmonids and the flexibility to increase that to 1.5 allows optimization of entrance conditions. Large fishways typically have operating gates that are used to optimize the attraction jet as the stream flow changes. Fishways on small dams and culverts are designed to operate without intervention. In that case the design usually cannot be optimized for all flows, but should be optimized for the prevalent fish passage flow and while being passable through the entire range of fish passage flows. An entrance design might result in trade-offs between a narrow vertical slot or an orifice and a weir crest optimally shaped for a specific flow. The vertical slot or orifice maintain better hydraulic conditions through a wider range of flows and continue to operate even if tailwater elevations are lower than expected. The weir entrance is optimized for a narrow flow range, is less vulnerable to debris, and has surface flow, which is attractive to leaping fish. Bates (1992) describes additional details of fishway entrances.

Pool and Weir Fishways

Pool style fishways are a series of pools at consecutively higher elevations. Water flows from pool to pool either over a weir (e.g., pool and weir), through a slot (e.g., vertical slot), through an orifice, or a combination (e.g., pool-and-chute). Fish leap or swim from pool to pool to gain elevation. The energy of the flow entering each pool is entirely dissipated in each pool before it flows to the next.

Pool and weir fishways are the most common style used at culverts and low dams and are applied to all scales of fish passage. The fishway is an open channel with pools that are separated by weirs, sometimes with orifices in the weirs. The shape and elevation of the weirs control the hydraulics within the fishway.

Pool and Weir Hydraulics

A primary limitation of the pool and weir fishway is the narrow range of operating flow. Two hydraulic conditions are important in the design of pool and weir hydraulics: the flow regime (plunging or streaming) and turbulence, which apply to other fishway styles as well. At the high passage design flow, the fishway flow should be in plunging flow regime and turbulence should be limited. These characteristics as well as freeboard, and fishway bends are described for pool and weir fishways but apply to various degrees to other fishway styles as well. Any differences are noted with the description of the other fishway styles.

<u>Plunging and Streaming Flow Regimes</u>

The normal flow circulation in a pool and weir fishway is the plunging regime. Plunging flow is characterized by a circulation pattern of water flowing over the upstream weir creating a nappe that plunges downward towards the fishway floor, then moves downstream along the floor and rises along the face of the next downstream weir before either dropping over the weir or rolling back upstream along the surface of the pool (Figure XII-44). As flow increases in the fishway, the hydraulics transition through a range of transition conditions and eventually to streaming regime. In streaming, a continuous surface jet passes over the series of weir crests and skims along the surface of the pools. Shear forces create a circulation in the pool opposite to that in the plunging regime.

Hydraulic instability such as surging and oscillations in the water surface often occur in the transition between the upper range of plunging flow and the lower range of streaming flow (Bell 1991). This transition regime should be avoided. Passage studies have repeatedly shown that when fishway flows operate at the transition point, passage delays occur.

The streaming regime is the basis of the hydraulics of baffles in culverts and flumes. It should be used with caution in fishways because the energy is not dissipated in each pool and the streaming jet is difficult to control.

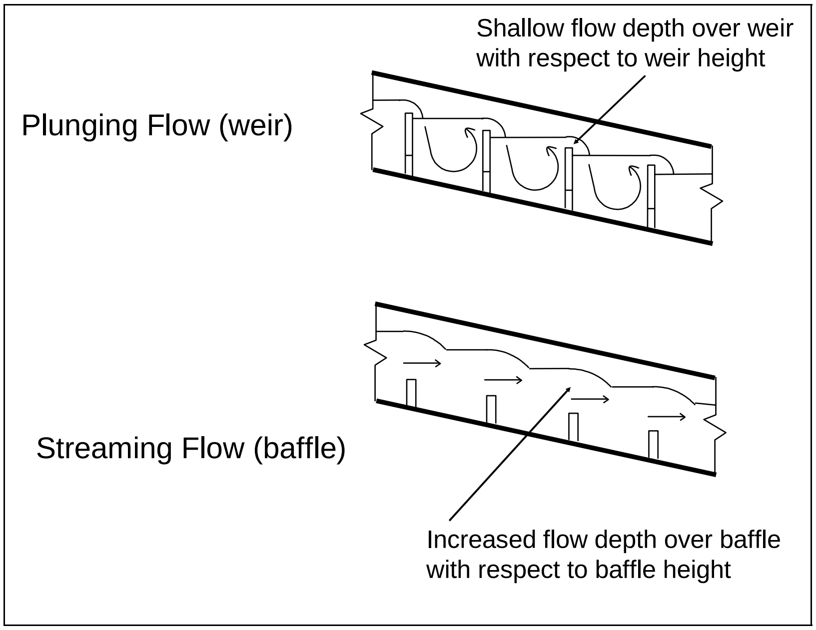


Figure XII-44. Plunging and streaming flow regimes relative to depth over the weirs or baffles.

The flow at which the regime transitions from plunging to streaming depends on the geometry of the pool, the flow, and the head differential between pools. Ead et al. (2004) describe these flow regimes and formulae for estimating the transition flow. Figure XII-45 is from Ead et al. and shows the relationship of plunging and streaming flows and pool geometry. The plot is non-dimensional, where:

Q_{t*} = Flow at which the transition occurs.
L = Length of fishway pool
p = Height of the weir

The equation reported by Ead et al. (2004) is rearranged to solve for the transition flow:

$$Q = Q_{t*}\sqrt{g}\,b_o S_o L^{3/2}$$ **Equation XII- 9**

Where:

Q Transition flow (cfs)

Q_{t*} Dimensionless transition flow (from Figure XII-45)

g Gravitational acceleration (32.2 ft/s^2)

b_o Width of fishway weir (ft)

S_o Slope of fishway (ft/ft)

L Length of pool (ft).

The original equation is non-dimensional but English units are provided as an example.

Figure XII-45 shows a wide range of flows in the band of transition between plunging and streaming conditions. Based on the flow characteristics described by Ead et al. for the purposes of fishway design, the upper limit of the plunging flow regime should be used. The work reported by Ead et al. is from horizontal weirs. The upper limit of plunging flow can be increased and the band of transition flows can be reduced with the shape of the weir crest as described in Weir Crests (page XII-117). Sloping weir crests can allow both plunging and streaming flow regimes to exist concurrently across the weirs. For sloping weirs, Equation XII-9 may be applied by approximating the weir shape as short segments with horizontal crests. Use the average elevation of a segment of the weir to determine the transition flow within that segment. This allows for estimating the portions of the weir section with plunging and streaming flows. Ead et al. also developed a formula for predicting the flow in streaming condition for pool and weir geometries.

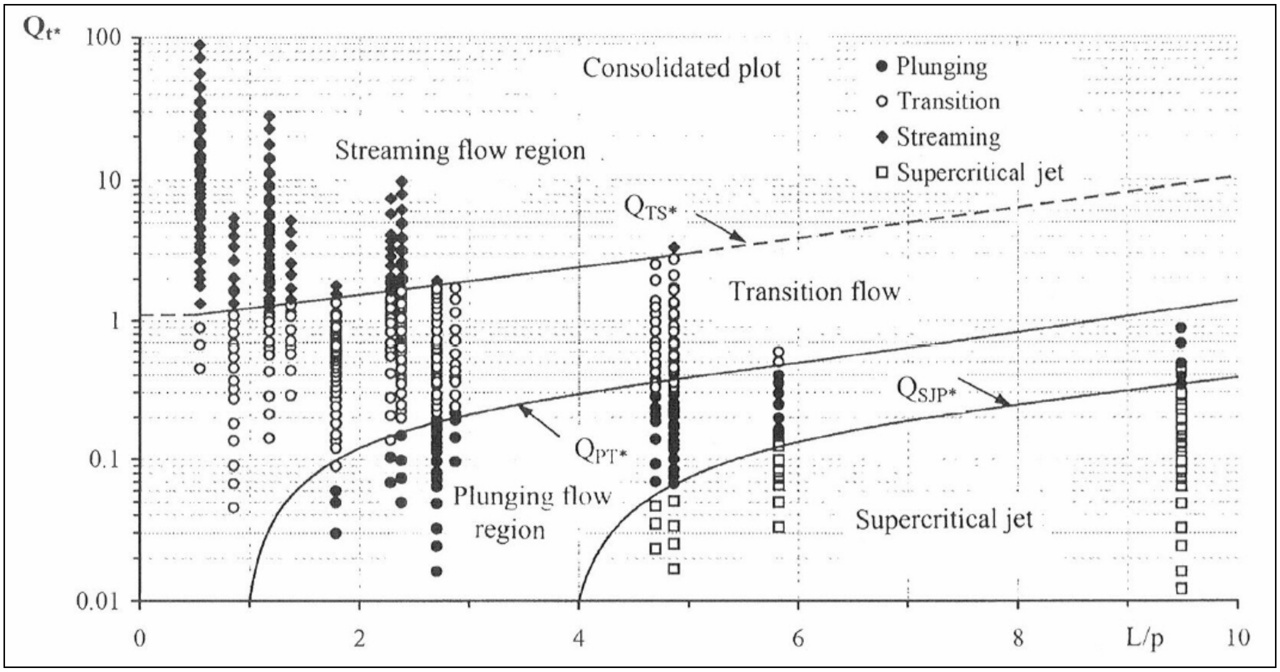


Figure XII-45. Plot of flow regimes in a pool and weir fishway, reproduced from Ead et al. (2004) with permissions from the publisher.

Turbulence

The volume in a fishway pool must be adequate to dissipate energy without being too turbulent for fish to hold and move through it. The rate energy is dissipated in a pool is described by the *energy dissipation factor* (EDF) and can be calculated with Equation XII-10. A maximum EDF of 4.0 foot-pounds per second per cubic foot of volume is recommended for adult salmon and steelhead (Bell 1991) and 3.0 foot-pounds per second per cubic foot of volume for shad and adult trout species, which would include resident rainbow and coastal cutthroat trout (Larinier 1990).

$$EDF = \frac{\gamma Q h}{V} \qquad \text{Equation XII- 10}$$

V Effective volume of the pool for dissipating energy (ft^3)
γ Unit weight of water (lb/ft^3)
Q Flow entering the pool (ft^3/s)
h Head of the drop flow entering the pool (ft)

The head of the flow is the sum of the static head (drop in water surface) and kinetic head (function of velocity) entering the pool. The effect of kinetic head is generally negligible. This relationship shows that the greater flow and/or head entering a pool, the greater the volume needed to dissipate the energy without excess turbulence. Flow and/or head can therefore be controlled to manage energy dissipation (see Fishway Flow Control page XII-129).

Portions of the pool, because of its length or shape, may not be effective to dissipate energy. Most of the energy is dissipated near the plunge and, since fish have to pass through that area, the calculation of EDF should focus on that area. Pool lengths greater than eight feet or deeper than four feet should not be included in energy dissipation volume calculations.

Specific dimensions of fishway pools depend on the style of fishway, target species, scale of the river, and degree of flow control. Typical pool lengths and widths vary from four by six feet to eight by twelve feet. Pools as small as several feet wide and four feet long have been successful for smaller fish and with very precise flow control. The fishway depth should be enough so fish will not be stressed or reject the fishway. Typical depths required for large fish vary from three feet in streams and smaller rivers to eight feet or more in large rivers. Exposure and bright light may increase stress of fish and therefore require more depth.

Fish Behavior

Fish behavior and swimming abilities affect design concepts and the details of fish ladder design because various species move through fishways in different ways. Chinook and steelhead use weirs and orifices; early migrating Chinook tend to choose to swim through orifices rather than over weirs. Steelhead often reject fishways that are undersized, shallow, or cause the fish to be exposed. Shad use weirs exclusively and generally seek streaming flow conditions. They are wall-oriented, and can be trapped in dead-end corners. Sturgeon, suckers, carp, and many warm water species typically use orifices.

There are many additional species of interest in California though little is known about their behavior in fishways. If a fish passage project includes non-salmonid target species, advice should be sought from biologists familiar with the species regarding any typical behavior patterns.

Head Differential

Head differential is the difference in water level between two adjacent pools or at the fishway entrance. The allowable head differential depends on the species and age class of fish to be passed, the style and dimensions of the fishway, and the flow in the fishway.

Pool and weir fishways are intended to operate with plunging flow so energy is fully dissipated in each pool. As described in Turbulence (page XII-54), the flow condition depends partially on head differential. Too high a head differential and there will be too much turbulence in the pool and/or a leap barrier for some fish. Head differential should be limited to 1.0 foot for adult salmonids.

The head differential can be increased if it is contained in a chute without free falling flow and strong swimming fish (e.g., adult salmonids) are targeted for passage. The entrance might be operated with a differential that exceeds the criteria to enhance attraction to the fishway as long as target species can burst through the higher velocity and the flow is streaming.

Freeboard

Freeboard is the dimension from the water surface to the top of the wall. It should be enough so leaping fish cannot easily leap out of the fishway. A minimum of three feet is suggested for adult salmonids though more is required if there is upwelling or other hydraulic conditions that might induce a fish to leap somewhere other than at the weir. The freeboard in smaller fishways can be easily extended by constructing a fence or a wall on top of the fishway wall flush with the inside wall. Be aware of the effect of debris becoming snagged by fencing or of being damaged by high flows.

Fishway Bends

Long fishways are often laid out to switch back on themselves through a series of bends. The fishways in Figure XII-42 and Figure XII-46 include bends. Weaver (1963) reported significantly longer passage times through corner and bend pools. Regardless of the fishway style, details of the bends should be considered carefully to eliminate upwelling in corners and to maintain consistent flow patterns. An additional pool length at the bend might be needed to realign the flow to the downstream weir or slot. The outside walls of the turn should be shaped to carry the jet from an orifice around the bend without impacting a wall where upwelling could distract fish.

