Design of Fish Passage Mitigation Measures for Existing Flood Control Channels

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ABSTRACT

Conventional flood control facilities and construction materials that have been traditionally applied are now challenged by environmental regulatory requirements to ensure compatibility for fish survival and eliminate potential barriers for anadromous fish passage. Unfortunately the majority of the published hydraulic design criteria related to maximizing fish passage performance in facilities is opposite the desired hydraulic characteristics to maximize flood control conveyance. In addition, the migration period of many of the fish species tend to be during the peak flood season, however, many times low-flow conditions become the governing condition, particularly in semi-arid areas such as California. Evaluating the effectiveness of potential mitigation measures for fish passage in flood control system requires a detailed understanding of the available design criteria, both biologic and hydraulic, particularly to quantitatively assess if existing facilities represent a constraint. Application of fundamental procedures to develop a successful plan formulation for mitigation measures that enhance fish passage rely on carefully balancing the objectives of both the flood protection needs, physical constraints of the existing channel system, and fish passage hydraulic characteristics. Accurate assessment of these features requires an understanding of the natural physical processes in the watershed, hydrology, historic flow conditions, river hydraulic, along with an accurate baseline database. A detailed survey of the various published criteria is reviewed to assess the applicability to flood control channel systems, rather than just individual stream crossings as the majority of the available procedures focus.

Introduction and Background

The National Marine Fisheries Service (NMFS) in August 1997 listed anasdromous steelhead in Southern California as endangered under the Endangered Species Act (ESA). Most recently in July 2000 the final rules for Endangered and Threatened Species; Salmon and Steelhead (50 CFR Part 223 4(d))were published. Steelhead rainbow trout are an anadromous form of resident trout, spending part of their life in the ocean and part in fresh water. Steelhead were historically present in most coastal California streams, however, in many hisotrical steehead stream, passage barriers have blocked migration to and from upper stream reaches and resulted in reducing steelhead populations. On many coastal California streams, there are natural and man-made barriers or impediments which include existing flood control facilities. The ESA affects the operation and improvements within any coastal stream or river as far south as Ventura County. Most of the coastal watersheds and rivers and rivers are managed at a minimum for flood control purposes. The effect of these environmental regulations is the need to address steelhead migration concerns for any proposed

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modifications to the stream course or channels for flood control purposes. Providing free and unimpeded fish passage for critical habitat areas is one of the objectives of these requirements and many existing river structures may act as barriers to fish passage, including channel improvements, roadway crossing, and culverts. Potential modifications or improvements to existing flood control facilities will require compliance with the ESA to address migratory fish passage in these facilities and integrating mitigation measures or speciality features during the initial planning stages. Commonly accepted enhancement measures and recent technology for migratory fish passage are available which can assist in mitigating potential impacts to riverine fish habitat.

Assessment of Fish Passage in Existing Facilities

Understanding fish behavior applicable to engineering criteria are essential to evaluating successful fish passage of watershed systems. Coupling engineering and biological information when developing a fish passage facility is a reasonable approach to this discipline. Success of fish passage facilities depends on understanding the target fish's migratory and swimming behavior as well as hydraulic and habitat preferences. The evaluation or design of fish passage facilities with the application of hydraulic design criteria is primarily based upon the maximum allowable velocity for the particular fish species to negotiate the fish passage. The bulk of the published criteria that has been developed focuses principally on the assessment and design of water crossing structures for roadways, such as culverts or bridges, to ensure free and unimpeded fish passage of adult and juvenile fish.

Hydraulic design criteria can be applied to specific fish passage requirements and verify the acceptability of potential hydraulic performance for fish passage. The intent of incorporating this criteria is to ensure that the swimming ability, timing of the target species, and size of the fish are accommodated in the anticipated hydraulic conditions. Steelhead may potentially have difficulty in migrating upstream during periods of winter and spring when streamflows are low without incorporating a low-flow passage channel within the main channel section to facilitate passage for anadromous fish. Specific parameters related to biological criteria which should be considered for fish passage evaluation include: (1) size of fish require for passage (lifestages), (2) time of year which fish passage is required (spawning migrations), and (3) high and low design passage flows

General Fish Passage Criteria

A detailed survey was performed of the available criteria from representative agencies in the Pacific Northwest and Canada where the majority of the research has been conducted regarding the fisheries resources in these areas. The bulk of the published criteria developed focuses principally on the assessment and design of water crossing structures, such as culverts, to ensure free and unimpeded passage. The intent of incorporating hydraulic criteria is to ensure that the swimming ability, timing of the target species, and size of the fish are accommodated in the anticipated hydraulic conditions. It is generally widely accepted that fish passage cannot be provided at all peak stream flows, but need to be available during the majority of the migration period. The criteria utilized by the Washington Department of Fish and Wildlife was adopted which specified that the hydraulic design

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criteria for fish passage must be satisfied 90% of the time during the migration season or the 10% exceedance flow is the fish high passage flow. Similar published criteria related to the allowable velocity and depth of flow for Steelhead was also adapted from the Washington Department of Fish and Wildlife (WAC 220-110-070) for culvert installations and applied to channel facilities for this project. These requirements indicate that the recommended fish passage maximum allowable velocity for culverts range from 3.0 to 6.0 fps for length ranging from 200 feet to 60 feet, respectively, and the corresponding minimum flow depth was 1.0 foot. Most of the published requirements associated with low-flow discharge focus on the 95% exceedance flow during fish migration period, however, for semi-arid areas such as Southern California this value is generally too small to be considered a reliable guide. Review of the different surveyed agency's criteria indicated that the general recommendations were consistent regarding fish swimming capabilities and there was minimal variation of the numerical criteria.

