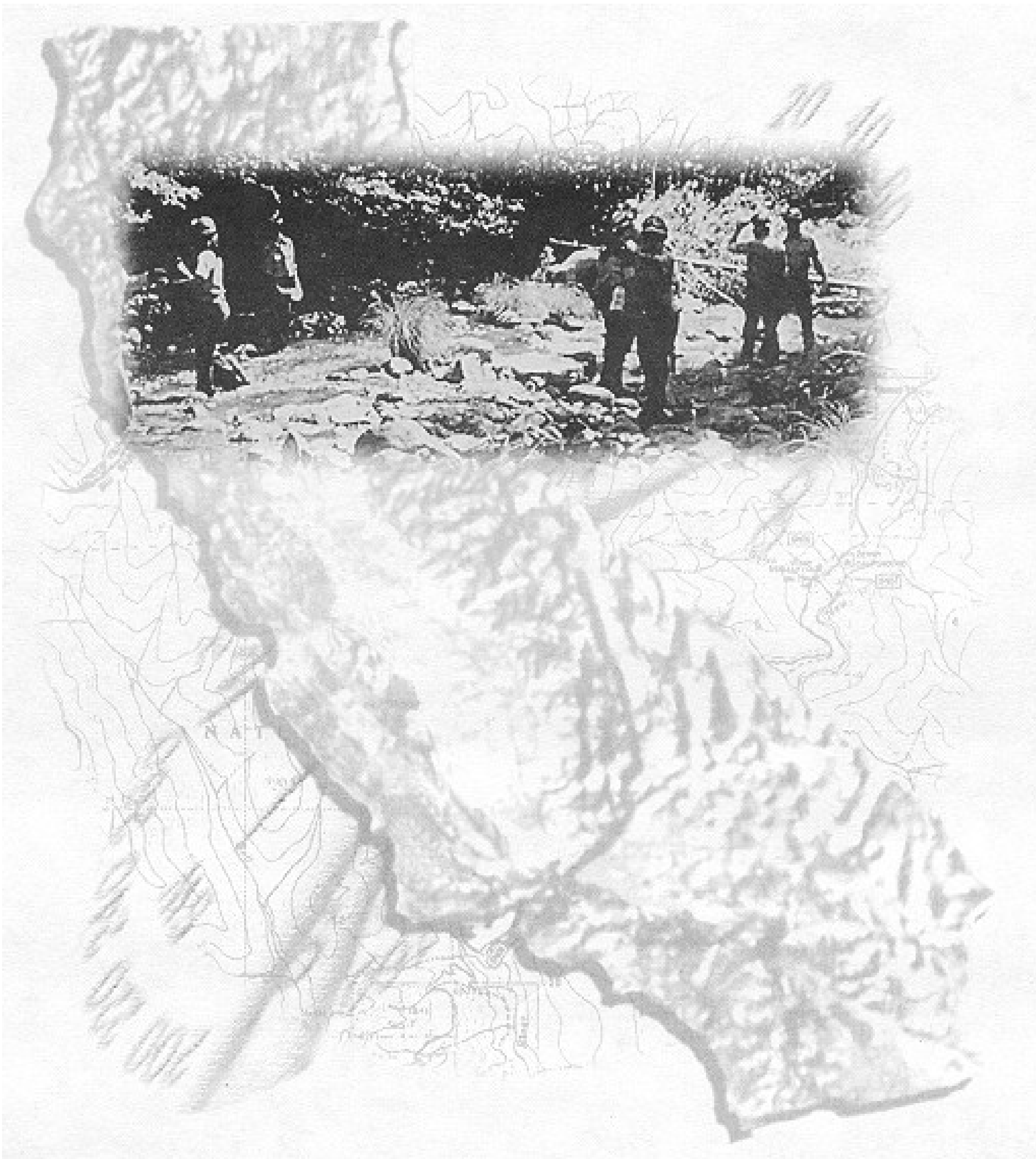
CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL

PART VI

PROJECT PLANNING AND ORGANIZATION



PART VI PROJECT PLANNING AND ORGANIZATION

The information and methodologies in this manual are intended to guide instream habitat improvement efforts to effect an increase in salmonid population numbers. However, there are factors that can occur in other phases of a targeted species life history that must be considered before initiating habitat improvement projects. Some of these include adverse oceanographic conditions, disrupted watershed and stream-side conditions, water diversions, migration barriers, excessive harvest, introduced predators, or the presence of toxic substances causing the loss of suitable water quality. Proponents should consult with local residents, as well as resource professionals like DFG basin planners and biologists on these and other issues before proceeding with instream habitat project and layout.

When extraneous factors are found to be suppressing the population of a species, consideration must be given to addressing those factors prior to further consideration of stream habitat modification. For example, if legal harvest of the target species is identified as a primary limiting factor, it should be addressed through the regulatory process; however, it is possible that this process could occur concurrently with stream habitat improvement efforts. Usually, a multi-faceted restoration prescription that includes watershed, riparian, instream, artificial propagation, conservation education, and regulation treatments is the best approach to take.