If the jet must follow the inside wall, the wall should be extended for a standard pool length downstream of the weir or a baffle should be added to disrupt the jet and deflect the flow into the center of the pool. For vertical slots, the baffle is essentially the same as the short wall forming a vertical slot. Fishway bends cannot be used in pool-and-chute fishways.

Weir Crests

The cross-section and longitudinal shapes of the weir crest are important features. The range of flows for which plunging flow persists is extended and the transition band is reduced or eliminated if the crest is rounded or chamfered on the downstream side. The value of Q_{t*} in Equation XII-9 can be increased by 25% by rounding the downstream side of the crest with a 6-inch radius. An orifice at the floor below the crest, such as an Ice Harbor Fishway (page XII-120) also extends the plunging regime.

The depth of flow over the weir crest should be at least the depth of target species that do not leap. A notch that is submerged by at least 6 inches by the backwater from next downstream weir works well. Notches should be V-shaped widening toward the top to help pass debris and to create a variety of hydraulic conditions for fish passage.

A minimum of 3 inches of depth over weirs in a fishways in small to moderate streams without flow control is reasonable for leaping fish. Depth at the crest can be somewhat controlled by the shapes of the weirs. For small applications, the width of a V-weir can be reduced by using half a "V" such as shown in the example of Little Fish Creek in Figure XII-46. The hydraulics of V-weirs can be analyzed by using standard V-weir equations or by analyzing them as short horizontal segments.

Design for Juvenile Salmonids

Juvenile salmonids (60 to 120 mm) can easily ascend a pool and weir fishway if the head differential, pool volume, and weir crest work together to create appropriate hydraulic conditions. Precise flow control is necessary to create passable conditions over more than a narrow range of flows. These fish can leap efficiently if conditions are good. First, to approach near the base of the weir, turbulence has to be low and not extend more than several feet downstream. To do that, the depth over the crest has to be shallow, no more than a few tenths of a foot deep and the flow has to plunge. A weir crest can be designed to gently slope across the fishway so there will always be a shallow depth at the water's edge at flows up until it is entirely submerged. The thickness of the weir should be minimized to less than four inches, so leaping fish more likely land in the pool rather than on the crest of the weir. If the wall thickness is greater than 4 inches, it is necessary to chamfer the downstream corner to reduce the thickness at the top of the wall to 4 inches or less.

Juvenile fish might be blocked at a fishway entrance that is designed with a high velocity to attract adult fish. There is no easy solution to this difference. A separate fishway entrance might be needed for juvenile fish. In an extreme situation, an entire second fishway might be needed.

Powers (1993) recommended that the head differential should not exceed 0.7 foot for sub-yearling coho. CDFG criteria and NOAA guidelines require a drop of 0.5 foot or less. Juvenile salmonids can leap higher than that but leaps become more erratic and less successful. Figure XII-46 shows an example of a fishway designed for juvenile coho with weirs as described above. A flow control weir just above the fishway exit controls flow to the fishway. An upstream migrant trap at the fishway exit has confirmed heavy use by the target juvenile coho.

Figure XII-46. Little Park Creek fishway design for juvenile salmonid passage. Baker Reservoir, WA.

Operation and Maintenance

Because hydraulics are critical to the performance of pool fishways, operations and maintenance are also critical. An important limitation of pool and weir fishways is that pool depth and volume are reduced if bed material accumulates there. Some gravel will be scoured from fishways that have plunging flow characteristics up to a relatively high flow. Gravel often reduces the pool depth to just a few feet and the entire pools will fill-in in the case of heavy gravel transport rates or cobble bedload.

Bedload bypasses and sediment sumps have been used to mitigate sediment accumulation but with only marginal benefits. Sediment bypasses have been built into the fishway exit so bed material is shunted over a spillway rather than into the fishway. The upper pool of a fishway could be designed as a sediment sump if there is a way to bypass the lower fishway pools with a sluice channel or to remove stop-logs to sluice the entire fishway channel. Sluicing at any but high flows may impact downstream habitats.

Sediment accumulation in the stream near the fishway exit can block low flow from entering the fishway or create a shallow condition that impedes fish exiting the fishway. The fishway design should include considerations of geometry of the dam or culvert and fishway that will affect sediment deposition and methods, access, and equipment needed for maintenance.

Debris is also a common problem in fishways. Small debris often blocks orifices and notches. Trash racks are commonly attached to the exits of bypass fishways but are not recommended if they will not be maintained regularly. A trash rack should be provided at the fishway exit when the fishway includes orifices or where pool dimensions are small relative to the size of debris present.

Written operating and maintenance plans should be developed for fishways so there is a good understanding of the maintenance effort expected by interested parties.

Ice Harbor Fishways

The Ice Harbor fishway is a specific pool and weir fishway with orifices, flow stabilizers, and a non-overflow section in the middle of each weir. It is built at a 1-on-10 overall slope (1 foot vertical to 10 feet horizontal). The half Ice Harbor fishway is, as the name implies, half of the Ice Harbor fishway, cut along the centerline. A schematic of a half Ice Harbor is shown in Figure XII-47. This configuration is recommended for moderate to large applications where good flow control is available. Wider non-overflow section and longer pools are acceptable.

A small half Ice Harbor fishway has a 3-ft weir crest and 15-inch square orifices and has a total flow of about 23 cfs with a foot of depth over the weirs. The flow must be consistent. The flow requirement is a limitation for the application of Ice Harbor fishways. To operate at a lower flow, the orifices would have to be equipped with sliding gates to close them off. Orifice dimensions as small as 12 inches by 15 inches have been used. The primary reason for not allowing smaller orifices is the increased risk of being plugged by debris.

There is little experience of sediment in Ice Harbor fishways since they are generally used at dams with flow control mechanisms that preclude the entry of bed material into the fishway. Small debris should not be a problem since the orifice at the floor will allow most of it to pass through.

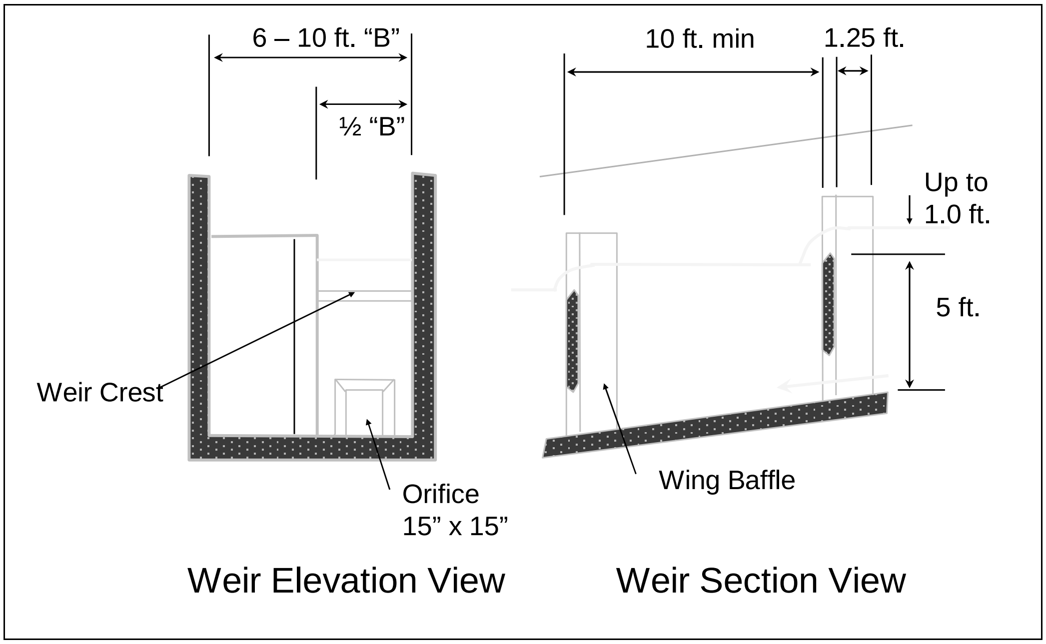


Figure XII-47. Half Ice Harbor fishway.

Pool-and-Chute Fishways

The pool-and-chute fishway is a hybrid fishway. It has a center notch or weir and sloping weirs that extend to the fishway walls. Parts of the fishway operate simultaneously in both plunging and streaming flow regimes at moderate to high flows. At low flow the fishway is essentially a pool and weir fishway as water spills over the center weir. At higher flows, water levels raise and flow spreads up the sloping weirs.

The fishway width is set so the high fish passage design flow does not quite cover the entire width of the sloping weirs. Shallow plunging flow exists at the flow margins so low-turbulence passage corridors are created along the sides of the fishway. Most of the flow streams down the center of the fishway at a high velocity and with high turbulence. If streaming flow is not achieved for the bulk of the flow in the center of the fishway, it will plunge and cause the entire pool to be turbulent. Figure XII-48 shows a pool-and-chute fishway at low flow. Figure XII-49 show a pool-and-chute fishway at low and high flow.

Figure XII-48. Fisher Creek pool-and-chute fishway at low flow.

(a)

(b)

Figure XII-49. Figure Silver Creek pool-and-chute fishway (a) high and (b) low flow.

The pool-and-chute design has some benefits over the traditional pool and weir fishway. For small tributary application, all of the flow can be contained in the fishway so attraction to the fishway is good and distraction caused by flow from a spillway is eliminated. Even when used as a partial-width fishway in a wide dam, the pool-and-chute fishway creates a strong jet, making it is very attractive to upstream migrants. Flood flows are contained within the fishway and can scour bed material and debris from the fishway, reducing maintenance. Diverse passage routes are available to fish moving upstream. Fishway pool sizes can be smaller than a traditional pool and weir fishway with the same range of operating flows.

It also has some disadvantages. Since there is a concentrated, high-velocity flow in the center of the fishway, it must be aligned in a straight line without bends. It therefore cannot normally be used in a bypass layout unless it has no bends and the entrance jet is directed into the stream. The entrance jet can cause erosion downstream if the channel is not wide enough or the fishway is not properly aligned with the channel.

Pool-and-chute fishways have not been extensively used or biologically evaluated. Hydraulics of the pool-and-chute are less certain than other fishways with more history. No more than five or six feet of head differential should be taken through a pool-and-chute because of the uncertainties of stability with the high energy in the fishway and the limited hydraulic verification done to date.

The fishway alignment in plan view must be straight with flow approaching from the upstream side parallel to the fishway walls. When used at the outlet of a culvert, the alignment must be parallel to the culvert flow, and be far enough downstream to allow the exiting flow to expand and achieve a low approach velocity before entering the fishway.

Pool-and-Chute Design

The basic layout consists of a center horizontal weir and two higher sloping shoulder weirs on the sides. Design of the pool-and-chute is complex. It requires a number of criteria be satisfied simultaneously and requires iterations among geometric and hydraulic parameters. The components used to define the pool-and-chute fishway are shown in Figure XII-50 pool-and-chute layout. Bates (1991 and 1992) developed the pool-and-chute concept and explained it more thoroughly.

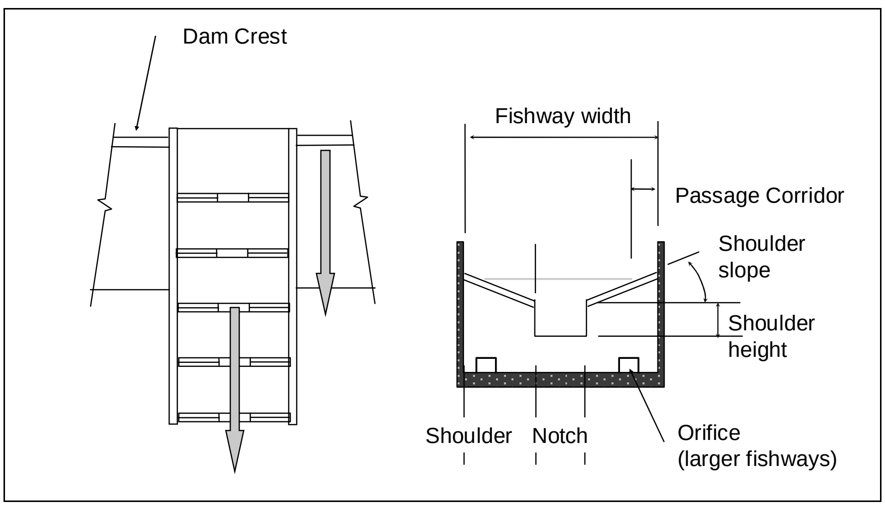


Figure XII-50. Pool-and-chute fishway layout with nomenclature.

Elevations of the horizontal notch weirs are based on plunging flow regime at low flow just as in a standard pool and weir fishway. The heights of the notch weirs control the pool depth at low flow.

The design of the sloping shoulder weirs is based on plunging and streaming flow regimes occurring simultaneously. There should be a corridor of plunging flow over part of the shoulder weirs when the flow over the horizontal weir transitions from plunging to the transition regime.

The depth over the edge of the shoulder weirs should be at least 6 inches when that transition occurs. See Plunging and Streaming Flow Regimes (page XII-113) for a description of plunging and streaming flow regimes and to estimate the transition flow at Q_{PT}* in Figure XII-45.

The drop per weir is based on fish passage criteria for a pool and weir fishway. The drops may also be affected by the hydraulic design in order to produce streaming flow at a given fishway flow. Streaming flow occurs at a lower flow when the head differential is reduced. Analysis of weir hydraulics must include velocity head within the fishway. The upstream weir has no approach velocity, and therefore should be 20% lower relative to the profile of the other weirs.