Three flow levels are considered when evaluating the effectiveness of a structure for fish passage. The first is the 100-year flowrate (Q_{100}), although this is not a fish passage design flow, it has a significant bearing on fish passage in that it establishes the largest flood flow that must be reasonably passed by the structure. The second is the highest design flow at which fish passage criteria must be met. It is often referred to as the high passage flow (Q_{hp}). The third is the low-flow and is referred to as the low passage flow (Q_{lp}). It is widely accepted in the design of fish passage facilities that passage cannot be practically provided at all peak streamflows, but needs to be available in the range between Q_{hp} to Q_{lp} so that unacceptable delays or prevention of migration do not occur. Most fish typically migrate to spawning grounds on the rising limb of the hydrograph, and commonly reach spawning grounds before or during the period when water levels return to channel maintenance stage.

Table No.1 - Comparison of Representative Agency Hydraulic Design Criteria for Fish Passage

Item Description	Washington	Oregon	British Columbia
Culvert Length	Maximum Water Velocity		
10-60 ft	6.0 fps	6.0 fps	1.8 m/s
60-100 ft	5.0 fps	5.0 fps	1.5 m/s
100-200 ft	4.0 fps	4.0 fps	1.2 m/s
greater than 200 ft	3.0 fps	2.0-3.0 fps	-------
Minimum Flow Depth at Low-Flow	1.0 ft	1.0 foot for adults 8-inches for juveniles	200 mm for juvenile 300 mm for adult
Maximum Vertical Drop	1.0 ft	1.0 ft adults 6- inches juvenile	0.3 meter
Hydrologic - High	10% exceedance flow	10% exceedance flow	No statistical criteria

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Table No.1 - Comparison of Representative Agency Hydraulic Design Criteria for Fish Passage			
Item Description	Washington	Oregon	British Columbia
Passage Flow	during migrating season	during migrating season	
Hydrologic - Low Passage Flow	95% exceedance flow during migration season or 2-year, 7-day low-flow	95% exceedance flow during migration season or 2-year, 7-day low-flow	No statistical criteria

Fish Passage Features and Design Requirements

The range of available potential fish passage features is generally limited by the conventional fish passage measures which have been successfully utilized for different applications to enhance migration. Fish passage facilities which can be considered include: (1) fish collection/bypass facility, (2) natural stream diversion facility around existing barrier, (3) standard fish ladder systems include the three most commonly used include the pool and weir, the vertical slot, and the Denil, (4) single natural low-flow channel within the channel invert, (5) separate parallel bypass channel for fish, (6) addition of fishway features into a modified low-flow channel, (7) trap and truck adults around the barrier, (8) remove concrete channel invert and replace with natural streambed, (8) “removable” permanent fishway features in modified low-flow channel, (9) parallel “natural-like” fishway, (10) armored rock channel invert with natural riffle-pool sequence, (11) low-height grade control in natural streambed, (12) cascade or stepped chute facility, (13) channel gradient reduction with grade control, and (14) introduction of baffles, weirs, and pools. Specific hydraulic design requirements have been developed which can assist in determining the particular requirements or facility requirements for a variety of applications.

There are significant design issues and constraints associated with integrating fish passage design, particularly into new or existing flood control facilities, which limit the available feasible alternatives for consideration. The constraints include both physical constraints as well as regulatory limitations. Some of the constraints include the following: (1) available right-of-way, (2) adjacent existing public and private facilities, (3) existing floodplain, (4) hydraulic controls, (5) topography, (6) watershed conditions, (7) fish passage criteria, (8) stream gradient, (9) vertical and horizontal limitations, (10) channel geometry, (11) utilities. Accurately assessing these constraints in the planning process through a detailed inventory will assist in determining the most suitable alternatives for the particular application and will ensure greater potential for successfully improving migratory fish requirements. A primary consideration for flood control facilities is to ensure the desired level of flood protection can be provided while providing fish passage, which is difficult since the hydraulic requirements tend to be opposing for these two objectives.