Final selection of project options will frequently be dictated by availability of funds, access, ownership, materials, capability of construction crews, and environmental protection considerations. In any case, other valuable fish and wildlife habitats should not be sacrificed for the benefit of a project unless there is clearly a net beneficial result to the environment as a whole and all losses are fully offset. There are many reasons why stream habitat modification may or may not be appropriate, but lack of assessment, analysis, imagination, inventiveness, or commitment by the planner or habitat specialist should not be among them. If, after thorough analysis, no reasonable habitat improvement project can be identified on a particular stream, none should be further promoted at the time. DFG Basin Planning efforts can help provide guidance to streams with suitable project reaches and sites, and recommend appropriate habitat improvement activities.

After historic and current watershed conditions, fish habitat, and fish populations have been inventoried and analyzed and a decision has been made to develop a restoration prescription, specific restoration treatments can be designed. Landowners and involved agencies must be consulted to ensure their interest and cooperation. Next, a written work plan must be developed for the overall project and its individual work sites. The work plan must identify present conditions, project objectives, expected results, and estimated labor, materials, tools, and equipment necessary to complete the project. The work plan must identify any necessary permits, and all permits must be in possession before any on-site work can begin. Regardless of permits, no work can be performed instream as long as there is a possibility that live salmonid eggs or fry are present. The plan should also include project evaluation and monitoring strategies.

Permits That May Be Required

- **Access Agreement.** This agreement is necessary to not only do the development work, but to enter onto property other than your own to do preliminary survey work. This agreement must be reached between the project sponsor and the landowner or manager.

- **Streambed Alteration Agreement**. This agreement, issued by the Department of Fish and Game, is necessary to perform any physical manipulation of the stream, including vegetation, within the high water mark (Fish and Game Code, Sections 1601/1603).

- **U.S. Army Corps of Engineers 404 Permit**. This permit, required pursuant to the Clean Water Act, may or may not be needed, but if the project proposes removal or placement of any materials in the stream area, or if the project area is a wetland, then the project proponent must apply to the Corps of Engineers to determine if a permit is necessary.

- **U.S. Army Corps of Engineers Section 10 Permit**. This permit, required pursuant to the Harbors and Rivers Act, is to be obtained for any construction between high water marks of navigable rivers.

- **Section 401 of the Clean Water Act**. Section 401 of the Clean Water Act requires that the California Regional Water Quality Control Board determine consistency between proposed projects, California water quality laws, and certain sections of the Clean Water Act. The California Regional Water Quality Control Board has established specific procedures for implementing this section. The project proponent may be required to submit a "Request for Certification" form to the California Regional Water Quality Control Board.

- **Department of Fish and Game Trapping and Rearing Permit**. If the restoration project proposes to trap and rear fish, a trapping and rearing permit must be obtained from the Department before any fish may be handled. This permit process requires the applicant to have an approved five-year management plan before the permit will be issued (Appendix B). Contact the local DFG district fishery biologist.

- **County and State Right-of-Way permits**. If the proposed project is near any public roads it could require agreements or permits with county and state public works departments. In addition, many counties have ordinances against working within a riparian corridor along a stream area. This usually falls under the county planning department.

- **State Lands Commission**. State Lands Commission is a permitting agency responsible for riverbed lands owned in fee by the State as sovereign lands, subject to the public trust for water-related commerce, navigation, fisheries, recreation, open space, and habitat. Project proponents should contact the State Lands Commission to determine if the project falls under Commission jurisdiction.

- California Environmental Quality Act (CEQA). Anytime an individual or a group (including public agencies), contracts with the Department of Fish and Game for fish habitat restoration projects, an environmental review is necessary. Individuals or groups conducting habitat restoration projects in a volunteer capacity may also need to have an environmental review of proposed projects, and should discuss proposed projects with the DFG district fishery biologist during the planning stages.

- **National Environmental Policy Act (NEPA).** This applies to projects which are carried out, financed, or approved in whole or part by federal agencies.

- **National Marine Fisheries Service (NMFS)**. Written authorization must be obtained for any activities that may impact a federally listed species.

FISH HABITAT RESTORATION CATEGORIES

Fish habitat restoration can be divided into five general categories: 1) upslope watershed improvements; 2) riparian and stream bank stability treatments; 3) instream habitat improvements; 4) artificial propagation; 5) watershed stewardship training.

Upslope Watershed Treatments

Watershed features determine the general condition of streams. In some cases, watershed conditions may preclude successful artificial propagation, instream treatment, or riparian restoration activity for fish. An extremely deteriorated watershed might exhibit poor water quality and result in extirpation of its fish populations. Fine sediments filling pools and sealing gravel, high water temperatures, high pH from mine drainage, or lack of flow during critical times of the year are examples of fish habitat problems that could be attributed to watershed conditions.

A basic inventory of past, current, and planned land and water uses in the watershed is a necessary step prior to restoration project activity. Usually a discussion with the landowner(s) and/or agencies like EPA, NRCS, CDF, or DFG, will provide a general understanding of the watershed. If warranted, sediment sources such as road systems and landslides, or waste water discharge points might need to be investigated further. Watershed inventory methodologies are available, but are beyond the scope of this manual. Watershed treatment techniques are often included in watershed restoration references, and improvement treatments include such varied activities as improved road drainage, road or trail obliteration, reforestation, or changes in land management priorities.