The maximum recommended fishway slope is 10%. At higher slopes, pool lengths have to be very short in order to get streaming flow over the notch weir. The pool lengths become inadequate to achieve the required energy dissipation factor over the shoulder weirs. Steeper slopes can be achieved if a narrow range fish passage flows is needed or of flow control is provided, which eliminates a great advantage of pool-and-chutes.

The sloping weirs slope up toward the fishway walls so at all flows, up to the high passage design flow, there is a shallow plunging flow regime at the water's edge. The outer edges of the shoulder weirs should be high enough so the outer two feet of the weirs are not submerged at the high fish passage design flow. Length and height of the shoulder weirs are set to maintain a fish passage corridor. A lateral slope of 1:4 or less is recommended. If low flows are high enough (about 30 cfs), orifices in the weirs and near the fishway walls can extend the plunging flow regime in that area. Orifices should be designed with considerations similar to the Ice Harbor design. As an added check, the energy dissipation factor (EDF) for the pool volume and plunging flow associated only with the shoulder weir portion of the width should satisfy the normal pool and weir criteria (see Turbulence page XII-54 for a description of EDF).

Once the geometry and high flow capacity of the shoulder weirs is set, the length of the notch weir is set to take the bulk of the fish passage design flow. The overall fishway width should be no wider than the channel because of the high velocity exiting the fishway.

Vertical Slot Fishways

Vertical slot fishways have distinct steps similar to pool and weir fishways, but hydraulic control is provided by narrow full-depth slots between the pools instead of overflow weirs Figure XII-51 is a schematic isometric view of a vertical slot fishway.

A great advantage of the vertical slot fishway is that it is entirely self-regulating. It operates without adjustment through the entire range of fish passage design flows. The difference and any change in elevation between the tailrace (entrance pool) and forebay (exit pool) is nearly equally divided among all of the fishway slots regardless of those water surface elevations and the river flow. Distributing the change throughout the fishway automatically compensates for any change in forebay and/or tailrace water surfaces.

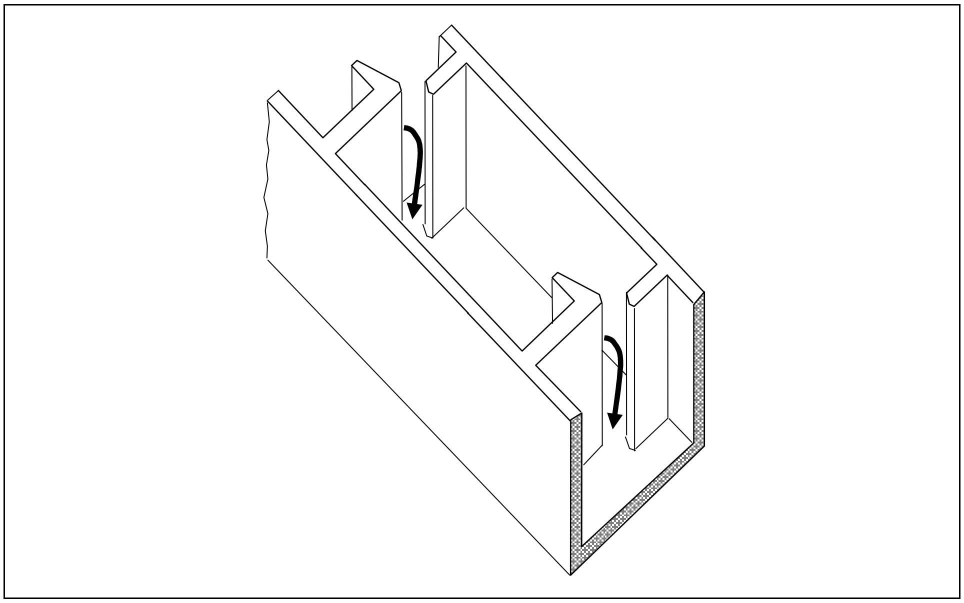


Figure XII-51. Isometric view of vertical slot fishway.

Energy is dissipated in each pool by the jet cushioning and mixing with water in the portion of the pool between the larger baffles. As additional flow passes through the fishway, the pool depths increase creating additional pool volume and maintaining appropriate levels of energy dissipation and turbulence. There is no need to calculate an energy dissipation factor as was described for pool and weir fishways as long as standard vertical slot fishway dimensions are used.

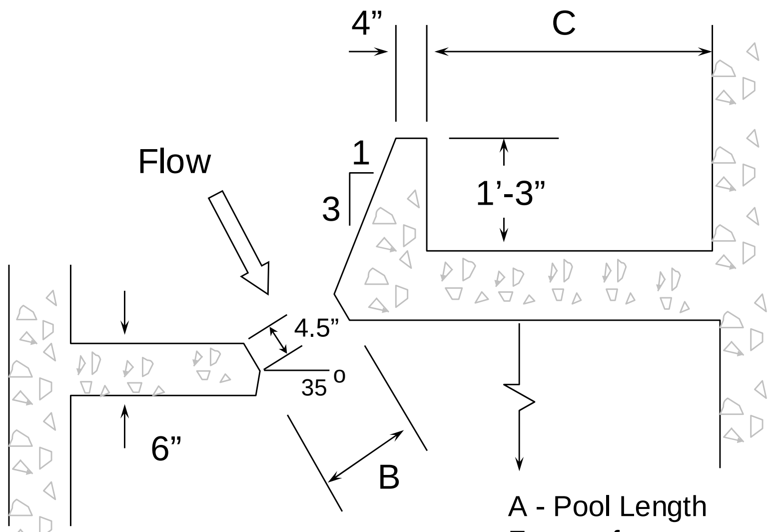
Passage

Another advantage of the vertical slot fishway is the full depth slots allow fish passage at any depth. Hydraulic studies by Rajaratnam et al. (1986) verified that the velocity through the slot is constant throughout the vertical profile.

The vertical slot is not usually suited for species that require overflow weirs for passage or that must orient to walls. For example, juvenile salmon can pass more successfully by leaping at a thin nappe over a weir than burst swimming though a high velocity jet. The vertical slot fishway gives those fish no opportunity to leap. Weak swimming fish may not be able to burst through high velocity jets in fishways designed for adult salmonids. Fish, such as lamprey and shad that orient to walls are often challenged and delayed by the tortuous pathway through vertical slots. Reducing the head differential and velocity through the slots can mitigate challenging conditions for these fish.

Dimensions

The dimensions of the vertical slot and pool are critical to the stability of flow. The dimensions shown in Figure XII-52 are described by Bell (1990) and should be adhered to unless specific experience or studies indicate that other configurations work. Generally, pools can be made larger in any dimension without a problem.



Ladder Width	A	B	C
8’	10’	12”	4’1”
6’	8’	9”	3’1”

Figure XII-52. Vertical slot fishway pool dimensions for 9” and 12” slots.

Any changes from the standard dimensions can result in unstable flow conditions and surging throughout the fishway. Surging oscillations as much as three feet have been experienced when the standard dimensions were slightly modified (Bates 1992).

Hydraulic conditions at shallow fishway depths are sensitive and most likely to be unstable. When the depth is too shallow, the jet exiting a slot tends to spread across the shallow floor rather than entering the cushioning pool and it tends to bypass the pool and move directly towards the next slot. Sills should be added if the slot is operated with a depth upstream of the slot less than about five feet or where the head differential may exceed the standard one foot. A sill is a short wall, generally 9-12 inches high in the bottom of a slot to make the slot shallower but still maintain minimum depth in the upstream pool. The sill allows the jet to occupy the same depths through and downstream of the slot and, therefore, stay more intact. Sills might also be used to ensure a minimum depth at low flow. Sills offer some benefit to the pool hydraulics at any depth but also incrementally diminish the fishway flow. Removable sills allow for easier cleaning at high sediment sites.

Standard widths of vertical slots are 9, 12, and 15 inches. Slots as narrow as 6 inches have been used for weaker swimming fish (Mallen-Cooper 2007). Other dimensions of the vertical slot, including the head differential between pools and therefore slot velocity, are reduced proportionately.

Flow

Flow through a vertical slot fishway is calculated as an orifice as in Equation XII-11.

$$Q = CwD\sqrt{2gh}$$ **Equation XII- 11**

Q = Fishway flow (ft^3/s)

C = Orifice coefficient (typically 0.75)

w = Slot width (ft)

D = Depth of water upstream of the slot (ft)

g = Gravitation constant (32.2 ft/s^2)

h = Head across the slot (ft)

The drop between successive pools is not always equal throughout the fishway. While the flow through each slot has to be identical, the depth of water in each slot may vary if the forebay and tailrace depths do not change equally as the river flow changes. This will create either a backwater curve in the lower pools (the tailwater level rising faster than the forebay with increasing flow) or a drawdown curve in the upper pools when the forebay rises faster than the tailwater.

Different design processes are required for the backwater or drawdown situations. However, in both cases, the floor elevations are based on minimum depth requirements at low flow. The number of slots is determined by the maximum forebay to tailrace head differential whether it is at low or high flow. The water surface profile is calculated for other flows to maintain a minimum head differential through the slots. A low head differential of 0.25 feet maintains an attraction velocity at the slot of about 3.0 fps. A normal minimum recommended depth, at the upstream side of a slot, is five feet though some vertical slot fishways are commonly operated as low as three feet.

Roughened Channel Fishways

Roughened channel fishways are as described for profile control in Roughened Channels (page XII-57). In addition to full-channel-width designs, as described in that section, they are often also designed with bypass layouts. Partial width roughened channel fishways might also work in some situations but the entrance usually has be located far downstream of the barrier and the structure itself takes up a large portion of the cross-section. The entrance can be located near the dam if the fishway can be built through the dam with most of its length upstream of the dam as shown in Figure XII-43b.

If low bank topography is available, a bypass layout can be routed around a dam so the entrance is near the base of the dam and the exit is some distance upstream of the dam. The fishway is a semi-natural channel excavated into the floodplain.

The design of a bypass roughened channel is a balance of flow control, stability design, and channel size. The stability of the channel, including slope of the channel and design of the bed, usually depends on good control of flow into the fishway so the fishway flow does not exceed a high structural design flow during high stream flow events. High fishway flow might be controlled for maintaining bed stability rather than for fish passage hydraulics, as it is for other fishways (see Fishway Flow Control page XII-129).

Flow control might be an orifice or gate built into a concrete or steel wall at the fishway exit. A similar device might be placed at the fishway entrance so some head differential is created for attraction of fish into the fishway. Figure XII-53 is a picture of a roughened channel bypass around a six-foot high dam on Spanaway Creek in Washington. Figure XII-54 is the orifice control at channel inlet. The flow control orifice in this example is equipped with adjustable plates so the flow control can be adjusted after monitoring.

One drawback of bypass roughened channels is that, in addition to the fishway flow being limited, the entrance is normally backwatered during high flows so there is no high velocity jet to attract fish to the entrance. Additionally, it is often difficult to design an entrance at an optimum location near the barrier since excavation of a channel near the base of a dam might be a structural risk. An orifice or slot similar to the flow control orifice, or at least a narrowed channel, might be provided at the entrance to enhance attraction. The scale of the project (width of the stream channel) in which the bypass roughened channel can be applied is therefore limited.

Figure XII-53. Spanaway Creek bypass roughened channel.

Figure XII-54. Flow control structure, Spanaway Creek bypass channel.

Roughened channels often depend to some degree on sediment recruited into the channel to replenish fine material that maintains a seal in the bed. If a bypass roughened channel exits into the forebay pool of a dam, that fine material may not be available naturally and may have to be added periodically as part a maintenance activity.

Denil and Alaska Steeppass Fishways

The Denil and Alaska steeppass fishways are fabricated flumes commonly constructed out of aluminum, steel, or wood with angled baffles to create enough roughness to control the velocity, even at high slopes. Both styles have been used extensively throughout the world but are not the first choice of fishway styles in settings where debris, sediment, and weak-swimming fish are to be passed. They have a limited headwater operating range and the baffles make them very susceptible to debris blockages. They are currently used in California primarily within trapping and evaluation facilities and for temporary fish passage during construction of other facilities. There are also some steeppass installations at small falls and dams.

Fishway Flow Control

Each of the various fishway styles described here has different ranges of flows through which they operate effectively. One extreme of operating ranges is the pool and weir fishway, which can only operate through a water level range of a fraction of a foot. A vertical slot, on the other hand, can operate through any water level fluctuations for which it is designed. The purpose of *flow control* is to extend the range of stream flows through which the fishway operates effectively by metering flow to the fishway. Flow control at the fishway exit may also be designed to maintain a specific head for a diversion. Regardless of the fish passage flow range, the fishway flow control might also be required to protect the fishway from damage during very high flows. This is especially true for roughened channel fishways.

There are five styles of flow control that can be used individually or in combination on any fishway. They are:

- Spillway control
- Self adjusting fishway
- Orifice or vertical slot flow control section
- Adjustable weirs
- Multiple level exit.

Spillway control is the most common and practical flow control method for fishways at culverts and small dams. Water is spilled over the spillway or dam to limit flow into the fishway. The geometries (length and opening dimensions) of the fishway and spillway act together to split and meter flows. Mechanical gates can be added to spillways to control water levels to within a very narrow range.

A vertical slot fishways is self-adjusting. No other flow control is needed. A vertical slot fishway can be used upstream of other fishway styles to control flow to them. Flow fluctuations in the fishway are reduced but not eliminated. If the upstream water level fluctuates only a small amount, the fishway flow may be within its design range. If it fluctuates greatly, the fishway design flow will be exceeded at some time. In that case, flow must either be added or taken out just upstream of the lower fishway as the forebay water level changes. For example, at low water levels a vertical slot segment can provide enough flow for a pool and weir segment downstream of it. At high water levels, additional water and headloss are taken through the vertical slot section and the excess water is bled off just upstream of the the pool and weir segment of the fishway so that segment has nearly a constant flow.