<u>Fishway Design</u> - Fishways are formal in-stream hydraulic structures that optimize fish passage conditions for maximum vertical gain over a given distance. A variety of fishways are available and the three most commonly used include the pool and weir, the vertical slot, and the Denil. Each of these structure has its own inherent limitations and advantages. In many situation based upon the

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project watershed conditions and hydrology dictate the selection of the **concrete vertical slot fishway** because of the stream sediment load and the wide range of flow conditions. Another advantage of the vertical slot fishway is that it is self regulating, while other fishways require pool elevations or flows that can be closely regulated, which is the primary limitation of the pool and weir fishways. The upper limit operation is the flow at which there is not sufficient volume in the pools to dissipate the energy entering the pools and there is too much turbulence to provide a successful fish passage. The vertical slot fishway structure essentially provides a series of pools, separated by baffles or a wall containing a vertical slot. Vertical slots between the baffles restrict flows to velocities negotiable by fish. The pools provide relatively low velocity zones, where migrating fish can rest as they negotiate the fishway. Water flowing down the fishway accelerates as it passes through each slot, then rapidly decelerates in the pool downstream. The principle utilized consists of turning the flow from a jet back on itself, increasing the efficiency of energy dissipation in the pools. Also the geometric pattern of eddies that are formed provide better resting areas. Velocity changes, and associated turbulence, are designed to dissipate about one foot at each slot.

<u>Underground Bypass Fishway</u> - The state of Washington Department of Fish and Wildlife has published criteria related to the design of culvert installations which can be applied to the design of the underground fish bypass pipe system. The fish passage design criteria for culvert installations is identified in *WAC 220-110-070 Water Crossing Structures* and in *Fish Passage Design at Road Culverts* (March 1999). The recommendations include that the invert within the pipe be filled with bed material from 30% to 50% of the culvert diameter. This amount of material will allow filling the channel to the widest part of the pipe. Size of the pipe is selected to satisfy the maximum velocity limitations for fish passage which is 3.0 fps for long culverts. The selection and gradation of the channel fill material must address the bed stability, particularly for flows which exceed the fishway design. Investigators have indicated that orifices with darkened backgrounds are not entered by the fish as readily as those with the backgrounds lighted. The light source may be by penetration through the water from either downstream or above the orifice.

<u>Boulder/slot fishway</u> - The objective of the vertical slot fishway is to provide a series of pools which are separated by baffles. The vertical slots between the baffles restrict flow to velocities negotiable by the fish. The pools provide relatively low velocity zones where migrating fish can rest as they negotiate the fishway. The design adaptation for this facility relies on boulders to form a series of stepped pools, with slots between the pools designed to permit fish passage. The criteria for the conventional vertical slot fishway can be used to determine pool to pool elevation change, size of pool, and the rock weir geometry and configuration. The cells of the fishway are aligned in series, with the number of cells determined by the total net vertical elevation difference required. Large boulders frame the cells and the typical dimensions of the boulders are 3.0 to 4.0 feet in diameter. Smaller boulders are used to fill in the gaps, and to form a small sill at the slot formed between pools. A cobble/ gravel substrate is placed in the floor of the pools. The slot is approximately 12-inches in width and 24 to 32-inches deep. During higher flowrates the slot flow capacity will overtop the boulder baffles separating the pools.

<u>Low-flow channel with fishway features</u>- Proposed optional modifications to the conventional low-

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flow channel are based upon ensuring that the recommended hydraulic design characteristics to enhance fish passage can be achieved. The optional modifications of the "low-flow" channel section rely on design recommendations for specific features of fishways or fish passage requirements through culverts. Common features such as baffled channel design incorporate recommendations associated with weir type fishways. These features include: (1) baffles, (2) weirs, (3) profile adjustment, (4) saw-tooth and adverse channel profile, and (5) notched channel section. The primary methods of velocity reduction within channels or culverts involve the placement of baffles of different configurations or geometries. The offset baffle has been used to increase the mannings coefficient in the channel. The optimum performance of this offset baffle worked the best when the fish passage flow just overtops them. This type of baffle is subject to sedimentation and allowances need to account for maintenance. The offset baffle utilizes two baffles side-by-side, one is perpendicular to the direction of flow and the other is at an angle of 30° to flow direction. The recommended spacing of the baffles is 1.12 times the width of the channel. The slotted weir consists of side-by-side weirs both perpendicular to the direction of flow. The length of each weir is 0.3 times the width of the channel and the recommended spacing is 1.2 times the width of the channel.

Maintenance and Long Term Operation Concerns

Maintenance of the fishway is vital to the successful operation of the facility and the annual maintenance requirements will generally be high, up to 5% of the costs of the structure, due to the fluctuating conditions of the stream. The type of maintenance normally required consists of repairing concrete lost through abrasion of the bedload, and removing deposited sediment and debris. Features which will assist in the maintenance of the facility would include (1) upstream in-channel desilting basin as previously discussed, and (2) flow control or isolation facility at the upstream entrance to the fishway in order to bypass flow while maintaining the fishway. The environmental regulatory permits which are obtained for the construction of these facilities should include special provisions to allow maintenance and removal of the sediment. Removable type systems, such as baffles or vertical slots, can assist in limiting the costs of sediment removal.

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