Riparian Zone Treatments

Watersheds and streams are dynamic; therefore, erosion and sediment transport are natural phenomena which can improve as well as degrade fish habitat. Bank failures and landslides can be the major source of large woody debris and boulder recruitment to the stream. Eroding gravel banks are a continuing source of gravel for the stream. High flows may shift gravel bars, cleanse spawning beds, and scour or deepen pools, all to the benefit of spawning and rearing salmonids. Erosion of fine-textured soils such as clays, silts, and fine sands, however, can reduce the quality of fish habitat. In streams or reaches flowing through these soil types, effects of stream enhancement work may be negated if erosion is not reduced or controlled. Part VII discusses various techniques for controlling erosion detrimental to fish production.

Near-stream and riparian zones supply the stream with large woody debris (LWD) that form the roughness elements the stream needs to provide diverse fish habitats. DFG has developed a survey methodology for assessing LWD in the stream channel, as well as live, dead, and downed trees in the near-stream vegetation zone. This survey can provide the information needed to better manage land use activity in these areas. The survey identifies revegetation project sites if needed; Part III contains this methodology.

Instream Habitat Improvements

Physical conditions within stream channels can be modified to improve or increase particular habitats and the overall mix of habitat types for salmonids. However, if such modifications are to have any degree of permanence and success, they must take into account the principles of stream hydraulics. The value of modifications depends on correct identification of critical stream habitat needs affecting the species in question. Part VII includes guidelines for location and design of instream structures for rearing and spawning habitat. Part III contains information on structure suitability by stream type.

Barriers to fish migration dramatically constrain fish populations. Impassible natural barriers define the limit of anadromous salmonid migration. Other temporary obstructions, such as log jams, landslides, beaver dams, and some plunges, occur and may impede fish passage into historically used reaches. Other structures such as dams and improperly installed road culverts also impede fish passage. Before a barrier modification project is undertaken, fish populations and habitats below and above the obstruction should be assessed. A review of historical information and a visual inspection or other sampling procedures should be conducted to identify fish populations and habitat potential. If the barrier is a natural geological feature, such as a waterfall, then special consideration should be given to the possibility that any fish found above the barrier may be part of an isolated population, that could be harmed by competition from downstream populations. Part VII, "Fish Passage," describes various approaches to overcoming both natural and human-induced obstructions.

In instream habitat improvement projects, including barrier modification, the potential short-term benefit for fish can be high. Nevertheless, the costs can still outweigh the benefits to be gained. Plans and wishes of involved landowners must be considered during any decision making process. Each situation must be individually evaluated.

Artificial Propagation

Artificial propagation is sometimes desirable to accelerate utilization of expanded or improved habitat conditions by a target species. This activity is intended to be short term and closely coordinated with other elements in the fishery restoration program. The DFG District Biologist must be closely consulted concerning the appropriateness of this activity. Timing, duration, location, availability of genetically suitable brood stock, and stock transfer are some of the elements that must be considered. Appendix B, "Cooperative Fish Production in California," provides guidelines to be followed when artificial fish production is considered.

Watershed Stewardship Training

If restoration activities being considered are to have a lasting and meaningful effect on the watershed and its drainage system, a public buy-in or education program in watershed stewardship is necessary. Public involvement should include landowners and managers, all sectors of the local community, and the area's public schools.

There is an active and widespread program using aquaria in school classrooms to teach appreciation of the aquatic environment. These projects, which are supported by DFG and various organizations, allow students to hatch salmonids, rear to fry, and release them to suitable streams. During this activity a coordinated watershed and stream environment curriculum is taught.

Practical watershed restoration advice for landowners, as provided by university extension advisors, NRCS, or watershed groups, can be an effective means of promoting fishery restoration. Rural watershed landowners and managers are usually receptive to suggestions to improve their road systems, especially if it can be demonstrated that they can save time and money in the process. Generally, landowners want their roads in useable condition, and they also want to retain the topsoil and productivity of their lands. Therefore, most landowners welcome constructive alternatives to conditions that are contributing to loss of desirable fish habitat.

INSTREAM STRUCTURE SUITABILITY BY STREAM TYPE

Any instream structure must be hydrologically, structurally, and biologically suitable for the specific physical conditions of the site. Adverse consequences of unsuitable structures can include accelerated erosion or deposition, physical structure failure, and displacement or replacement of a beneficial species. Stream channels operate in a consistent and predictable manner and the knowledge of such channel response to artificially placed structures must be used to select, design, and place improvement structures.

Rosgen's stream classification system, presented in Part III, provides a basis for evaluating instream structure suitability. A variety of commonly used structural enhancement designs that can be applied to a wide range of stream types are also presented in Part VII. The potential effectiveness guidelines for fish habitat improvement structures are based on morphology of the stream types involved. The guidelines are derived from actual observations of both good and poor applications of a given structure type in a particular stream type. They are only guidelines and are meant to provide general direction or highlight potential problems, and are not intended to be rigid dogma or to evolve into hard rules, and in no way substitute for the services of a qualified fisheries specialist or hydrologist in planning projects. The guidelines may, however, "red flag" some potential problem areas that require more detailed, site-specific analysis prior to structure selection. The rating categories for suitability are excellent, good, fair, and poor. These ratings do not reflect 1) the biological effectiveness for meeting limiting habitat factors in any particular stream, 2) costs or difficulty of construction, or 3) cost/benefit relationships.