Flow control schemes that add water at low flow rather than bleed it off at high flow are also possible. They are not passive; they require water level sensors and automated gate operators and are therefore generally not preferred. An orifice flow control section is similar, but with submerged orifices rather than vertical slots. It is less preferred because fish are forced to sound and go through orifices, and the orifices may be difficult to inspect and maintain.

There are several mechanical flow control systems often used on large dams; they are not generally suitable for the scale of projects addressed in Part XII. Adjustable weirs and multiple level exits adjust the elevation of the fishway or fishway exit to the forebay elevation. Automatically telescoping or tilting weirs, in the upper portion of the fishway, can accommodate a small variation in forebay elevation. If a forebay is operated in more than one distinct operating range or if upstream water levels vary gradually, multiple level exits, together with other flow control measures, can be used. A low exit simply branches off of the fishway at the appropriate elevation and exits through a gated conduit in the dam. When not in use, the lower branch is closed. The switch between high and low exits is manual. When the flow is switched, the fishway must be inspected and any stranded fish removed.

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GLOSSARY

The terms in this glossary are defined relative to their use in Part XII. The first occurrence of each term is italicized in the document. The text in parenthesis following each definition is the initial location in the document where the term is used or other important uses of the term. They are included here for context.

Active channel – The portion of channel receiving sufficient and frequent enough flows to maintain cleanly scoured substrate. Margins of the active channel are located along the stream banks, often defined by *ordinary high water marks*. (Pre-Design Site Assessment)

Aggrade – Raising the level of a channel bed through general deposition of sediment. (Project profile design)

Armor – A surface streambed layer of bed material larger than that below it and that is rarely transported. This layer protects (armors) the underlying bed material from erosion and transport at flows that it would otherwise be mobilized. A well-armored bed suggests a supply-limited channel and low mobility. (Pre-design Site Assessment)

Attraction – Physical conditions that facilitate the fish finding the entrance of a fishway. (Fishway Entrance)

Baffle – Baffles are a series of flow obstructions placed in a culvert or flume to improve fish passage by increasing water depth at lower flows and/or decreasing water velocity at higher flows. (Overview of the Hydraulic Design Approach)

Bankfull – The location along the channel banks in which the channel flows full and a further increase in depth results in a rapid increase in width as flow spreads across the floodplain. It provides a consistent morphological index, which can be related to the formation, maintenance and dimensions of the channel as it exists under the modern climatic regime. (Pre-design, Stream Simulation)

Base level - The lowest level to which a stream can erode the channel through which it flows, locally equal to downstream bedrock, immobile feature or a larger water body. (Pre-Design Site Assessment)

Bedform – Features of the bed such as bars, steps, pools, etc. that are formed by high flows and are characteristics of the reach sediment supply and transport capability. (Stream simulation, Roughened channel)

Bedload – The part of sediment transport that is not in suspension, consisting of coarse material moving on or near the channel bed surface. (Project profile design, Stream Simulation)

Cascade channel – A channel classification of a steep channel characterized by large roughness elements relative to the water depth and without repeating bedforms as defined by Montgomery and Buffington (1997). (Stream Simulation, Roughened Channels)

Chutes and pools – Repeating bedform consisting of a short steep channel section (rapid or cascade) followed by a pool, used as profile control. (Roughened channels)

Colluvium – Rocks moved and introduced to a stream by gravity, such as by creep or slides, rather than being transported by the flowing water of the stream. Generally colluvium also includes soil material. (Pre-Design Site Assessment, Stream Simulation)

Contraction – A channel characteristic in which the width and/or depth of flow rapidly decreases, causing the flowlines to converge and the flow to accelerate. (Roughened Channels, Baffle Retrofits at Stream Crossings)

D_{xxx} - The size of a particle of which xxx% (e.g., 84%) of the particles of a mixture are smaller. For example, 84% of the particles in a specific mixture have median dimensions smaller than D_{84}. The median dimension of a particle is commonly used for this analysis. (Stream Simulation, Roughened Channels)

Degrade - Lowering of the level of a channel bed through general erosion of a reach. (Project profile design)

Deposition, sediment – Buildup of sediment within the channel, occurring when sediment transport forces become insufficient to keep the particle in motion. Deposition can be local due to a feature of the channel, or general as aggradation. (Pre-Design Site Assessment)

Drawdown – Decreasing depth of flow in the downstream direction due to an increase in water velocity (decrease in roughness or increase in slope), and/or change in the channel cross section. (Roughened Channels, Baffle Retrofits at Stream Crossings)

Dune ripple channel – A channel classification characterized by a low gradient channel with sandy bed and bedforms as defined by Montgomery and Buffington (1997). (Stream Simulation)

Ecological connectivity - The capacity of a landscape to support the movement of organisms, materials, or energy, including maintaining linkages of biotic and physical processes between upstream and downstream reaches. (Ecological Considerations of In-Channel Structures)

Embedded, culvert – A culvert with the floor below the channel profile. (Low-Slope Stream Simulation)

Energy dissipation factor (EDF) - The rate of energy dissipation within a volume of water, used as a measure of turbulence in the hydraulic design approach for roughened channels and fishways. (Roughened Channels, Fishways)

Engineered streambed material (ESM) – Streambed material for a roughened channel consisting of a well graded mixture of rock designed to be immobile up to the *stable bed design flow*. (Roughened Channels)

Entrenchment – The relative floodplain width, defined as the floodprone width divided by the bankfull width. (Stream simulation, Roughened channels)

Fish passage design flow, low and high - The range of flows (low to high) at which fish passage design criteria are satisfied in the hydraulic design approach. Water depth is usually primarily an issue at the low fish passage design flow. Water velocities and turbulence are commonly issues at the high passage design flow. Hydraulic drop criteria can be an issue at any flow between the low and high passage design flows. (Definition of the Hydraulic Design)

Fishway – A channel or structure specifically designed to produce suitable hydraulics for fish passage. (Overview of Hydraulic Design Approach)

Flanking - Erosion around the end of a structure causing the stream flow to flow around rather than over or through the structure. (Profile Control Structures)

Flooding, constructed streambed – Saturating the surface of the constructed channel bed or banks to consolidate and compact the material. (Roughened Channels)

Floodprone width – The width, measured perpendicular to the channel, susceptible to inundation during flooding, and commonly measured at twice the bankfull depth. (Pre-design Site Assessment)

Flow control – A system to meter the rate of flow into a fishway and the hydraulic head and/or depth at the entrance, exit, or other locations as stream flow changes. (Fishways)

Forebay – The impoundment of a dam just upstream of the dam or intake. (Fishways)

Forced profile - A channel profile that is controlled by flow obstructions (forcing features), whether natural or artificial. The obstructions cause the bedform to differ from the freeformed morphology for a similar sediment supply and transport capacity. (Project Profile Design, Profile Control Structures)

Forcing feature - Hard structure within the channel such as colluvium or large wood that controls the stream's elevation. (Profile Control Structures)

Headcut – A sudden unstable over-steepening in the channel profile located at the upstream extent of an incised channel. (Project profile design, Profile control structures)

Headwater – The water surface immediately upstream of a structure, such as a culvert. (Stream Simulation, Fishways)

Imbrication – Bed material particles in the channel overlay one another to form a pattern of shingles that shed water downstream. Imbrication suggest an armored bed and relative immobility. (Pre-design Site Assessment)

Incision - The process of channel bed lowering (degrading) and the resulting change in channel cross section shape and elevation. (Pre-design Site Assessment, Profile Control Structures)

Inlet control, culvert – The hydraulic condition in which the headwater depth at a flow is governed only by the geometry of the culvert inlet, and not by the hydraulics inside the culvert or the tailwater depth, which is *outlet control*. (Baffle Retrofits of Stream Crossings) (Milo 1991).

Inlet headloss – Dissipation of the flow's energy (potential and kinetic) as it enters a structure, such as a culvert. (Baffle Retrofits of Stream Crossings)

Invert, culvert – The elevation of the line that follows the lowest point along the inside bottom of a culvert or the floor of a flat-bottomed culvert. (Baffle Retrofits of Stream Crossings)

Jetting, constructed streambed – Washing the surface of the constructed channel bed or banks with water under high-pressure to consolidate and compact the material. (Implementation of Roughened Channels)

Key feature – Permanent or semi-permanent structures such as bedrock outcrops, large woody debris, stable debris jams, boulder steps, and human made structures that control the channel shape and/or grade and bed material sorting. (Pre-Design Site Assessment)

Knickpoint – Location along the profile of a stream at which a sudden gradient change occurs, often associated with a headcut. (Project Profile Design)

Mobility - The frequency of flow at which bed material moves. For example, key particles forming the steps in a step-pool channel might become mobile only at flows occurring once in 30 years. (Project Profile Design, Stream Simulation)

Nappe – A jet or sheet of water flowing over a weir or other drop. (Fishways)

Ordinary high water mark – Generally, the lowest limit of perennial vegetation. There are also legal definitions of ordinary high water mark that include characteristics of erosion and sediment. (Pre-design Site Assessment)

Outlet control, culvert - The hydraulic characteristic of a culvert in which headwater depth is governed at a flow by the tailwater depth, hydraulic conditions inside the culvert and the geometry of the culvert inlet. (Glossary)

Pebble count – A sampling method for characterizing the size of particles on the surface of a streambed. (Pre-design Site Assessment) (Wolman 1954).

Perch, culvert – A culvert characterized by an outlet elevated above the downstream channel forming a falls or cascade. (Project profile design)

Piping – The condition in which water flowing through substrate or under a structure erodes and carries fine particles from the material thus making it more porous and weaker. (Roughened channels)

Plane bed channel - A channel classification characterized by a channel bed without bedforms such as discrete bars, a low width to depth ratio and large values of relative roughness defined by Montgomery and Buffington (1997). Plane bed channels are dominantly gravel to cobble bedded and are in straight reaches. (Stream Simulation)

Planform – The layout of the stream, road, and other features as viewed from overhead looking directly down. (Pre-design Site Assessment)

Pool riffle channel – A channel classification characterized by an undulating bed that defines a sequence of bars, pools, and riffles as defined by Montgomery and Buffington (1997). (Stream Simulation)

Profile control – The use of structures, such as weirs, roughened channels or fishways, to steepen the channel beyond its naturally stable slope or to stabilize the bed of a degrading channel. (Pre-design, Profile Control)

Project profile – The channel profile through a crossing that will be constructed or will initially develop following completion of the project. (Pre-design)

Reference reach – A selected stream segment that represents a channel used to develop natural channel design criteria based on the reach characteristics, including stream channel dimensions, pattern and profile. (Stream Simulation)

Relative submergence – Used to describe the flow resistance imposed by the channel bed material, it is defined as the ratio of the hydraulic radius (R) or the average hydraulic depth (d) to the D_{84} particle size (R/D_{84} or d/D_{84}).

Riprap – Large, durable fractured rocks used to protect a stream bank or lakeshore from erosion. (Roughened Channels)

Rock ramps – A roughened channel that mimics a cascade or plane bed channel in that it is uniform without bedform features. (Roughened Channels)

Roughened channel – A constructed channel stabilized with an immobile framework of large rock mixed with smaller material. (Roughened Channels)

Roughness – An irregular surface or alignment such as boulders, baffles, or channel bends, that creates turbulence and therefore dissipates stream energy, increases water depth, and reduces average velocity. (Profile control, Stream Simulation, Roughened Channel, Baffle Retrofits of Stream Crossings)

Run – A plane-bed channel that lacks discrete bars found in relatively straight channels that may be either unconfined or confined by valley walls. Typically lack rhythmic bedforms and are characterized by long stretches of relatively featureless bed. (Ecological considerations)

Soffit, culvert – The inside top or ceiling of a culvert. (Stream Simulation)

Stable bed design flow – The flow at which the large rock forming the framework of the channel bed is sized to remain immobile. (Stream simulation, Roughened channels)

Stable channel (Stability) - A channel that is neither aggrading nor degrading over time. (Pre-Design Site Assessment, Project Profile Design)

Step pool channel – A type or classification of channel characterized by longitudinal steps formed by large clasts (cobbles or boulders) organized into discrete channel-spanning structures that separate pools containing finer material. (Stream Simulation, Roughened Channels)

Stream simulation – A natural channel design approach for stream crossings or elsewhere that includes construction of a channel that simulates characteristics of the natural channel. A stream simulation channel should present no more of a challenge to movement of organisms than the natural channel. (Stream Simulation)

Structural design flow – The flow at which a structure, such as a culvert, is designed to function without suffering damage. (Final Design and Construction)

Tailout, pool – Downstream end of a pool where bed material deposits causing a rise in the channel profile. (Ecological considerations)

Tailwater – Water surface downstream of a structure, such as below a culvert outlet or a dam. (Fishways)

Tailrace – The area of a channel just downstream of a dam. (Fishways)

Thalweg – The longitudinal line connecting the points of deepest water along a stream, which is located in the lowest point of a channel cross section. (Pre-design Site Assessment)

Transition, hydraulic – A change in the water surface slope caused by a change in channel geometry, slope, or roughness. (Roughened Channels)

Turbulence – Hydraulic condition characterized by rapid fluctuations in water velocity and flow direction and that dissipates kinetic energy. (Roughened Channels, Baffle Retrofits of Stream Crossings, Fishways)

Vertical adjustment profiles - The potential range of elevations the channel might experience throughout the lifetime of the project. (Project profile design)

Well-graded – A characteristic of a granular mixture in which the diversity of particle sizes is uniformly distributed from the smallest to largest. (Stream Simulation, Roughened Channels).