PROJECT RECOMMENDATION DEVELOPMENT FROM HABITAT INVENTORY DATA

Every stream inventory report based on DFG format contains general recommendations for fish habitat improvements, or further assessment needs.

1) Management as an anadromous, natural production stream.

    a) Management as an anadromous, natural production stream includes all streams and stream reaches that currently support anadromous fish, or are restorable to do so. These streams, reaches, and naturally reproducing stocks provide the foundation of the DFG salmon management program.

    b) In some cases cooperative fish production is desirable if the fish rearing facilities are linked to restoration goals and objectives approved by the Department. Hatchery enhancement programs are reviewed carefully by DFG Regional and IFD personnel. These programs must have a five-year management plan that shows a clear need, a specific purpose and benefit, and scientific justification.

2) Design and engineer pool enhancement structures to increase the number of pools or deepen existing pools, where the banks are stable or in conjunction with stream bank armor to prevent erosion.

    a) In general, pool enhancement projects are considered when primary pools comprise less than 40 percent of the length of total stream habitat. In first and second order streams, a primary pool is defined as having a maximum depth of at least two feet, occupy at least half the width of the low flow channel, and be as long as the low flow channel width. In third and fourth order streams, a primary pool must be at least three feet deep.

    b) In the Part III section, “Stream Channel Type Descriptions and Structure Suitability,” specific structure recommendations are included for each channel type. Instream habitat improvement is only appropriate in stream reaches suitable for habitat improvement structures.

    c) In Part V, Table 2, “Summary of Habitat Types and Measured Parameters,” found in the stream inventory report lists the Level IV habitat types for the stream inventoried. Habitat types such as step runs and low gradient riffles can often be converted into pool habitat if pools are needed.

    d) Table 4, Part V, “Summary of Maximum Pool Depths By Habitat Types,” found in the stream inventory report lists the depth of the pools by habitat type. Pools too shallow to qualify as primary pools can often be enhanced by increasing scour.

e) In Part VI, "Project Planning and Organization," and Part VII, "Project Implementation," must be thoroughly reviewed before proceeding with a pool enhancement project.

3) Increase woody cover in the pool and flatwater habitat units, with complex, woody cover, especially where the material is locally available.

a) In streams or stream reaches where the mean pool shelter ratings are calculated to be less than 80 it is desirable to increase the amount of cover. Part V, Table 1, "Summary of Riffle, Flatwater and Pool Habitat Types," lists the mean shelter ratings for the Level II habitat types. Log and root wad cover structures in the pool and flatwater habitats are needed to improve both summer and winter salmonid habitat. Log cover structure provides rearing fry with protection from predation, rest from water velocity, and also divides territorial units to reduce density related competition. Part V, Table 5, "Summary of Mean Percent Cover By Habitat Type" identifies the type of cover by habitat type present.

b) In the "Stream Channel Type Descriptions and Structure Suitability" section of Part III, includes specific structure recommendations for each channel type. Cover structures should only be considered in stream reaches suitable for habitat improvement structures.

c) Part VI, "Project Planning and Organization," and Part VII, "Project Implementation," must be thoroughly reviewed before proceeding with a cover enhancement project.

4) Increase canopy by planting willow, alder, or native conifers along the surveyed stream banks where shade canopy is not at acceptable levels, or in reaches above the survey section when temperature impacts have originated upstream. Planting must be coordinated with bank stabilization and/or upslope erosion control projects.

a) Where summer water temperatures are above the acceptable range for salmonids (Appendix P) increasing the canopy is desirable. Water temperatures taken during the fish habitat inventory are found in Part V, Table 8, "Fish Habitat Inventory Data Summary". Some reports also contain more extended recording thermograph data.

b) In general, revegetation projects are considered when canopy density averages less than 80 percent in specific steam reaches or sub-areas. Canopy density, listed by the coniferous and deciduous components is found in Part V, Table 8.

c) The mean percentages of the right and left banks covered with vegetation are found in Part V, Table 7, "Summary of Mean Percent Cover For The Entire Stream". The mean percentages of dominant substrate and dominant vegetation are found in Part V, Table 9. Using these two tables, stream reaches can be identified where the dominant elements composing the structure of the stream banks are silt, clay, sand, or gravel, and riparian vegetation is lacking. These areas are good candidates for revegetation.

d) The "Revegetation" section of Part VII contains detailed instructions on techniques including willow sprigging and planting seedlings.

5) To establish more complete and meaningful temperature regime information, twenty-four hour monitoring during the warm summer water temperature season should be conducted for a period of three to five years.

a) This recommendation is made when limited water temperature data are available, but either the survey samples or short-term thermograph data suggests that maximum temperatures are likely to be above the acceptable range for juvenile salmonids. These streams or reaches are usually candidates for revegetation.

6) Inventory and map sources of stream bank erosion and prioritize them according to present and potential sediment yield. Identified sites should then be treated to reduce the amount of fine sediments entering the stream.

a) Bank erosion sites are listed in the "Comments and Landmarks" section in the stream inventory reports.

b) The "Watershed and Stream Bank Stability" section of Part VII, details many techniques for treating stream bank erosion.

7) Active and potential sediment sources related to the road system need to be identified, mapped, and treated according to their potential for sediment yield to the stream and its tributaries.

a) Sediment related to roads impact cobble embeddedness. These values are summarized in Part V, Table 8. Cobble embeddedness measured to be 25 percent or less, a rating of 1, is considered to indicate good spawning substrate for salmon and steelhead. Road systems have been attributed to generate as much as 70 percent of the sediment yield produced in most watersheds. Part VI, "Upslope Watershed Treatments," includes information on potential actions to identify and reduce upslope sediment.

8) Projects should be designed at suitable sites to trap and sort spawning gravel in order to expand redd site distribution in the stream.

a) Projects to increase spawning gravel are desirable where suitable spawning gravel is found on relatively few reaches, or crowding and/or superimposition of redds has been observed during winter surveys.

b) When a large percentage of the low gradient riffles has substrate other than gravel or small cobble as the dominant substrate, gravel trapping structures may be considered. Part V, Table 6, "Summary of Dominant Substrates By Habitat Type," has the summary information about the stream substrate.

c) The "Stream Channel Type Descriptions and Structure Suitability" section in Part III, makes specific structure recommendations for each channel type. Instream habitat improvement structures should only be considered in suitable stream reaches.

d) Part VI, "Project Planning and Organization," and Part VII, "Project Implementation," must be thoroughly reviewed before proceeding with instream structures to enhance spawning substrate.

e) A stream reach located below a dam or other gravel supply restriction may need spawning gravel replenished. The "Placement of Imported Spawning Gravel" section of Part VII, has recommendations for this treatment.

9) Modification of log debris accumulations is desirable, but must be done carefully, over time, to avoid excessive sediment loading in downstream reaches, and to preserve the larger beneficial scouring elements.

a) Log debris accumulations (LDA's) are listed in the stream inventory report in the "Comments and Landmarks" section.

b) A log debris accumulation should only be modified if it is retaining a significant amount sediment, and the biological inventory confirms it is creating a fish passage problem, or the LDA is causing to significant bank erosion.

c) In Part VII, "Fish Passage," methods are detailed for modifying fish passage.

10) Fish passage should be monitored and improved where possible.

a) High gradient streams or streams containing an >A= or >G= type channel, or streams with high gradient riffles, cascades or bedrock sheets as habitat types may limit fish passage, especially in years with limited rainfall. Good water temperature and flow regimes and suitable habitat for rearing fish must exist upstream for this to be a concern.

b) In some streams selective barriers exist. For example, a stream could have a barrier to coho but not steelhead. Selective barrier conditions must be confirmed with a biological inventory.

c) Before any barrier modification is undertaken, the DFG District Biologist must be consulted to determine if modification of the barrier is desirable and to confirm the status of resident stocks in order to avoid impacting the genetic integrity of existing or native stocks.

d) The “Waterfalls and Chutes” section of Part VII details methods for improving fish passage through these areas.

11) Culvert modification or replacement.

a) Culvert types, dimensions, condition, and the height of the jump into the culvert are listed in the stream inventory reports in the “Comments and Landmarks” section.

b) Replacing a culvert with a bridge is desirable when a high jump and/or the velocity of the water in a culvert, makes the culvert a probable fish migration barrier.

c) A culvert that is adequately sized, in good condition, and accessible to anadromous fish, may benefit from the installation of baffles. The “Culverts” section of Part VII has several examples of baffle installation. Culverts should only have baffles installed after consulting with a qualified engineer.

d) In some cases, culverts have been installed too high to allow anadromous fish to jump into the culvert. If the culvert cannot be replaced with a bridge or with a new culvert below stream grade, it may be desirable to construct a fishway. Part VII, “Fishways,” has examples of commonly used designs. Prior to the construction of a fishway, a qualified engineer must design and engineer the project.

12) Exclusion of livestock from the riparian corridor except at controlled access points should be explored with the grazier and developed if possible.

a) Areas where livestock are impacting the riparian zone are listed in the stream inventory reports in “Comments and Landmarks.”

b) The “Exclusionary Fencing” section of Part VII details some options for excluding livestock from riparian zones.

PROJECT SITE LAYOUT

Once the need for instream habitat improvements have been made, project sites located, and suitable enhancement structures selected, actual project layout must be developed. Hydraulic profiles for base flow, bankfull discharge, and flood flows should be developed at each project site, and a schematic display of proposed structure(s) and job site layout drawn. The drawing must include upstream and downstream limits of the project site, established cross sections, and a longitudinal profile. At the project site an elevation benchmark monument must be established and described. Triangulation, or the so-called “two-pin method” can be useful for layout of stream habitat enhancement designs and for establishing permanent reference points (Appendix L).

For evaluation and monitoring purposes, it is important to accurately record and monument the project location, and describe and record pre-treatment conditions at the site. Identify and monument photo points, describe the camera location and angle for the photo, and record the type of camera and lens used. Accurately measure the location of the project benchmark monument from a fixed, easily identified landmark such as a permanent bridge, confluence with a blue line or named tributary, or the stream mouth. Determine the latitude and longitude of the project from a USGS 7.5-minute quadrangle using the Coordinator tool or an accurate GPS location. If the stream has been habitat typed, record the habitat unit number from the survey. Finally, be sure to include access routes to the project, noting any special considerations like locked gates, or requirements from landowners.