APPENDIX XII-A

CULVERT DESIGN DATA FORMS

Design data forms are provided to summarize the design process of a culvert. The purpose of the forms is to guide, document, and assist the design and reviews of culvert projects. There are two data forms, one for stream simulation design that includes the low-slope approach and a second for hydraulic design approach (baffles, gradient control). The design data forms include only fish passage, geomorphic, and hydrologic design information; other aspects of the project (e.g., traffic, geotechnical, road characteristics) should also be documented during pre-design.

Data is summarized to show design milestones, assumptions, and conclusions. The last step of the pre-design, as described here, is selection of the method for fish passage design. It is important to document project milestone decisions such as how the design method was selected.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Not all sections will apply to any culvert; so chose the sections relevant to the specific culvert design process. There are two separate forms; one applies to culverts designed under the stream simulation option and the second applies to culverts designed under the hydraulic or low slope options.

Stream Simulation Design Data Checklist

This is a guide and summary for design and review of a stream simulation road - stream crossing including the Low-Slope design approach. Data is summarized to show design milestones, assumptions, and conclusions. This is not likely all of the data required for a complete design. Other design data sheets are available for other design methods.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project

Project name and ID		
Stream		
Road, location		
Lat / Long (d/m/s)		
Interdisciplinary Design Team members		
Date		

Brief description of project ____

____

____

Project type (new, retrofit, replacement) ___________________________________

Design approach (stream simulation, low-slope) ______________________________

Does final design satisfy stream simulation design criteria? Explain deviations and limitations.

Y / N ____

Site characteristics (LS)

Is there an existing Culvert(s)? Y/N

Existing culvert perched: Y/N Height of perch ______________

Downstream channel incised Y/N Depth of incision ______________

Evidence of incision ______________________________________

____

Upstream backwater deposition Y/N

Evidence and extent ______________________________________

Project ________________ Project ID ________________
Date ________________

2 – BASIS OF DESIGN

ReferenceReach

Description of reference reach

Location of reference reach (e.g., "150' upstream from crossing)

____

Show location of reference reach on plan view sketch and profile.

Length of reference reach __________________________

Describe reference reach channel types (e.g., 75% pool-riffle, 25% plane bed)

____
____

Key bed features, function, and spacing (e.g., debris, steps, bends, etc.)

____
____
____

Bed mobility and how it was determined (e.g., observation, model applied, etc.)

Hydrology

Watershed characteristics

Area __________sq miles Mean elevation ______________ ft above sea level

Mean annual precipitation _____________________inches

Other hydrologic or flow characteristics (hydrologic province, area of lakes, northing, etc.)

____

Peak design flows	Derived flow (cfs)	Standard error (%)	Design flow (cfs)
2 - yr flow			
10 - yr flow			
25 - yr flow			
100 - yr flow			

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)

Describe how hydrology was calculated and any assumptions (e.g., future conditions) made.

____
____

Project ________________ Project ID _______________
Date _______________

3 - BASIS OF DESIGN

Reference reach cross sections

Cross section labels			
Locations			
Channel type (M&B classification)			
Bankfull width			
Bankfull depth			
Floodprone width			
Elevation of high water mark			

Reference reach slope Average ________ Range______

Reference reach bed material

	Particle size (inches or mm)	How was particle size determined?
D_{95}		
D_{84}		
D_{50}		
D_{16}		
D_{5}		
Fines		

Reference reach key features

	Size (inches or mm)	Function	Spacing	Drop supported by feature	Permanence, mobility, condition
Debris and live wood					
Colluvium					
Bedrock					
Steps, clusters					

Function: Profile control, Roughness, Confinement, Bank stability

Project ________________ Project ID _______________
Date _______________

4 - DESIGN

Proposed Project Profile and Alignment

Proposed new channel within crossing Slope__________ Length __________
Upstream channel within project Slope__________ Length __________
Downstream channel within project Slope__________ Length __________

	Downstream end	Upstream end
Bed Elevation - project profile		
Bed Elevation - low potential profile		
Bed Elevation - high potential profile		

Stream simulation bed material

	Particle size (inches or mm)	How was particle size determined? (what model, observations)
D_{95}		
D_{84}		
D_{50}		
D_{16}		
D_{5}		

Additional features if included in the design

	Describe material, particle size (inches or mm)	Frequency, spacing
Disrupters, bands		
Banklines		
Key features		

High flow hydraulics

Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	HW depth (HW/culvert rise)
2 - yr flow					
10 - yr flow					
25 - yr flow					
100 - yr flow					

Describe methods and sources of data high flow hydraulic calculations.

____

____

Project ________________ Project ID _______________
Date _______________

5 - DESIGN

Culvert Description

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	ft	
Rise	ft	ft
Upstream Invert Elevation		
Downstream Invert Elevation		
Culvert Length	ft	ft
Slope	%	%
Percent Embedded	%	%

Note: for bottomless structures, report elevations of tops of footings.

Description of proposed culvert; Choose one or more in each line

Shape: Round -Arch –Box

Other ____

Material: Corrugated metal -Smooth metal –Concrete

Corrugation dimensions: __________________________

Style Full pipe –Bottomless

Road and Alignment

Height of fill on upstream face: ___________ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel ________ degrees Road to culvert ________ degrees

Proposed alignment, transition changes____

____

Describe permanent benchmark and elevation ___________________________________

____

Other special considerations, recommendations _________________________________

____

____

____

____

Hydraulic Design Data Checklist

This is a summary for design and review of a road / stream crossing using the hydraulic design approach for fish passage at culverts. Data is summarized to show design milestones, assumptions, and conclusions. This is not likely all of the data required for a complete design. Other design data sheets are available for other design methods.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project

Project name and ID		
Stream		
Road, location		
Lat / Long (d/m/s)		
Interdisciplinary Design Team members		
Date		

Brief description of project ____

____

____

Project type (new, retrofit, replacement) ____________________________________

Does this design satisfy hydraulic design approach criteria? If not, explain deviations and limitations. Y / N ____

____

Site characteristics

Is there an existing culvert(s)? Y / N

Is existing culvert perched? Y / N Height of perch__________________

Is downstream channel incised? Y / N Depth of incision_________________

Evidence of incision ____

____

Upstream backwater deposition Y / N

Evidence and extent ____

____

Project ________________ Project ID ________________
Date ________________

2 – BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Hydraulic criteria		
			Max velocity (fps)	Min depth (ft)	Max turbulence (ft-lb/s/cuft)

Describe data sources ____
____

Hydrology

Watershed characteristics

Area ________________ sq miles Mean elevation ft ________________ above sea level

Mean annual precipitation ______________ inches

Other hydrologic or flow characteristics (hydrologic province, area of lakes, northing, etc.)

____

____

Peak design flows	Derived flow (cfs)	Standard error (%)	Design flow (cfs)
2 - yr flow			
10 - yr flow			
25 - yr flow			
100 - yr flow			

Fish passage design flows

Species	Age class	Movement seasons (months)	High design flow (cfs)	Low design flow (cfs)

Describe how hydrology was calculated and any assumptions (e.g., future conditions) made.

____

____

Project ________________ Project ID ________________
Date ________________

3 – DESIGN

Channel

	Downstream	Upstream
Average slope	%	%
Average bankfull width	ft	ft
Bed Elevation - project profile		
Bed Elevation - low potential profile		
Bed Elevation - high potential profile		
Channel type (M&B classification)		
Channel roughness (n)		
Elevation of downstream control		

How is profile controlled? ____

____

Culvert Description

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	ft	
Rise	ft	ft
Upstream Invert Elevation		
Downstream Invert Elevation		
Culvert Length	ft	ft
Slope	%	%

Note: for bottomless structures, report elevations of tops of footings.

Description of proposed culvert; Chose one or more in each line

Shape: Round - Arch - Box

Material: Corrugated metal - Smooth metal - Concrete

Corrugation dimensions: ____

Style: Full pipe - Bottomless

Project ________________ Project ID _______________
Date _______________

4 - DESIGN

Fish Passage Hydraulics

Flow (cfs)	Tailwater elev	Roughness (n)	Velocity (fps)	Depth (ft)	EDF (ft-lb/sec/cuft)	Passability (%)

Describe roughness (corrugation dimensions, bed material or roughened channel description, baffle geometry, etc.)

____

____

Describe methods and sources of data for fish passage hydraulic calculations.

____

____

High flow hydraulics

Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)
2 - yr flow					
10 - yr flow					
25 - yr flow					
100 - yr flow					

Describe methods and sources of data high flow hydraulic calculations. ______________________

____

Road and Alignment

Height of fill on upstream face: ___________ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel ________ degrees Road to culvert ________ degrees

Proposed alignment, transition changes

____

____

Describe permanent benchmark and elevation ______________________________

____

APPENDIX XII-B

COMPUTING CHANNEL ROUGHNESS

Overview

To accurately predict water depths and velocities, especially at fish passage flows, estimation of hydraulic roughness, or flow resistance, is essential. Velocity, and therefore depth, is commonly predicted using the Manning equation (U.S. customary units):

$$V = \frac{1.486 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$ **Equation XII-B- 1**

Where *V* is the average water velocity, *S* is the water surface slope, *R* is the hydraulic radius and *n* is the Manning's roughness coefficient. The Darcy-Weisbach equation is also used to predict flow resistance. It is related to Manning equation by:

$$n = 0.0926 R^{1/6} \sqrt{f}$$ **Equation XII-B- 2**

Where f is the Darcy-Weisbach Friction Factor.

Selection of a flow resistance coefficient influences water velocity and flow depth predictions. Studies have found channel roughness depends on the depth of flow relative to the size of the bed substrate (Bathurst 1978, 1985 and 1987). This ratio of the hydraulic radius (R) or the average hydraulic depth (d) to the D_{84} particle size (R/D_{84} or d/D_{84}) is used to describe the *relative submergence* of the channel bed at a given flow. At shallower depths, flow resistance is very sensitive to changes in the depth of flow and substrate size. Flow around the larger bed particles causes additional roughness. Flow resistance becomes less sensitive to changes in depth as flows increase.

Numerous equations have been developed to estimate roughness coefficients. The equations presented in this document are those that are most applicable to steep channels and to roughened channels, where the grain size of the engineered streambed material is large relative to the water depth and therefore significantly impacts channel roughness. Each equation is applicable over a limited range of relative submergence, slope and substrate size. It is not uncommon to use one method for computing a roughness coefficient for fish passage flows and another one for estimating roughness at the structural design flow.

Methods to Compute Roughness

Definition of Variables

b *Active channel* width

d Average hydraulic depth (flow area divided by top with)

R Hydraulic radius

D_n Particle size, where the designated percent of particles in the gradation are smaller than n

W Top width of flow

S Water surface slope

n Manning's roughness coefficient

f Darcy-Weisbach friction factor

g Gravitational acceleration

R/D_{84} or d/D_{84} Relative Submergence

All equations presented are in US Customary Units.

Comparison of Methods for Predicting Roughness

Methods for predicting roughness coefficients are summarized in Table XII-B-1, accompanied by their range of application. Each equation is then discussed in detail in the following sections, along with recommended application.

Author	Slopes	Sediment Sizes (D_{50}) (feet)	Relative Submergence R/D_{84} or d/D_{84}	Data Origin
Mussetter (1989)	0.54-16.8%	0.1-2.1	0.2-3.7	CO mountain streams
Bathurst (1985)	0.2-4% (tested for slopes up to 9%)	0.2 - 1.1	0.4-11	gravel and boulder bedded rivers
Rice, et al. (1998)	1-33%	0.1-0.9	0.3-1.9	riprap on steep slopes in flume
Bathurst (1978)[1]	0.8-1.7%	0.6-0.8	0.4-1.3	Regulated river in Great Britain
Hey (1979)[1]	0.09-3.1%	0.1-0.7	0.7-17.2	Straight gravel bedded rivers
Limerinos (1970)	Not provided	0.02-0.8	0.9-69	CA rivers with coarse beds
Jarrett (1984)	0.2-4%	0.2-1.4	0.4-10.8	cobble & boulder streams
Bathurst (2002)	0.2-4%	0.4-2.5	0.4-11	compilation of stream data sets

Table XII-B-1. Methods to determine Manning's n and the range of conditions under which they were derived.

[1] Methods presented in Thorne and Zevenbergen (1985)

Note that all of the equations have considerable error associated with them. When estimating a roughness coefficient, it is important to select a method that is most suitable for the channel type, flow conditions, and range of flows and depths. It is helpful to compare results among equations, check the range of application, and understand how uncertainty in the roughness calculations can influence the design. Refer to the section on each individual method for the recommended conditions for application.

Figure XII-B- 1 presents Manning's n values predicted using the various methods presented in this document. For the figure, the equations were applied to dimensions of a typical roughened channel with a 1.5% slope and a D_{84} of 1.56 feet in a trapezoidal channel with a 10-foot wide bottom that had a 5H:1V side slopes and banks with 1H:1V side slopes. The estimates of Manning's n vary significantly depending on the methodology used.

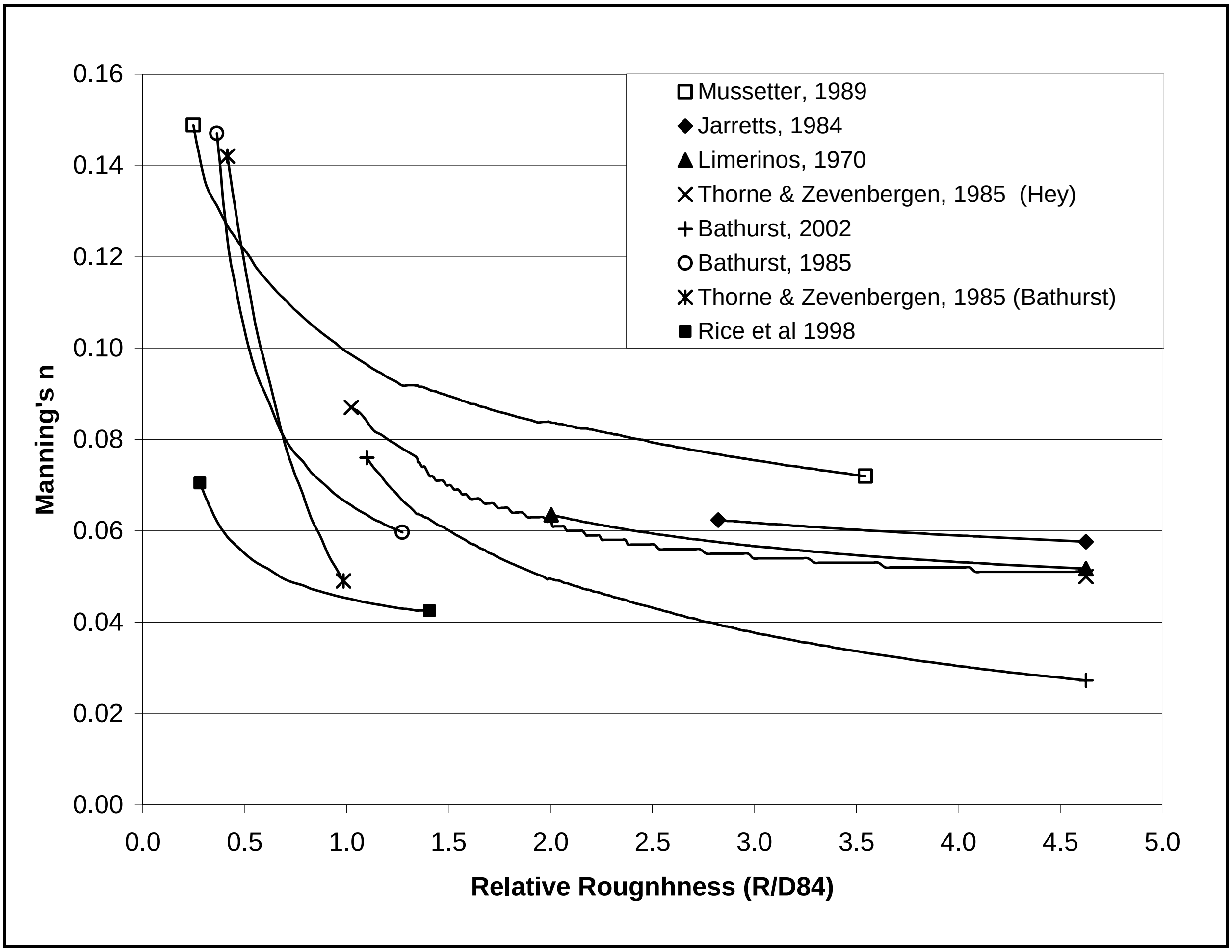

Figure XII-B- 1 Manning's n predicted using various methods for the same channel. Values are shown within their range of applicability.

Mussetter 1989

Mussetter (1989) combined several data sets encompassing a wide range of hydraulic conditions to develop the following equation:

$$\left(\frac{8}{f}\right)^{0.5} = 1.11\left(\frac{d}{D_{84}}\right)^{0.46}\left(\frac{D_{84}}{D_{50}}\right)^{-0.85} S^{-0.39}$$ **Equation XII-B- 3**

Mussetter developed this equation from a large dataset of Colorado rivers with slopes of 0.54-16.8%, d/D_{84} values from 0.24 to 3.72, and D_{50} sediment sizes from 0.1 to 2.1 feet. Most data points fall between d/D_{84} values of 1 and 2.

Mussetter found that Equation XII-B-3 underestimate channel roughness, with a mean error of 3.9% for channel slopes less than 4%, compared to measured field data. Simons & Senturk (1992) recommend use of this equation in steep gradient streams with large cobble and boulder sized bed material. Bates et al. (2003) noted that the equation's accuracy decreases when velocities are greater than 3 ft/s, and recommends limiting its use to determining velocities and depths for fish passage flows.

Bathurst 1985

Bathurst (1985) developed the following equation for predicting flow resistance derived from several high gradient gravel and boulder bedded streams:

$$\left(\frac{8}{f}\right)^{0.5} = 5.62\log\left(\frac{d}{D_{84}}\right) + 4$$ **Equation XII-B- 4**

This equation was derived from a compilation of data sets with slopes ranging from 0.2% to 4%, D_{50} sizes from 0.2 to 1.12 feet, and d/D_{84} values of 0.43-11.

Bathurst indicates the equation has the least error with low to moderate relative submergence; where d/D_{84} is less than two, it underestimates roughness by approximately 13%. For higher values of relative submergence the estimated error increases to $\pm$ 25-35%. When used for conditions with higher values of d/D_{84}, results should be compared with those obtained from other methods. Musetter (1989) found this equation to under-predict roughness in channels with slopes greater than 1.5% and relative submergence less than 4%.

Rice et al. 1998

Rice et al. (1998) derived a roughness equation from experiments of uniformly sloped rock chutes in flumes. Though derived for uniform slopes ranging from 2.8-33%, Rice compared results to data in Abt et al. (1988) for slopes between 1-20% and found similar accuracies.

$$\left(\frac{8}{f}\right)^{0.5} = 5.1\log\left(\frac{d}{D_{84}}\right) + 6$$ **Equation XII-B- 5**

This equation was derived specifically for shallow, uniform flows with an R/D_{84} range of 0.27-1.93 over rock chutes comprised of a relatively uniform gradation (D_{60}/D_{10} from 1.47 to 1.73) of material with a D_{50} ranging from 0.17-0.91 feet.

The equation predicts low roughness values when compared to other methods, likely due to the uniform gradation of the material and uniformity of the bed morphology. The equation is not recommended for application in natural channels, but may be suitable for predicting roughness of roughened channels with constant slope and no protruding boulders.

Thorne and Zevenbergen 1985

Thorne and Zevenbergen (1985) assessed several methods of computing roughness in mountain rivers with coarse bed material, steep slopes and shallow flow depths. They identified flow resistance equations developed by Bathurst (1978) and Hey (1979) as most accurately predicting roughness and mean velocity. The assessment was based on two field sites with slopes of 1.43-1.98%, a D_{50} sediment range of 0.43-0.53 feet, and R/D_{84} values of 0.89 to 1.56.

Thorne and Zevenbergen recommend a method that the use the Bathurst (1978) equation for large relative submergence ($R/D_{84} < 1$) and Hey (1979) equation for moderate to low relative submergence ($R/D_{84} \geq 1$). The authors recommend this method be used for determining roughness of riprapped channels and banks.

Thorne and Zevenbergen hydraulic roughness computations are included in the software package WinXSPRO (Hardy et al. 2005).

Bathurst 1978

Bathurst (1978) derived a flow resistance equation based on several field sites located on a single river with slopes of 0.8-1.74%, a D_{50} sediment size of 0.6 to 0.8 feet, and R/D_{84} values of 0.37 to 1.32.

$$\left(\frac{8}{f}\right)^{0.5} = \left(\frac{R}{0.365D_{84}}\right)^{2.34}\left(\frac{W}{d}\right)^{7(\lambda_E - 0.8)}$$ **Equation XII-B- 6**

where $\lambda_E = 0.039 - 0.139Log\left(\frac{R}{D_{84}}\right)$

Bathurst recommends that this equation not be used when R/D_{84} exceeds 1.5. Thorne and Zevenbergen recommend applying Bathurst (1978) for situations with large relative submergence ($R/D_{84} < 1$).

Hey 1979

Hey (1979) developed the following equation from a large dataset from straight, gravel bedded rivers with slopes of 0.09-3.1%, R/D_{84} values of 0.7 to 17.23, and a D_{84} sediment size of 0.13 to 0.65 feet.

$$\left(\frac{8}{f}\right)^{0.5} = \frac{V}{gRS} = 5.62\log\left(\frac{a'R}{3.5D_{84}}\right)$$ **Equation XII-B- 7**

where $a' = 11.1\left(\frac{R}{d_{\max}}\right)^{-.0314}$

For smaller relative submergence, where $R/D_{84} \geq 1$, Thorne and Zevenbergen recommend the equation by Hey for deeper flows. Grant et al. (1990) found the Thorne & Zevenbergen method best fit field data of high gradient boulder bed step-pool and cascade streams in Oregon. Bathurst (1985) found that Equation XII-B-7 over-predicted roughness, with greater error with deeper flows ($R/D_{84} > 6$).

Limerinos 1970

Limerinos (1970) derived the following roughness equation from coarse bedded streams and rivers in California:

$$n = \frac{0.926R^{\frac{1}{6}}}{1.16 + 2\log\left(\frac{R}{D_{84}}\right)}$$ **Equation XII-B- 8**

The equation was derived based on data from numerous river channels in California with R/D_{84} values ranging from 0.9 to 69 and D_{50} sediment size ranging from 0.024-0.83 feet. The equation was found to have an error of $\pm$ 19%. The data used in the derivation of Equation XII-B-8 included a few sites with low R/D_{84} values, but most values were greater than 2.0, indicating the equation will better predict roughness for deeper flow and small relative submergence.

Equation XII-B-8 has been widely recommended for calculation of Manning's roughness values in streams, especially for higher velocity and larger flows (ACOE 1994; ACOE 2008; Richardson 1990; Thomas 2002).

Jarrett 1984

A flow resistance equation was derived by Jarrett (1984) based on data from 21 high gradient streams in Colorado with slopes ranging from 0.2-4%, sediment size D_{50} ranging from 0.2 to 1.4 feet, and R/D_{84} values from 0.4-10.8. The following equation estimates the average roughness through an entire stream reach, which may include multiple bedforms (e.g., steps and pools).

$$n = 0.39S^{0.38}R^{-0.16}$$ **Equation XII-B- 9**

Jarrett's hydraulic roughness computations are included in the software package WinXSPro (Hardy et al. 2005).

Jarrett found the equation overestimates Manning's n by as much as 30%, with the greatest error occurring at lower flows when $R/D_{50} <7$. Assuming $D_{84}= 2.5D_{50}$ for natural gravel rivers (Bates et al. 2004), Jarrett's equation is most applicable at deeper flows where $R/D_{84} >2.8$.

Bates et al. (2003) and Hardy et al. (2005) recommend using Jarrett's equation for bankfull and larger flows. Because the equation does not include a particle size, it is recommended that this equation only be used for roughness assessment of natural channels and channels designed using the stream simulation method. It is not recommended that it be used for assessment of constructed roughened channels.

Bathurst 2002

Bathurst (2002) combined previously published field data for mountain rivers to derive two flow resistance equations dependent on channel slope:

$$\left(\frac{8}{f}\right)^{0.5} = 3.10\log\left(\frac{d}{D_{84}}\right)^{0.93}$$ **for slopes > 0.8%** **Equation XII-B- 10**

$$\left(\frac{8}{f}\right)^{0.5} = 3.84\log\left(\frac{d}{D_{84}}\right)^{0.547}$$ **for slopes < 0.8%** **Equation XII-B- 11**

These equations were derived based on data from in-bank flows in channels with slopes ranging from 0.2 to 4%, D_{84} sediment sizes of 0.45 to 2.5 feet, and R/D_{84} values of 0.37 to 11.

Bathurst notes that these equations only consider the impacts of bed grain roughness with uniform flow, and neglect bed and bank form roughness and non-uniform flow conditions. Bathurst indicates that these equations correlate well with the field data and have less data scatter than other flow resistance relationships in the literature, but suggests the resulting roughness values should be considered minimum values. Figure C-1 indicates that during deeper flows (higher R/D_{84}) this equation predicts low values of n compared to other methods, which could result in under-prediction of flow depth and over-prediction of flow velocities.

APPENDIX XII-C

HYDRAULIC DESIGN OF BAFFLES

Baffles are added to existing culverts or flumes to increase water depths and decrease water velocities for fish passage. The material presented in this appendix supplements the discussion provided in Baffle Retrofits of Stream Crossings (page XII-95). Limitations of Baffles (page XII-96) discusses the use and limitations of baffles and should be reviewed before beginning a baffle retrofit design. This appendix first describes current methods used to perform the analyses needed to design baffle retrofits, and then summarizes the overall design process. The methods presented here represent current practice but ongoing research efforts and field assessments of retrofit installations continually improve our understanding of baffle performance. The aspects of baffle design covered in this appendix are:

- Selecting a baffle type and geometry
- Analyzing hydraulics to predict water depth, velocity, and turbulence at low and high fish passage design flows, and
- Evaluating the impact of baffles on the hydraulic capacity of the culvert.

These topics are followed by a step-by-step design procedure for baffles, which is provided at the end of this appendix. Though this section focuses on baffles in culverts, the same designs can be used in open flumes of comparable shapes.

Geometry of Baffles

Many types of baffles have been installed in culverts. However, the hydraulics of only a few have been studied or evaluated in detail. The following sections describe the most widely accepted baffle types for circular and flat bottom culverts. Studies of these baffle types have found they produce hydraulic conditions believed to be suitable for passage of adult salmonids, with the potential of providing passage for smaller fish at low flows. There have been no valid empirical biological studies to confirm passage through culverts at high fish passage design flows. Empirical equations have been developed to predict hydraulic performance for these baffle types based on culvert slope and size and baffle height and spacing. The baffles described below are the only types recommended at this time. Other types of baffles may be used in projects if their hydraulic behavior can be predicted and the baffles have been shown to produce suitable fish passage conditions.