Using Basic Hydraulic Analysis For In-Channel Design

Addition or removal of gravel, boulders, structures, vegetation etc., within a stream channel alters its existing cross-sectional shape. Furthermore, when material is added or removed from a stream channel it changes the channel's ability to convey water and sediment. Designers should carefully consider effects these alterations have on local channel geometry. For example, addition of a wing-deflector typically narrows the cross-section, resulting in some backwater and increased erosional force. Channel-form changes and deposition in the vicinity of the structure can be anticipated through basic hydraulic analysis.

The following channel assessment method (adapted from Inter-Fluve, Inc. 1984) is based on formal hydraulics and can help determine dimensions, locations and elevations of channel modifications. The method requires hydraulic data collection, (longitudinal and cross-sectional elevations) and interpretation of these data (drafting and analysis of longitudinal and cross-sectional elevations). Designs are developed for individual sites by subjecting specific cross-sections to hydraulic analysis. After the design is developed on paper, it can be constructed according to criteria generated (new longitudinal and cross-sectional elevations).

Surveying the Longitudinal and Cross-Sectional Profiles

Longitudinal and cross-sectional information is gathered to identify elevation of the stream bottom and various water levels. By convention, longitudinal profile is surveyed along the thalweg at locations where pronounced changes in bed slope occur. Cross-sectional profiles are surveyed at specific sites along the longitudinal profile to highlight special features.

Longitudinal distance markers (station, river mile, etc.) should be established systematically, usually every 100 feet, along the right or left bank, as you face downstream, with tagged rebar or wooden stakes. By convention, distance is measured from the start of the reach upstream; also, the first station is normally located at a reproducible location such as a bridge pier, culvert, or tributary junction. Distance of each pool and riffle feature is then recorded. For example, the first unit in the longitudinal profile, a riffle, may extend from 0' to 55', and the first pool from 55' to 75'. Distance surveyed should not only include the reach of stream under investigation but also several pool/riffle sequences, upstream and downstream. Elevation data are gathered by standard surveying techniques, with particular attention to changes in the streambed and major longitudinal slope breaks. Identifying these breaks in slope can be difficult, but often pools usually require a minimum of five longitudinal readings, while riffles tend to be more consistent and may only require three readings. Of course, complex streams may require more frequent readings. Figure VI-1 depicts a longitudinal profile and its various features; of special interest is the location of elevation shots and their importance in characterizing stream channel shape.

Cross-sections are recorded at specific locations along the longitudinal profile. This information is usually gathered at the time of the longitudinal survey, but additional sites may be surveyed later. For a given reach, cross-sections should be measured at both riffles, runs and pools. These data are gathered for two basic purposes: 1) to describe a location in elevational form which you wish to emulate or use as a reference cross-section; and 2) to describe a location in elevational form which you wish to alter or use as a potential design site. Elevation data in cross-sectional form are very important to hydraulic calculations.

Number and location of appropriate measurements must be subjectively determined in the field based on natural stream variability. Measurement techniques for either pool or riffle cross-sections are the same (Platts et al. 1987). Cross-sectional profiles for any particular location should include left and right bank elevations, floodplain elevation(s), intermediate channel to bank elevations, and estimated bankfull discharge water surface elevation (even if this elevation must be intuitively reasoned). Again, complex channels will require more elevation recordings.

To adequately describe a location in numeric form may require establishing a number of cross-sections. The large variation inherent in pools normally requires three cross-sections to adequately describe a single location. These measurements should be taken at the entrance to the pool, through the deepest part of the pool, and at the pool exit or tail-out. In contrast, riffles exhibit less variation and usually require less intensive measurement. After the longitudinal and cross-section elevation data are gathered they should be plotted (Figures VI-1 and VI-2).

Graphically displaying the profiles allows the designer to identify pool, run and riffle features and determine site specific hydraulic variables. Figure VI-2 depicts a series of cross-sectional profiles (reference cross-sections) and their various features; of special interest is the location of elevation shots and their importance in characterizing stream channel shape.

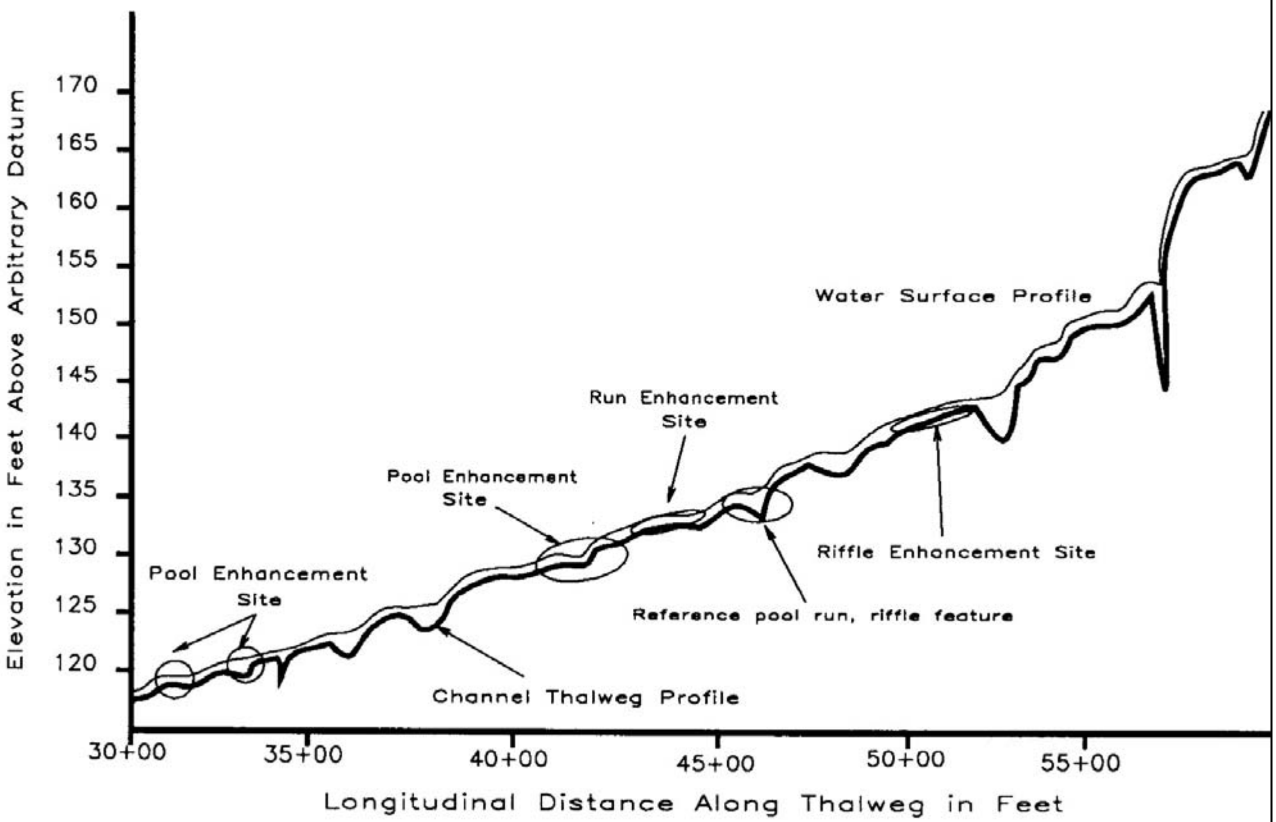


Figure VI-1. Longitudinal profile of channel bed depicting locations of possible enhancement sites.