Corner and Weir Baffles

Corner and weir baffles are the baffle configurations recommended for circular and pipe-arch (squashed) culverts (Figure D-1). Weir baffles are typically used for wider and steeper circular culverts. The choice between these styles becomes apparent in the design process.

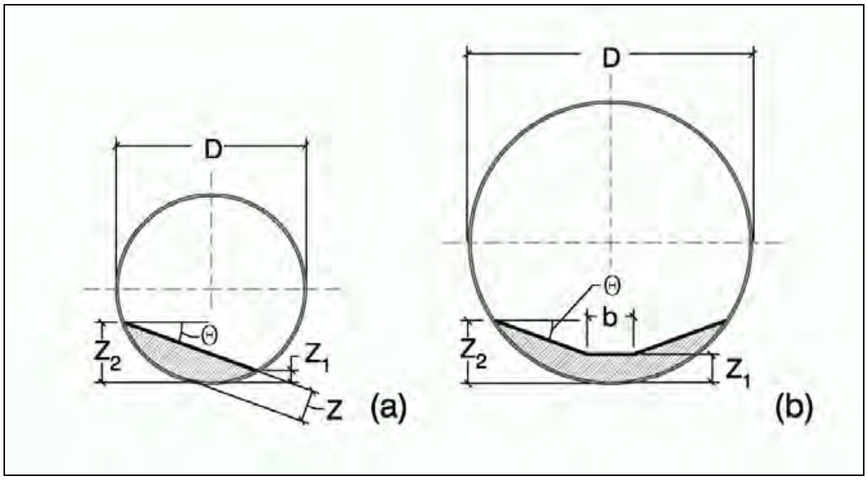

Figure XII-C-1. Design dimensions for (a) corner and (b) weir baffles.

For these baffle types the following variables are defined:

- D = culvert diameter or span for pipe-arches (ft)
- Z = baffle height normal to the crest of a corner baffle as shown (ft)
- L = spacing between baffles (ft)
- Θ = corner baffle side-slope (degrees from horizontal)
- Z_1 = height of low end of baffle, measured from invert (ft)
- Z_2 = height of high end of baffle, measured from invert (ft)
- b = length of horizontal baffle crest

For corner baffles in round culverts circular, geometry and trigonometry are used to calculate Z_1 and Z_2 once Z and Θ are determined in the design process:

$$Z_1 = \frac{D}{2}\left[1 - \cos(\phi + \theta)\right]$$

$$Z_2 = \frac{D}{2}\left[1 - \cos(\phi - \theta)\right]$$

Equation XII-C- 1 and Equation XII-C- 2

Where:

$$\phi = \cos^{-1}\frac{(D - 2Z)}{D}$$

Equation XII-C- 3

Typical angles for Θ are between 15^{o} and 25^{o}. The angle is adjusted by rotating the baffle but keeping Z_1 constant to satisfy minimum depth criteria at low passage flows while keeping the high part of the baffle dry at high passage flows. If this can not be achieved, Z may need to be increased.

Angled Baffles

Angled baffles are the baffle configurations recommended for flat bottom culverts, such as box culverts (Figure XII-C-2), and open flumes.

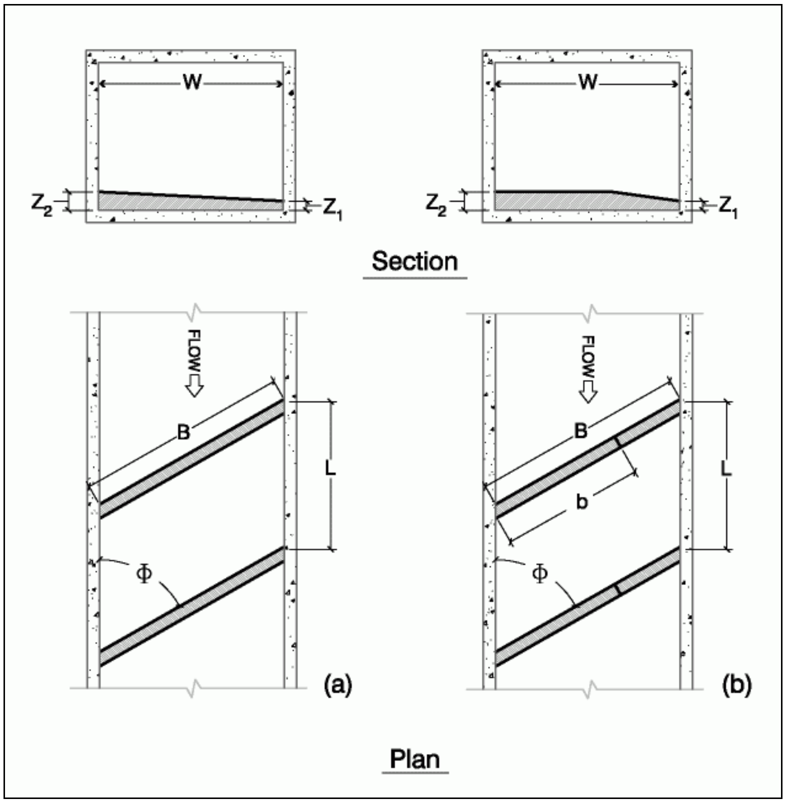

Figure XII-C-2. Design dimensions for (a) full taper and (b) partial taper angled baffles.

For angled baffles the following variables are defined:

W	= culvert width (ft)
Z_1	= height of low end of baffle, measured from invert (ft)
Z_2	= height of high end of baffle, measured from invert (ft)
L	= spacing between baffles (ft)
Φ	= inside angle of baffle with wall in planform (degrees)
B	= length of baffle (ft)
b	= length of horizontal baffle crest (ft)

For angled baffles, the baffle length is:

$$B = \frac{W}{\cos(\Phi)} \qquad \text{Equation XII-C- 4}$$

The recommended angle for Φ is 60^o. A smaller angle may create adverse hydraulic conditions. A large angle may reduce its ability to create slower and less turbulent water along the margin located at the high side of the baffle.

Baffle Hydraulics

At lower flows the corner, weir, and angled baffles produce plunging flow. At higher flows water begins to stream over the baffle. Ead et al. (2004) and Rajaratnam et al. (1988) provide some relationships for predicting the flow rate at which the transition from plunging to streaming flow occurs for pool and weir fishways. These can be applied to baffle arrangements if the baffle arrangement falls within the relationship's limits of application. Refer to Plunging and Streaming Flow Regimes (page XII-113) for more detail on plunging and streaming flow and determining the transition flow between them. Based on evaluation of these studies, a good assumption is that for baffles designed using the methods described below, plunging flow will occur at the low passage design flow, streaming flow will occur at the high passage design flow and all flows greater, including the culvert capacity flow, and there will be a transition between the regimes at a flow somewhere in between.

It is important to realize that all of the hydraulic calculations are for clear water, and do not account for affects associated with sedimentation or debris clogging within the baffles. Baffle Retrofits of Stream Crossings (page XII-95) and the design procedures outlined in Appendix XII-C Procedures for Baffle Hydraulic Calculations (page XII-C-10) provides guidance on means to reduce, but not eliminate, these risks.

Hydraulics of Plunging Flow across Baffles

Under plunging flow conditions, the baffle hydraulics can be approximated by modeling the baffles as sharp-crested weirs. The equation for a one-sided triangular sharp-crested weir is used to approximate plunging flow conditions over corner and angled baffles. Flow over weir baffles can be approximated using the equation for a sharp-crested trapezoidal weir. Note that while water depth criteria for fish passage are based on depth above the culvert bottom, the depth used in the weir equations is measured from the lowest point along the baffle crest. Plunging flow over other baffle shapes can by analyzed at a specified water depth by calculating weir flow in small segments across the crest length and then summing to obtain the total weir flow.

Weir submergence occurs when the water surface downstream of the weir becomes higher than any part of the weir crest. In plunging flow, submergence decreases the flow over the weir for a given depth, which can be accounted for using the equation provided by Villemonte (1947):

$$Q_s = Q\left[1-\left(\frac{h_d}{h_o}\right)^n\right]^{0.385} \qquad \text{Equation XII-C- 5}$$

Where:

Q = weir flow over the baffle without accounting for submergence (cfs)
Q_s = weir flow over the baffle accounting for submergence (cfs)
h_o = upstream water depth above the weir crest (feet)
h_d = downstream water depth above the weir crest (feet)
n = coefficient equal to 1.5 for rectangular weirs and 2.5 for triangular shaped weirs

Hydraulics of Streaming Flow across Baffles

Under most streaming flow conditions, the water depth and velocity can be estimated using empirical equations for corner and weir baffles in circular culverts and angled baffles in box culverts. These empirical equations provide an estimate of normal depth in the baffled culvert at a given flow. Once a suitable baffle arrangement has been determined, it is often preferable to back-calculate a Manning's roughness coefficient based on the predicted normal depth. Because the roughness coefficient for a baffled culvert changes significantly with changes in flow, it must be calculated for each flow of interest, including the high passage design flow for each target species and the culvert capacity flow. The roughness coefficient can then be used in a backwater analysis of the culvert using standard hydraulic models to predict water surface profiles at a flow rate. The headwater depth and hydraulic conditions throughout the baffled culvert can be calculated, including the hydraulic transitions located at the inlet and outlet.

Corner and Weir Baffles

Based on flume studies and dimensionless analysis, Rajaratnam and Katopodis (1990) developed an empirical equation for predicting the hydraulics of weir baffles having a level crest. Lang (2008) modeled corner baffles in a flume at varying slopes. Results suggest that using the Rajaratnam and Katopodis coefficients for predicting hydraulics of corner baffles provides reasonable results. Due to a lack of available study of baffle hydraulics, the Rajaratnam and Katopodis results, combined with sound judgment, are considered suitable for design of both corner and weir baffles in circular culverts.

The Rajaratnam and Katopodis results can also be used to approximate the hydraulics of weir baffles in pipe arches (squashed pipes) by substituting the culvert span for the diameter. At higher flows this approach is not suitable. Instead, use the equivalent diameter of a circular pipe to model hydraulics of weir baffles in the pipe arch at capacity flows.

The equation provided by Rajaratnam and Katopodis has been rearranged to solve for average water depth in the culvert (Equation XII-C-6).

$$Y_o = D\left[\frac{Q}{C\sqrt{gS_oD^5}}\right]^{\frac{1}{a}}$$

Equation XII-C- 6

Where:

Y_o = water depth, measured from culvert invert (ft)
D = culvert diameter (ft)
S_o = culvert slope (ft/ft)
Q = flow in the baffled culvert (cfs)
g = gravitational acceleration (32.2 ft/s^2)
C = coefficient unique to baffle arrangement
a = exponent coefficient unique to the baffle arrangement

The baffle dimensions and their respective coefficients for Equation XII-C-6 are provided in Table XII-C-1. The coefficients were developed for culvert slopes from 1% to 5%. The first column lists the name of the baffle arrangement tested. Data for those ending with an '*e*' are extrapolated. It may be necessary to interpolate coefficients for other baffle height and spacing arrangements. The baffle height, Z, is measured as indicated in Figure B-2. For weir baffles $Z = Z_1$.

Baffle Arrangement	Z	L	C	a	Limits of Application
Weir Baffle D1	0.15D	0.6D	5.39	2.43	$0.25 \le Y_o/D \le 0.8$
Weir Baffle D2	0.15D	1.2D	6.6	2.62	$0.35 \le Y_o/D \le 0.8$
Weir Baffle D2*e*	0.15D	2.4D	8.5	3.00	$0.35 \le Y_o/D \le 0.8$
Corner Baffle	0.10D	0.5D	7.81	2.63	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D3	0.10D	0.6D	8.62	2.53	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D4	0.10D	1.2D	9.0	2.36	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D4*e*	0.10D	2.4D	9.6	2.50	$0.20 \le Y_o/D \le 0.8$

Table XII-C-1. Baffle arrangements for circular culverts and resulting spacing, height, and hydraulic coefficients as a function of culvert diameter. Weir baffle data from Rajaratnam and Katopodis (1990). The corner baffle from Lang (2008).

The wetted area associated with Y_0 is needed to calculate water velocity. From simple geometry and trigonometry in a circular pipe, the flow area (*A*) between the baffles in a circular culvert is:

$$A = \frac{D^2}{8}(\phi - \sin\phi)$$

Where the angle of the circular sector, ϕ, is calculated in radians as:

$$\phi = 2\cos\left(\frac{D - 2Y_0}{D}\right)$$

For pipe-arch culverts, refer to tables of water depth verses wetted area, provided by manufacturers and also available in AISI (1994).

Angled Baffles

Lang (2008) developed empirical relationships for predicting the hydraulics of angled baffles in box culverts based on flume studies and dimensionless analysis. The angled baffles had a constant sloping crest and were skewed 60^0 relative to the culvert wall, as shown as ϕ in Figure B-2. The angled baffles were modeled in a square box culvert at slopes between 0.5% and 4%.