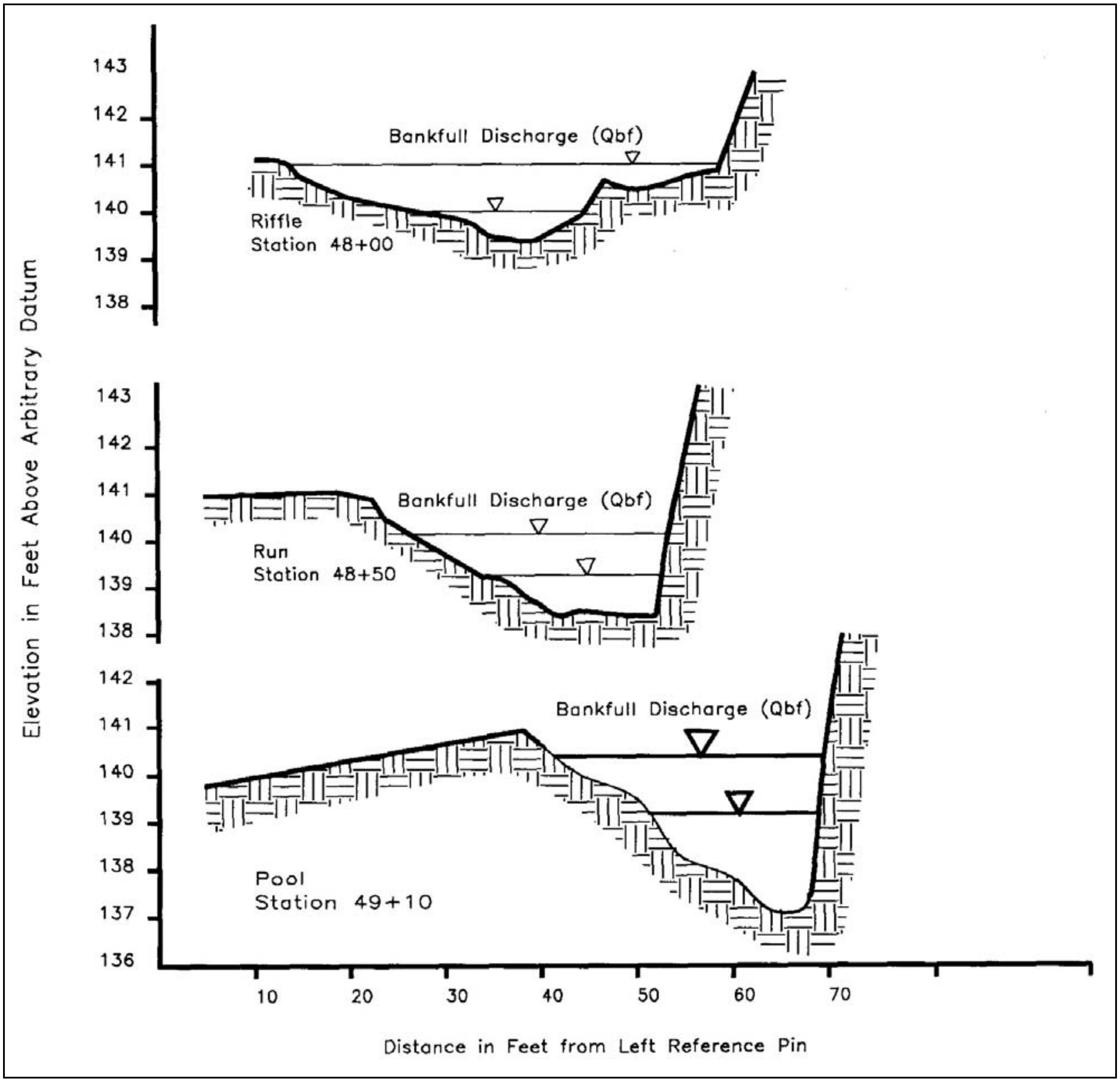


Figure VI-2. Selected cross-sectional profiles for reference pool, run, riffle features.

Analysis of Longitudinal Profile

The longitudinal profile is the most important tool in determining location of channel enhancement opportunities. The profile depicts existing features that reflect past geomorphic channel activity. Visual analysis will show depths of various pools, length of riffles, locations of runs and transitions. Pools and runs are most often found at localized slope breaks, i.e., steep slope changing to a shallow downstream slope. In general, the magnitude of these slope breaks determines energy available for sediment scour or fill. Energy expenditure is ultimately manifested in depth of water in the pool or run. Deeper pools are often found below steeper riffles; conversely, shallow pools or runs are most often found below less dramatic breaks in slope.

One should keep in mind that longitudinal information supplements other field observations, such as location of a bedrock bank, sudden change in stream direction, or instream roughness objects. Slope breaks are tools that designers can use to plan locations of channel alterations.

Enhancement is most often directed toward modifying transitional areas that appear from the data to be poorly developed pools, riffles or runs. For example, if the focus is on developing better pools, the first task is to look at the longitudinal profile and identify conditions depicting exemplary pool habitat. Factors to characterize might include slope and length of the upstream riffle, slope and length of the downstream riffle, and slope and length of the existing pool. This exemplary pool habitat characterization, when combined with other field data (e.g. location of a bedrock bank, sudden change in stream direction, or instream roughness objects), provides the designer with a "reference profile template" for pool habitat. Once a reference profile template is developed, potential enhancement sites can be located by fitting the template into existing conditions. A reference pool template will normally best fit areas which are "tending to be pools." Similarly, a reference run template will best fit areas which are "tending to be runs," and reference riffle templates will fit areas which are "tending to be riffles." With suitable templates, enhancement involves modifying existing conditions to emulate the reference template exhibiting desired habitat.

From the viewpoint of hydraulics, the most useful longitudinal templates are ones that can be described mathematically. In order to extract a mathematical template from the longitudinal profile, it is necessary to calculate average slope of the reach, or various specific segments. This task is accomplished by fitting a straight line between upstream and downstream elevations on the profile. The slope of the resulting line is calculated by dividing vertical change in elevation by longitudinal distance. Slope is also calculated for short segments, such as that which might be used for site-specific templates, or for somewhat longer distances, such as average slope for a particular reach within the overall profile. Both average slope of the longitudinal profile, and shorter segment slopes have utility and are used in hydraulic calculations discussed below.

Analysis of Cross-Sectional Profiles

Cross-sections provide the designer with an in-depth look at existing conditions, provide mathematical templates (reference cross-sections) for exemplary habitat types and also serve as guides for construction of restoration features. Two types of cross-sectional profiles are analyzed: 1) cross-sections for use as reference cross-sections (exemplary habitat types); and 2) cross-sections which you wish to alter (potential design sites). Items of particular interest, in addition to the actual cross-sectional configuration, are estimated bankfull discharge, mean annual discharge, bed and bank substrate types, location of large woody debris, stability of bank and floodplain vegetation, slope and length of upstream riffles, slope and length of downstream riffles, and slope and length of pools for each type of cross-section. Again, similar to the longitudinal profile, cross-sectional profiles should supplement/support other field data.

Cross-section profiles selected for restoration should be plotted on a design sheet. Similarly, reference cross-sections should also be plotted to provide the designer with cross-sectional templates. Comparison of reference cross-sections with a location under consideration for restoration can be particularly informative in regard to different channel configurations. During the initial comparison process, designers should pay careful attention to other field data, as many factors not accounted for on the reference template may influence its shape. Ultimately, a suitable reference cross-section(s) is selected as a restoration goal for a specific cross-section profile(s) that has been selected for restoration.

Selection of a suitable cross-section reference template to be used as a guide for alteration of a selected cross-section profile must be done carefully. Again, similar to longitudinal profile templates, reference pool cross-section templates will best fit areas which are "tending to be pools". A reference run cross-section template will best fit areas which are "tending to be runs," and reference riffle cross-section templates should fit areas which are "tending to be riffles." Each cross-section profile selected for restoration is paired to a specific reference cross-section. By carefully selecting suitable templates, enhancement of a chosen cross-section involves modifying its configuration to emulate its paired reference template. Modification of the cross-section selected for restoration is guided by using an iterative hydraulic analysis known as the Manning Equation (Appendix H).

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