Based on Lang's work, Equation XII-C-7 predicts water depth for angled baffle arrangements:

$$Y_o = Z_2 \left[\frac{Q}{C\sqrt{gS_oW^5}} \right]^{\frac{1}{a}}$$ **Equation XII-C- 7**

Where:

- Y_o = water depth, measured from culvert invert (ft)
- Z_2 = height of high end of baffle, measured from invert (ft)
- W = box culvert width (ft)
- S_o = culvert slope (ft/ft)
- Q = flow in the baffled culvert (cfs)
- g = gravitational acceleration (32.2 ft/s^2)
- C = coefficient unique to baffle arrangement
- a = exponent coefficient unique to the baffle arrangement

Angled Baffle Arrangement	L	Z_1	Z_2	C	A
Close-Spacing Tall Baffle Height	0.50W	0.132W	0.202W	0.122	1.85
Close-Spacing Medium Baffle Height	0.50W	0.092W	0.158W	0.123	1.70
Close-Spacing Low Baffle Height	0.50W	0.050W	0.112W	0.113	1.64
Intermediate-Spacing Tall Baffle Height	0.75W	0.132W	0.202W	0.139	1.82
Intermediate-Spacing Medium Baffle Height	0.75W	0.092W	0.158W	0.125	1.82
Intermediate-Spacing Low Baffle Height	0.75W	0.050W	0.112W	0.119	1.68
Far-Spacing Tall Baffle Height	1.00W	0.132W	0.202W	0.169	1.79
Far-Spacing Medium Baffle Height	1.00W	0.092W	0.158W	0.166	1.73
Far-Spacing Low Baffle Height	1.00W	0.050W	0.112W	0.180	1.64

Table XII-C- 2. Angled baffle arrangements in box culverts with specified baffle spacing and height as a function of culvert width. Hydraulic coefficients were developed by Lang (2008) and are applicable for water depths Y0 > 1.1 Z2 and Y0 < 0.80H, the culvert height.

Table XII-C- 2 lists the angled baffle arrangements that were tested and the corresponding values for coefficient used in Equation XII-C-7. Equation XII-C-7 and associated coefficients are applicable for water depths greater than 1.1 times the maximum baffle height ($Y_0 \geq 1.1 * Z_2$) but less than 0.80 the culvert height ($Y_0 \leq 0.80 * H$).

Turbulence

Baffles create *turbulence*, which is characterized by rapid fluctuations in water velocity and flow direction. Excessive turbulence can create a fish barrier. Insufficient turbulence during bedload transport flows can lead to excessive sediment deposition between baffles, reducing their effective roughness.

The measure of turbulence commonly used in fish passage design is the *Energy Dissipation Factor* (EDF). The EDF quantifies the rate energy is dissipated within a specific volume of water. Baffles function in plunging flow and streaming flow, and the EDF for these two flow regimes is calculated differently.

Turbulence for Plunging Flow

At low flows baffles typically function as weirs that create plunging flow. In plunging flow the energy is dissipated within the pool formed between the baffles. For plunging flow the EDF of the receiving pool is calculated as:

$$EDF = \frac{\gamma Q h}{V} \qquad \text{Equation XII-C- 8}$$

where γ is the unit weight of water (62.4 lb/ft^3), Q is the flow in the baffled culvert (ft^3/s). *V* is the effective pool volume between the baffles (ft^3), which is just the portion of the pool in which the energy is dissipated. Because the energy dissipation is concentrated within the upstream portion of the pool, in general the effective pool length for calculating EDF should not exceed 8 feet when baffle spacing is greater. The maximum EDF for plunging flow commonly used for adult salmon and steelhead is 4.0 ft-lb/s/ft^3, and 3.0 ft-lb/s/ft^3 for adult resident trout. Maximum EDF values for other species and life stages have not been determined. Refer to Pool and Weir Hydraulics (page XII-113) for a more through description of turbulence and EDF in pools.

The EDF for plunging flow conditions should be calculated at the flow estimated as the transition from plunging to streaming. With some baffle arrangements this can be estimated using equations provided by Ead et al. (2004) and Rajaratnam et al. (1988), but check the limitations of the equations. The equation by Ead et al. and its limitations are described in detail in Pool and Weir Hydraulics (page XII-113). Estimate the dimensionless transition flow using Ead et al. Figure XII-45 using the plunging transition, *Qpt**. Calculate the transition flow using Equation XII-9 and then the EDF using Equation XII-C-8. If there is excessive turbulence at flows within the plunging flow regime, the crest of the baffle may need to be raised to increase pool depth. Be aware that decreasing the EDF at the fish passage design flow might lower it at higher flows so sediment partially fills the pools.

In low slope culverts where baffles are often spaced far apart, the baffle arrangement may be beyond the limits of the empirical data for the plunging-streaming transition equation. In that case, EDF for plunging flow should be checked at the low fish passage design flow. Although it is difficult to predict the transition from plunging to streaming flow, it typically occurs at flows higher than the low fish passage design flow. Therefore, the calculated EDF at the low passage design flow should be less than the maximum recommended value.

Turbulence for Streaming Flow

In the streaming flow regime, baffles function as larger roughness elements and the EDF is calculated as:

$$EDF = \frac{\gamma QS}{A} \qquad \text{Equation XII-C- 9}$$

where γ is the unit weight of water (62.4 lb/ft^3), Q is the flow in the baffled culvert (ft^3/s), *A* is the wetted area between the baffles (ft^3), and S is the hydraulic slope (ft/ft).

There is little research available to determine the appropriate maximum EDF for fish passage in baffled culverts. For streaming flow in baffles, Bates (2003) recommends a maximum EDF of 5.0 ft-lb/s/ft^3 at the high passage design flow for adult salmon and steelhead. This recommendation is based on indirect measurements and observations of fish passage through a number of baffled culverts with various flows and values of EDF. A higher EDF is suitable for channels with more cross sectional hydraulic diversity than a culvert with simple baffles. The maximum EDF for passage of weaker swimming fish, such as juvenile salmonids, would be lower. However, additional data is needed to determine an allowable EDF for other salmonid life stages and other fish species as well as to confirm the EDF recommended for adult salmon and steelhead.

Bed Material Scour and Turbulence

Deposition of sediment between baffles can reduce their effective roughness, potentially eliminating the fish passage benefit of the baffles. Adequate water velocities and turbulence can reduce the risk of sedimentation. Generally, a drop of at least 0.2 feet between baffle crests should be maintained to provide sufficient scouring forces. A minimum EDF of 3.0 ft-lb/s/ft^3 is recommended in the baffled culvert at a flow in which the upstream bed material begins to mobilize, which may be approximated in stable channels as the bankfull flow. If the EDF is much less, the scouring forces associated with turbulence and water velocity may not be sufficient to avoid excessive sedimentation between baffles.

Culvert Capacity

By design, baffles increase the roughness of the culvert, which often decreases its hydraulic capacity. Normal depth of a baffled culvert at a capacity flow can be estimated using an appropriate empirical equation for the baffle arrangement (i.e., Equations XII-C-6 and XII-C-7). The limits of application should be noted when using this approach. These equations are often not applicable if the culvert barrel is flowing full.

Once the water depth is determined, the Manning's roughness coefficient should be back-calculated and then applied to the culvert in a backwater analysis using standard backwater models for culvert hydraulics (HY-8, HEC-RAS, FishXing). If the culvert is found to be inlet controlled at the capacity design flow, the influence of the baffles on culvert hydraulic capacity is minimal.

If the calculated capacity of the baffled culvert is not sufficient, the spacing and height of the baffles can be modified to decrease roughness. Moving the first baffle further into the culvert and lowering its height can also increase hydraulic capacity. In some cases these changes can keep a culvert flowing as inlet controlled at the capacity design flow. Obviously, these modifications have to be weighed against their effects on fish passage. It may be found that a baffle design cannot satisfy the project objectives and another design approach might be necessary.

The flood analysis should consider the effects of increasing the culvert backwater upstream of the inlet on over-bank flow, channel processes, and infrastructure. The design should also meet or exceed other applicable local, state, or federal standards for hydraulic capacity, headwater depth, and other design parameters.

Procedures for Baffle Hydraulic Calculations

This procedural summary is intended to provide general design guidance. Baffle design is an iterative process. When retrofitting an existing culvert there are numerous constraints to consider. For example, typically the culvert size and slope are predetermined and there is a little, if any, extra culvert capacity. As a result, it is frequently not possible to satisfy all of the provided guidance and criteria. In such cases, it is important to have clearly defined and accepted project goals, weigh the impact of each decision on passage performance, and document the decision process. In the end, a design's acceptability relies on the degree to which the project satisfies the goals and objectives.

1. Determine the low passage design flow (Q_{LP}), high passage design flow (Q_{HP}), sediment transport flow (Q_{BF}), and the depth, velocity and EDF (if available) criteria for each target fish.

2. Select an initial estimated baffle spacing (L) and height (Z_1 and Z_2) given the culvert diameter (D) or width (W) and culvert slope (S). Initial baffle spacing and height should be selected to satisfy the low flow depth criterion. Recommended maximum culvert slope where baffles should be applied is 4% and minimum baffle spacing is 5 feet.

3. Assume plunging flow with the baffles functioning as weirs at the low passage design flows for each target species, Q_{LP}:

   a. Use a sharp crested weir equation to calculate depth of flow over the baffles (Y_0) at the low passage design flow. Account for submergence, when present. To calculate Y_0 the baffle height (Z_1) needs to be added to the depth predicted from the weir equation.

   b. Calculate the minimum water depth (Y_{MON}) within the pools between the baffles at each Q_{lp}. The minimum depth occurs at the upstream end of the pool:

$$Y_{MIN} = Z_1 + Y_0 - L\ S$$

   c. Compare the minimum water depth to the depth criterion for each target fish.

      i. If there is insufficient depth at Q_{LP}, return to step 2 and increase the baffle height or decrease the baffle spacing, or both. The entire baffle may not have to be raised; increase the elevation of the lower edge of the baffle; Z_1.

      ii. If there is more than sufficient depth and EDF is low it may be desirable to return to step 2 to decrease the baffle height or increase the baffle spacing, or both to minimize the baffles' impact on culvert capacity.

iii. For angled baffles, the baffle should become fully wetted at approximately Q_{LP} for the largest design fish. This is intended to minimize impacts on culvert capacity while meeting minimum water depth criteria. To achieve this may require returning to step 2 to modify the baffle height or shape.

d. Calculate the EDF in the pools between baffles at the transition flow (plunging to streaming).

i. Calculate the transition flow using the equation by Ead et al. (2004). If the baffle arrangement is beyond the equation's limits of application, use Q_{lp} of each target species to evaluate EDF.

ii. Evaluate the EDF at the transition flow. If EDF is excessive, return to step 2 and increase the baffle height to increase the water depth. If using Q_{LP}, EDF should be well below the threshold for the target species.

4. Assume the flow is streaming and the baffles are functioning together as roughness elements at the high passage design flows (Q_{HP}). Under this assumption, use the appropriate empirical equation or an estimate of the hydraulic roughness coefficient to calculate water depth and velocity. Coefficients for the empirical equations may need to be interpolated to fit the baffle configuration. Note the limits of application of the equations and coefficients and apply sound judgment.

a. At Q_{HP} calculate the water depth (Y_o) for the selected baffle arrangement. Y_0 may be used to back calculate the Manning's roughness coefficient of the baffles, which can be use in a culvert backwater model.

b. Calculate the average cross sectional water velocity (V) for Q_{HP} using the relationship:

$$V = Q / A$$

The wetted cross sectional area (A) is measured between the baffles.

c. Calculate EDF for streaming flow in baffles using the equation:

$$EDF = \lambda QS/A$$

d. Compare the calculated water velocity and EDF to the velocity and EDF criteria for each target fish. If the velocities or EDF are excessive, return to step 2 to increase baffle height or decrease baffle spacing, or both.

e. In circular culverts the top corner of the baffle (Z_2) should be close to the water surface at Q_{HP}. To achieve this may require returning to step 2 to modify that dimension.

It may not be possible to simultaneously satisfy the velocity and turbulence criteria and the baffle height guidance. Velocity and turbulence levels greater than the target criteria may have to be accepted if additional roughness causes other criteria (e.g., culvert capacity) to be exceeded.

5. Calculate the EDF at a flow that the upstream bed material begins to mobilize, which is often assumed to be the bankfull or 1.5 year discharge in natural alluvial channels. Compare the EDF to the minimum EDF of 3 ft-lb/s/ft^3 for gravel-bedded streams to ensure sufficient scour between baffles. An acceptable level of turbulence is typically generated if the drop between baffles is 0.2 feet or more.

6. Evaluate the hydraulic transition between the culvert outlet and tailwater pool. Calculate a tailwater rating curve to obtain the tailwater elevation at the low and high fish passage design flows. For each design flow, compare the predicted normal water level within the culvert at the outlet (Y_o) to the level of the tailwater. The objective is to have the tailwater elevation be equal or greater than the water level in the culvert at each fish passage design flow. If the tailwater is lower than the water surface in the culvert outlet, there will be a hydraulic drawdown, or drop, and acceleration in water velocities near the outlet.

Possible modifications to the baffle arrangement to reduce or eliminate a hydraulic drop are limited because the culvert size, slope, and elevation are fixed. Baffles height may be reduced or spacing increased to lower the water surface in the culvert, but this may compromise fish passage. Alternatively, downstream gradient control measures, such as rock weirs, can be installed to raise the tailwater and eliminate the hydraulic drop. If site limitations prevent sufficiently raising the tailwater to match the water surface exiting the culvert outlet, it may be acceptable to have a drop or drawdown (M2 curve) in the water surface at the outlet. This can be evaluated with a backwater analysis. If a drawdown is allowed, check the water depth, velocity and EDF throughout the drawdown to ensure fish passage criteria are satisfied. To minimize the drawdown, a special outlet baffle should be installed (see Outlet Transition page XII-101). The resulting outlet drop should not exceed fish passage design criteria for hydraulic drops at culvert outlets.

7. Identify the structural design flow for the culvert (e.g., 100-year flow) and check the hydraulic capacity of the baffled culvert.

a. Use the empirical equations to calculate the water depth at the structural design flow and then back calculate the corresponding Manning's roughness coefficient.

b. Using the Manning's roughness coefficient, perform a standard culvert capacity analysis. Compare the headwater depth of the baffled to the unbaffled culvert to determine the impact of the baffles on capacity.

c. Evaluate the risks of sediment or debris accumulations on fish passage and culvert capacity.